Boundary Creek, Big Swamp and surrounding environment

Remediation and Environmental Protection Plan

Submitted: 20 December 2019
Amended: 27 February 2020

Acknowledgements

Barwon Water wishes to acknowledge the contribution of the Boundary Creek and Big Swamp Remediation Working Group whose valuable insights, local knowledge and passion for the environment helped shape the Remediation and Environmental Protection Plan.

Representatives included Traditional Owners, Land and Water Resources Otway Catchment (LAWROC), Corangamite Catchment Management Authority, Colac Otway Shire Council, Environment Victoria, Upper Barwon Landcare Network, Boundary Creek landowners, and other interested community members.

Barwon Water also wishes to recognise the technical expertise of Dr. Darren Baldwin, Dr. Vanessa Wong and Professor. Richard Bush who provided independent support to the Remediation Working Group.

Executive Summary

In June 2017, Barwon Water acknowledged that historic management of groundwater pumping had an environmentally significant impact in the Boundary Creek catchment. Reductions in flows caused by groundwater extraction coupled with a drier climate and the ineffective regulation of passing flow conditions all contributed to the drying out of Big Swamp. This resulted in the activation of acid sulfate soils and ongoing release of acidic water to the lower reach of Boundary Creek.

In May 2018, Barwon Water established a community and stakeholder working group to develop a remediation plan for Boundary Creek and Big Swamp. As part of this process, Barwon Water invited the working group to nominate their own technical experts to help support them in their discussions to shape the remediation plan.

Barwon Water's commitment to undertake remedial works was legally strengthened through the issuing of a Ministerial Notice under section 78 of the Water Act, 1989. This notice mandated the development and implementation of the Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP) by March 2020.

This document addresses the requirements of the s78 notice to submit the REPP following 18 months of scientific studies, advice from independent technical experts and valuable community feedback.

Eight key principles underpin the REPP (see overleaf) including continuing an open and transparent relationship with Traditional Owners, the community and key stakeholders. Through this relationship, the desire to allow groundwater levels to recover in the Lower Tertiary Aquifer was clearly expressed. Barwon Water fully supports this aquifer recovery and incorporated this into the principles.

Remedial works aims to improve water quality in Big Swamp, stabilise the acidification process that takes place due to the drying and wetting of the acid sulfate soils in the area, and reduce the risk of acid flush events from Boundary Creek in the long-term.

This will occur through the continual wetting of Big Swamp through controlled release of water to Boundary Creek and the installation of hydraulic barriers to maintain surface water flows and groundwater levels within Big Swamp.

The REPP also outlines how possible impacts in other areas within the regional groundwater system will be investigated and determine if further remediation work is necessary.

The REPP employs an adaptive approach to allow continued environmental monitoring to inform requirements for remediation.

As remedial works are implemented, it is anticipated that low pH events will diminish over the next decade and that ecological values of the swamp will improve.

1 Response to Southern Rural Water's feedback

1.1 Introduction

Barwon Water welcomes the feedback[1] from Southern Rural Water on the Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP), which took into consideration a review undertaken by the Independent Technical Review Panel and recommendations from their Community Leaders Group.

The feedback endorsed the preferred remediation option for Boundary Creek and Big Swamp and confirmed the need for an adaptive management approach so that the Plan can be responsive to new data and information as it becomes available.

The REPP is a clear statement of Barwon Water's unwavering commitment to delivering successful environmental outcomes and demonstrates the significant progress made since July 2019 in determining the preferred remediation option, and proposed actions and controls for improved environmental outcomes for Boundary Creek and Big Swamp.

It also outlines a robust process to undertake investigations to verify if other areas within the regional groundwater system have been impacted by historical management of groundwater extraction.

Barwon Water will begin implementation of the REPP by 01 March 2020 as soon as it is accepted. This will include continuing the release of supplementary flow and collection of more data to refine the design of the preferred remediation option and installation of new monitoring equipment in the surrounding environment. This will occur in parallel to addressing feedback from Southern Rural Water.

1.2 Addressing the feedback

The adaptive approach outlined in the REPP is acknowledgment that remediation is complex, with the proposed remediation option for Boundary Creek and Big Swamp developed using a time limited dataset available at the time of submission of the REPP on 20 December 2019.

In providing their feedback, Southern Rural Water has acknowledged that considerable work and time is required to address particular questions that they have raised, including a longer period for data collection and assessment. While addressing some of these questions already aligns with the further technical work proposed in the REPP, Barwon Water will work on all of the items in the feedback prior to preparing responses to ensure that they are understood and are adequately addressed.

In response to Southern Rural Water's feedback and in acknowledging the technical nature of the work, Barwon Water proposes to incorporate in the REPP a meeting with Southern Rural Water to outline the items of feedback that are not already addressed by the REPP, including work plans, timeframe and prioritisation of actions.

[1] Specifically, feedback from Southern Rural Water dated 20 February 2020 and subsequent email clarification dated 25 February 2020.

As part of this process, Barwon Water will also consider the feedback provided by the Independent Technical Review Panel and Community Leaders Group as context.

In some cases, the feedback relates to matters that are beyond Barwon Water's control. Recovery of groundwater levels in the aquifer is understandably complex and susceptible to fluctuations through use by third parties and the future impact of a drier climate. Success measures and targets relating to objectives must reflect what is *practicably achievable* by the actions and controls being implemented by Barwon Water. This is consistent with the intent of SMART principles.

The targets currently in the REPP were developed with input from our community and stakeholder Remediation Working Group and their independent nominated experts.

In some cases, the refinement of success targets may be required based on what is being observed and how the environment is responding to remediation works. This will enable the setting, monitoring and adapting of meaningful and realistic targets linked to proposed actions and controls for remediation. A register of the feedback received from Southern Rural Water that Barwon Water will address through this process is provided below.

Barwon Water proposes the following process and the development of a work plan for addressing feedback and progressing implementation of the REPP that will require acceptance from Southern Rural Water.

Table 1: Proposed work plan to address feedback

Milestone	Timeframe
Meeting with SRW to be held at the Barwon Water office to develop work plan towards confirming priority actions relating to feedback provided. SRW to accept outcomes of the workshop whereby a register of feedback is confirmed for Barwon Water's response.	By 30 April 2020
Submission of a work plan detailing how Barwon Water will respond to the register of feedback, including prioritisation of actions, the timeframe for responding to each item and the process for reporting and closing out each item. SRW to accept the work plan.	By 31 July 2020

1.3 Governance

A crucial element for successful remediation is the development of a governance framework so that:

- responsibilities are clear, and
- that it is clear when acceptance of revisions to the REPP may be sought by Barwon Water from Southern Rural Water.

Barwon Water will propose any changes or improvements to the REPP and seek acceptance of these changes from Southern Rural Water based on evaluating the effectiveness of actions and controls, outcomes of the monitoring and assessment program, scientific data and expert advice and/or feedback from stakeholder and community engagement.

Barwon Water's commitment to continuing an open and transparent relationship with the community and key stakeholders including local environmental groups during the implementation of the REPP will also be a key component throughout the implementation of the REPP.

A communications and engagement plan will be developed in 2020. This will be informed by input from Barwon Water's existing Remediation Working Group with regard to the appropriate level of engagement, and method of engaging in their community. This may include the establishment of a new Remediation Working Group.

Barwon Water will invite Southern Rural Water to observe stakeholder and community engagement undertaken by Barwon Water. This will be important to ensure both Southern Rural Water and the community remain informed through every step of the remediation process.

In line with the accepted governance and approvals framework, as a minimum, Barwon Water proposes that the following key milestones would require acceptance from Southern Rural Water. It should be noted that ad-hoc requests to amend the REPP may also require acceptance from Southern Rural Water outside the proposed timetable below as new data or information is obtained.

Table 2: Proposed milestones and timeframes for implementation of the REPP

Milestone	Timeframe
Endorsement of a governance framework clearly outlining roles and responsibilities of stakeholders involved in the REPP, a decision making process to determine how revisions to the REPP in the form of controls or actions are accepted or rejected and how controls and actions are implemented. SRW to accept the governance framework.	By 31 July 2020
Submission of detailed design of the hydraulic barriers outlining proposed controls or actions and any revisions to success measures/targets. SRW to accept the detailed design, including proposed actions, controls, and success measures/targets.	01 July 2021
Outcomes of the Surrounding Environment investigation to be progressively provided to Southern Rural Water as they come to hand. SRW to decide if further action is required.	31 July 2023
Barwon Water to provide progress updates against annual work plan on a quarterly basis.	Quarterly
Barwon Water to submit annual work plan as part of the Annual Report. SRW to accept annual work plan.	Annually

1.4 Feedback register

Feedback	
SRW Cover Letter	
01	Definition of remediation does not match what is in the notice. The definition in the plan should not limit the intent or extent of the S78 notice. Risks and limitations around achieving remediation are appropriate within the plan.
02	Principles need to be consistent and align to the definition of 'principle'. See attachment 1 for further guidance.
03	Prioritising Boundary Creek and Big Swamp over surrounding areas is an acceptable approach, however more detail is required as to what will be done for surrounding areas.
04	The 2ML per day supplementary flow into Boundary creek is the same as the historic licence condition. The REPP should identify what the objective of the flow is, why 2ML is the appropriate flow to achieve the objective, and how higher flows have been considered and not adopted.
05	All remediation and investigative options explored need to be presented and analysis or commentary provided with regard to why they were or were not pursued.
06	Works and timetable contain 10 year objectives which are very general. The REPP should be specific on the actions to be taken and their timeframe for completion ie what the action will be, who will do it, when it will happen etc
07	The success targets presented are general and aspirational. It is entirely appropriate to include aspirations and goals, however the targets themselves should be described using the SMART principles. As an example, "recovery trend for groundwater levels in the LTA" is an aspiration. As a SMART target it needs to express each of the principles, including what the measurable is (a specific groundwater level or range), relevance in relation to stream gaining conditions, the timeframe it is expected to be achieved. There are no targets for groundwater levels in the observation bores listed or a timeframe within which they should be met.
08	To support the adaptive approach and the considerable timeframes proposed in the REPP, a framework for governance and decision making, including how the community and their Expert Panel will be involved should be included.

Feedback	
09	Consistent with Section 78, the footnote on page 45 flags the need for ongoing improvements of the REPP in line with the adaptive approach. The REPP should propose a more specific process and work plan for monitoring, for determining what constitutes the need for an improvement to the REPP and how this will be proposed to SRW and implemented. The matters raised in this correspondence should be identified within the REPP as part of this point.
SRW feedback attachment 1: Principles	
10	Principle 1 - A remediation principle regarding full recovery of the aquifer has been discounted, this needs to be further explored, and more information is required to evidence whether or not this should be a principle/objective. This could include scenario modelling of filling under different scenarios.
11	Principle 6 – It is unclear how this aligns with the evidence which suggest that both passive and active remediation actions are likely required. SRW suggests that the principle is the focus on remedying the "cause of the issue …" is an appropriate principle statement, however ruling in or out engineering or passive intervention is appropriate for analysis and conclusion within the plan itself.
12	Principle 2 – This should be more explicit in describing the circumstances in which a qualification of rights may be sought.
13	Principle 3 – This principle states that remediation actions must relate directly to 'confirmed environmentally significant adverse impacts'. How is 'environmentally significant' defined?

Feedback	
14	Principle 8 – The REPP makes a number of assertions that are not supported with data or technical analysis, indeed the Jacobs review does not raise this issue to the level that the REPP does. Whilst SRW agree and support any notion that the dam owner must operate in compliance with their license, the statements in the REPP appear to overstate the impact of previous practices with respect to the dam. Without diminishing the importance of compliance it is not clear how this matter should sit at a principle level given the focus and nature of the other principles. The REPP identifies 2ML as the relevant flow required at McDonalds dam in order to meet 0.5ML per day at the Yeodene gauge. It is not clear in the REPP what the purpose of the flow is, and basis for arriving at these volumes as preferable to any other volume. In this regard REPP should: - Describe the purpose of the release into Boundary Creek. - Clarify the scientific basis of 2ML/day as the proposed volume that is required to be released into Boundary Creek. Revise and provide evidence supporting the extent of impact of the operation of "McDonald's dam" - In the success target for flows in Boundary Creek (page 36 of the REPP) includes an assumption about operation of the dam. It is acceptable to raise assumptions and risks in the text, however these would generally not be highlighted within the success target. We note that the other success targets do not contain commentary around risks and assumptions. - In light of the above, reconsider the matter as a principle as opposed to text within the plan. The principle may more appropriately address risk management and mitigation to any number of events that could impact the progress and success of the plan.
SRW feedback attachment 1: Modelling	
15	The conceptual and numerical models they are critical for ensuring a shared understanding and informing decisions. The REPP should; - be informed by the most up-to-date data and information, i.e data from newly installed bores. The current conceptual model presented does not take this new information into account; - prioritise the action to update and refine both the conceptual and numerical models and develop a clearly defined work plan that describes the methodology and timeframes;
16	The impact of modelling uncertainty on broader investigations should be more clearly articulated throughout the document
17	The impact of depressurisation on direct discharge and vertical flows into Big Swamp, particularly at the western boundary is a fundamental conceptual question that requires specific attention

Feedback	
18	Figure 6 - The conceptual diagram indicates losses between McDonalds Dam and Big Swamp are between 1.5 - 2.0ML/d, this suggests that in dry weather (when inflows to McDonalds dam are 0, then a release of 2ML/d is unlikely to make it to Big Swamp. Are these losses included in the SW/GW modelling and the options assessment? Reach 2c (Big Swamp) is identified as neutral in regards to water balance. What is the estimated volume of Evapotranspiration/evaporation/drainage from the swamp and how does this compare to other water balance components?
19	Based on the evidence presented in the Jacobs SW/GW modelling report that acknowledges 't*he available groundwater level records for bores in the swamp (June to September 2019) is of insufficient duration to allow a robust transient calibration that tests the model over a range of climatic and surface water hydrological conditions*.' and concludes that 'a continuous release of water and installation of hydraulic barriers can be expected to increase groundwater levels throughout the swamp and to maintain flow in Boundary Creek, however this would need to be confirmed with further modelling...'. It is important to highlight that the flow and barrier option is unconfirmed and further modelling and site trials are required before confidence in this option can be improved.
SRW feedback attachment 1: Success targets and measures	
20	SRW acknowledges use of an adaptive management approach and the reasons BWC have proposed to use that model. Where clear, measurable success targets exist, actions can be taken, the response observed and the actions adjusted as dictated by the data. The current success measures generally are not described specifically enough to show when the target will be met or on what basis the mitigation options will be changed. For example “an increasing trend” is not a “SMART” goal and would be better expressed in terms of lower and upper range limits of the trend;
21	Further, a time period of 2 years is stated for recovery; is this 2 consecutive years, or 2 cumulative years? And what is the target after 2 years?
22	The targets around acid generation propose 10 year timeframes. The plan should include options analysis detailing why 10 years and not something less is appropriate. Including options analysis of potential intermediate targets and timeframes for pH in Boundary Creek, noting the Jacobs report says ½ have met targets already.
23	In general, success measures, targets and timelines should be more explicit, consistent and transparent.
SRW feedback attachment 1: Options analysis and the plan	

Feedback	
24	SRW believe it is critical to the process and transparency to have insight into the rationale behind the position presented in the REPP. The plan should provide reference to the suite of remediation options assessed and an analysis that supports the conclusion to rule them in or out. As an example; was artificial recharge of the aquifers considered and assessed, and what were the outcomes of this assessment?
25	Technical evidence suggest that the preferred remediation option carries a risk that acidity and iron discharges will increase in the short term. More information is required on the potential effects of this risk downstream, and also the level of confidence in potential mitigation measures.
26	Section 3.2.1 – It was not clear how the boundaries of the area of confirmed impact in Figure 1 were defined. Please provide the rationale that informed either the inclusion of exclusion of areas
27	Section 3.3 - The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) have been used in the risk assessment. The guidelines refer to High Value GDEs. The REPP should make it clear how it has defined 'High Value' and how the definition of remediation relates to ecological value
28	Figure 4 – The diagram should include other impacts, loss of stream ecology, loss of stock access, impacts in upper Boundary creek etc
29	5.2.2 – reference to maintenance of 'minimum flows' in Reach 3 of Boundary creek all year round. It is unclear what 'minimum flows' means.
30	5.2.3 – The text above Figure 10 that refers to 'reduced releases from McDonald's Dam' is incorrect
31	5.3 - It is not clear from the map or the text why the areas for investigation have been chosen and how these relate to the broad areas of high and medium risk across the map. The report states '*This process was detailed in the revised scope of works submitted to and approved by Southern Rural Water*.' This statement should be caveated by the comments provided by SRW and the Independent Review Technical Panel on the Scope of Works and the risk assessment process, the model calibration, and the need to refine the risk assessment process as the model is improved. It would be useful to specifically address the sites/areas identified by the local community and to explain why these are not included.
32	Figure 36 – Is this figure correct? Where are the locations of ASS sampling?
33	6.1.8 – There is no target related to the Barwon River, so as it reads it is unclear how sampling of chemistry and macroinvertebrates in the Barwon River relates to the REPP

Feedback	
34	6.5.2 - Vegetation in Big Swamp is assessed as "current" with no further changes proposed. This does not alter the system "back" to any former condition or species type in the swamp. Saturation of parts of the swamp is assumed to cause alteration to species tolerant to wetter soils. The plan should include options analysis to demonstrate this is acceptable within the context of remediation. (S6.5.2 Table 23)
35	Contingency measures should be linked to specific triggers. At present it is not clear when contingency measures will be initiated.
36	There is very little detail around the costings provided, and they seem optimistic. More detail around these would be beneficial.
SRW feedback attachment 1: Supporting technical reports	
37	The Prof. Perran Cook report concludes that inundation '*still produces mobile potential acidity in the form of dissolved iron (II), and any release of this from groundwater would regenerate acidity upon contact with oxygen. Longer term immobilisation of acidity also requires sulfate reduction to take place and present indications suggest this process would not occur for several years and even then, there is unlikely to be enough sulfate present in the soil to lead to the complete immobilisation of dissolved iron*.' This aspect appears to be crucial to the design of the remediation options, and it appears to merit further work. How will this question be confirmed, in order to enable a robust remediation approach?
38	The GHD report concludes ... '*The geochemical processes associated with each management and remediation option under consideration suggest that no single management and remediation option under consideration is capable of mitigating acid generating processes associated with the primary acid source minerals, primary acidification reactions and secondary acidification reactions. Therefore, a combination of management and remediation processes is likely to be required.' and 'the results of the geochemical assessment are subject to considerable uncertainty and should be used with an appropriate amount of caution in the design of the management and remediation options...*' The REPP should be clearer on how it will reduce this uncertainty, and which recommendations will be addressed.
SRW feedback attachment 1: Previous feedback	
39	The ITRP identified previously, and in the current review, that misconceptions regarding the conceptual model have been presented repeatedly and need to be corrected to "*avoid further promulgation of false understanding and to avoid inappropriate remedial action*."
40	The report states '*Monitoring Data used to validate risk and determine level of impact*'. The ITRP provided previous feedback on the Scoping Document to the effect that monitoring per se will not inform the level of impact, this will be informed by modelling historic and future scenarios (data will be used to refine the conceptual and numerical model)

Feedback	
41	The delineation of the reaches within Boundary Creek has been raised previously as a point to requiring attention. We do not accept the justification presented in the REPP. The position taken is inconsistent with scientific principles and with Barwon Waters own applied to the 3 sub-reaches within Reach 2. We believe the community have the ability to understand the scientific reasoning.
SRW feedback attachment 1: Future process and requirements	
42	Given the adaptive approach presented and the timeframes indicated (10 years) it is expected that more clarity is provided around the future process and framework that will guide Barwon Water, particularly around decision making, community engagement and approvals.

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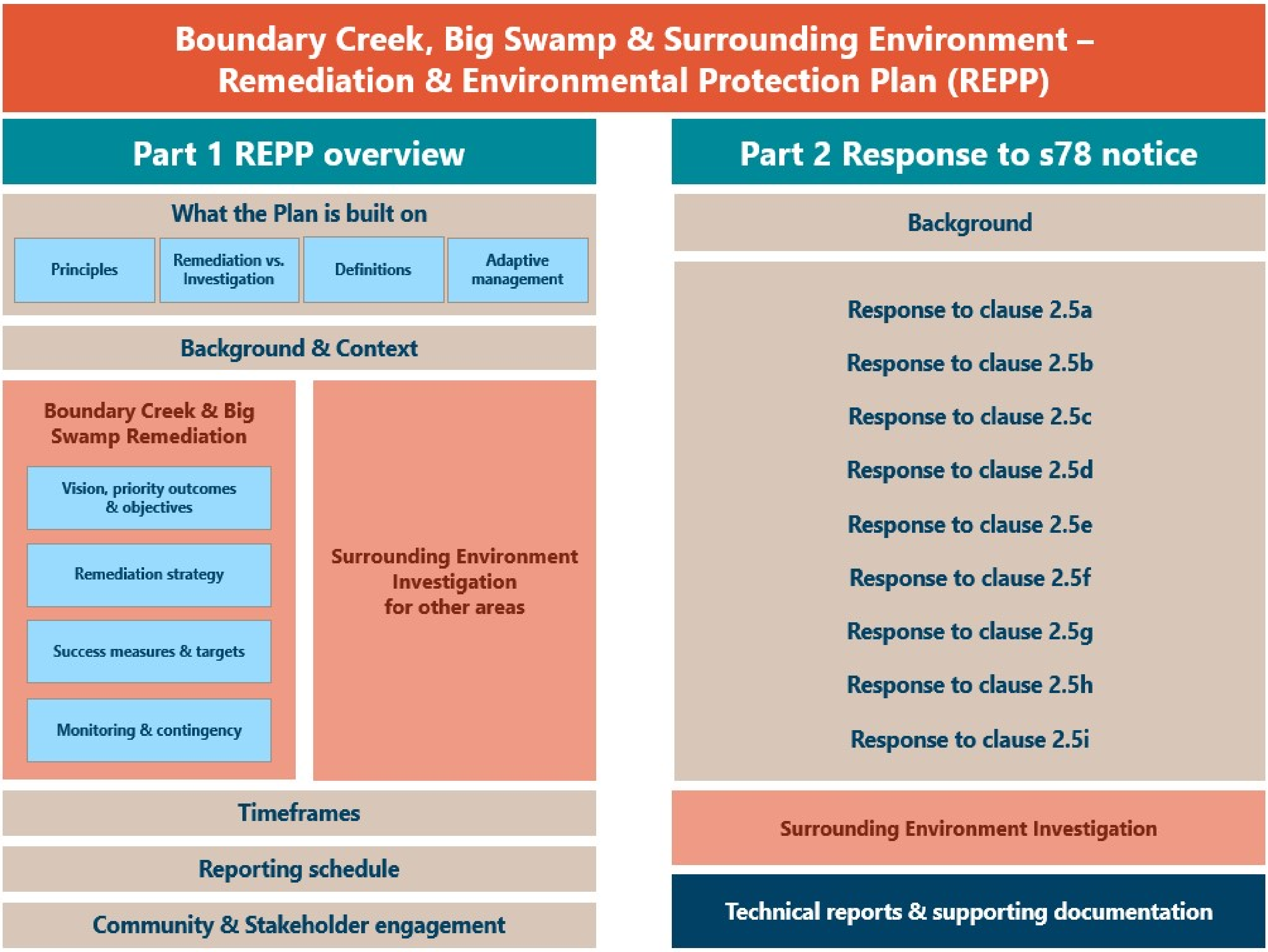
2 How to navigate this document

The Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP) is separated into two sections:

- Part 1 provides an overview of the REPP, and
- Part 2 contains the technical responses to meet the requirements of the section 78 Ministerial Notice.



Part 1

Remediation & Environmental Protection Plan **Overview**

3 What the Plan is built on

This section outlines the fundamental principles upon which the Boundary Creek, Big Swamp and Surrounding Environment - Remediation and Environmental Protection Plan (REPP) has been developed in response to the requirements of the section 78 Ministerial Notice (s78 notice).

3.1 Principles

The eight principles that underpin the REPP can be found in Table 3.

Table 3: Principles of the REPP

Principle	Why is this a principle?
1. Barwon Water supports the recovery of groundwater levels in the Lower Tertiary Aquifer (LTA) and its surrounding environment and ecosystems as intended under the current Permissive Consumptive Volume (PCV) set for the Gerangamete and Gellibrand Groundwater Management Areas. **Barwon Water will not undertake actions in relation to the Barwon Downs borefield that could jeopardise this recovery.**	Barwon Water fully supports the Victorian Government's reduction in the PCV limits which will allow for the recovery of this resource and its surrounding environment and ecosystems. These PCVs place a cap on the volume that can be allocated for extraction from the system (not just by Barwon Water) and therefore provides greater protection for this system. Barwon Water will not – and cannot – consider any future use of the borefield or applying for another licence as the PCV limit has been set by the Victorian Government to a very low level to enable the aquifer to recover. Barwon Water fully supports this aquifer recovery. The Remediation Working Group's independent nominated experts have advised that the recovery of the LTA to pre-pumping groundwater levels is not a suitable target as it is dependent on factors such as third party users and climate. Positively, the effect of the current PCV limit will be a recovering trend in groundwater levels. As such a target reflecting this has been incorporated into the REPP. The only potential exception to this principle, is if the Barwon region faces an 'emergency' water shortage. In such a highly unlikely scenario, Barwon Water would be required to go through the qualification of rights process as per Section s33AAA of the Water Act, 1989. This is a rigorous process that is overseen by DELWP with the final decision to be made by the Minister for Water.

Principle	Why is this a principle?
2. No groundwater extraction from the Barwon Downs Borefield by Barwon Water during remediation.	Barwon Water does not have a licence to use the borefield, and therefore, there will be no groundwater extraction from the Barwon Downs Borefield by Barwon Water during the REPP. Our previous licence expired on 30 June 2019. The PCV and the s78 notice prevents any groundwater pumping occurring in the Gerangamete Groundwater Management Area other than by three other licensees for dairy wash and irrigation purposes or for maintenance/testing purposes. Barwon Water will not – and cannot – consider any future use of the borefield or applying for another licence as the PCV limit has been set by the Victorian Government to a very low level to enable the aquifer to recover. Barwon Water is also currently preparing for the next 'Urban Water Strategy' to explore other long-term water supply opportunities with the community, as part of Barwon Water's Water for our Future Program.
3. Remediation actions which may be required to be carried out by Barwon Water must directly relate to confirmed environmentally significant adverse impacts caused by the historical management of groundwater extraction at Barwon Downs Borefield by Barwon Water in order meet the requirement of the s78 notice.	Barwon Water will consider remediation actions and controls in the area which surround Boundary Creek and Big Swamp if measurable and evidence-based scientific methodologies conclude that historical groundwater pumping by Barwon Water at Barwon Downs Borefield has caused an environmentally significant adverse impact in that area. Remediation actions and controls in the area will be considered if they are reasonably practicable and proportionate and will achieve environmental improvements.
4. Barwon Water highly values its partnerships with Traditional Owners and is committed to working with, and learning from them to ensure that cultural history and values are considered during the implementation of the REPP.	Waterways are the lifeblood of our land and Aboriginal and Torres Strait Islander peoples have been managing the waterways we all have relied upon for thousands of years. By respecting and understanding the cultures and histories of Aboriginal and Torres Strait Islander peoples within the region, Barwon Water can learn to look at the environment through the eyes of an Aboriginal and Torres Strait Islander person.

Principle	Why is this a principle?
5. Barwon Water is committed to continuing an open and transparent relationship with the community and key stakeholders including local environmental groups during the implementation of the REPP.	We want to ensure insights and knowledge of the community, local environmental groups and stakeholders are considered and help to inform the implementation of the REPP. We also want to build community and stakeholder confidence in the implementation of the REPP. Like the REPP itself, the long-term approach to engagement with the community and stakeholders will adapt as outcomes from the REPP come to hand.
6. The Boundary Creek and Big Swamp Remediation Plan will prioritise actions and controls that have minimal engineered intervention (unless necessary) and target the source of the issue to enable the system and its ecological values to improve progressively over time.	Actions that address the source of poor quality water are considered to be more resilient in the long term and in line with the vision and objectives set out in the Remediation Plan. Barwon Water acknowledges that it may take a decade to realise improvements from remedial works, particularly an increase in median pH values. However, this needs to be balanced with practicality as required by the s78 notice, along with the environmental implications, costs, risks and trade-offs associated with implementing ongoing artificial treatment.
7. The REPP is based on an adaptive management approach.	Barwon Water has adopted the following definition for adaptive management of the REPP: 'a continuous cycle of improvement based on setting goals and priorities, developing strategies, taking action and measuring results, and then feeding the results of monitoring back into new goals, priorities, strategies and actions' (Mackay, 2016). An adaptive approach to remediation is considered best practice, where adaptation occurs continuously to improve the REPP's ability to deliver on the vision and objectives. Barwon Water proposes that any improvements made to the REPP in light of the adaptive management approach is put forward and approved by SRW as part of the annual reporting process for the s78 notice.

Principle	Why is this a principle?
8. Successful remediation of Boundary Creek and Big Swamp is dependent on passing flow conditions being enforced at 'McDonald's Dam' in accordance with its licence conditions (dam licence no. WLE043336).	Critical to the success of the REPP will be consistency with the powers and responsibilities of respective parties under the Water Act, 1989. Southern Rural Water is responsible and accountable for effectively regulating compliance with the passing flow conditions, including Barwon Water's supplementary flows, with the holder of the dam licence.

3.2 Confirmed impact and other areas of investigation

The Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP) will be delivered under two parallel work packages:

I. The **Boundary Creek and Big Swamp Remediation Plan** to address remediation of confirmed impact in the Boundary Creek catchment resulting from historical management of groundwater extraction.

II. The **Surrounding Environment Investigation** to investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction.

This approach was supported by the Remediation Working Group as it recognises the need for immediate action to remediate confirmed impacts within the Boundary Creek catchment and the need to investigate for impacts in an expanded area.

This two pronged approach was outlined in the revised scope of works which was approved in October 2019 by Southern Rural Water and its Independent Technical Review Panel subject to addressing any recommendations and feedback in the REPP.

3.2.1 Boundary Creek and Big Swamp Remediation Plan overview

The area of confirmed impact is approximately 0.42 km^2 in size, from immediately upstream of Big Swamp to the confluence of Boundary Creek and the Barwon River (refer to Figure 1) which is the basis of the Boundary Creek and Big Swamp Remediation Plan.

While the area of confirmed impact is constrained to the Boundary Creek catchment, it is recognised that the Barwon River is also impacted from discharge from the swamp and that it is a major asset that requires protection.

Historically, groundwater from the regional aquifer helped maintain flows in Boundary Creek, especially during dry periods.

Recognising that summer base flow in the creek was reliant on groundwater, a supplementary flow condition was written into the Barwon Downs groundwater licence in 2004 with the intent of offsetting the loss of flows due to groundwater pumping.

As predicted, groundwater pumping reduced groundwater contributions to flows into Boundary Creek. Technical studies in 2017 confirmed that the historical management of groundwater extraction from the Barwon Downs borefield over the past 30 years was responsible for two thirds of the reduction of groundwater base flow into Boundary Creek, increasing the frequency and duration of no flow periods in the lower reaches of Boundary Creek. The dry climate experienced during the same period accounts for the remaining one third reduction.

Although Barwon Water complied with licence conditions, investigations confirmed that the ineffective regulation of passing flow conditions, including the supplementary flow released by Barwon Water to counter the expected losses in the creek, was not effectively reaching downstream reaches of Boundary Creek.

The reduction in flows was the main contributor that caused drying of Big Swamp, leading to the oxidation of naturally occurring acid sulfate soils and poor environmental outcomes downstream.

Monitoring data has enabled potential impacts to be confirmed for Boundary Creek and Big Swamp.

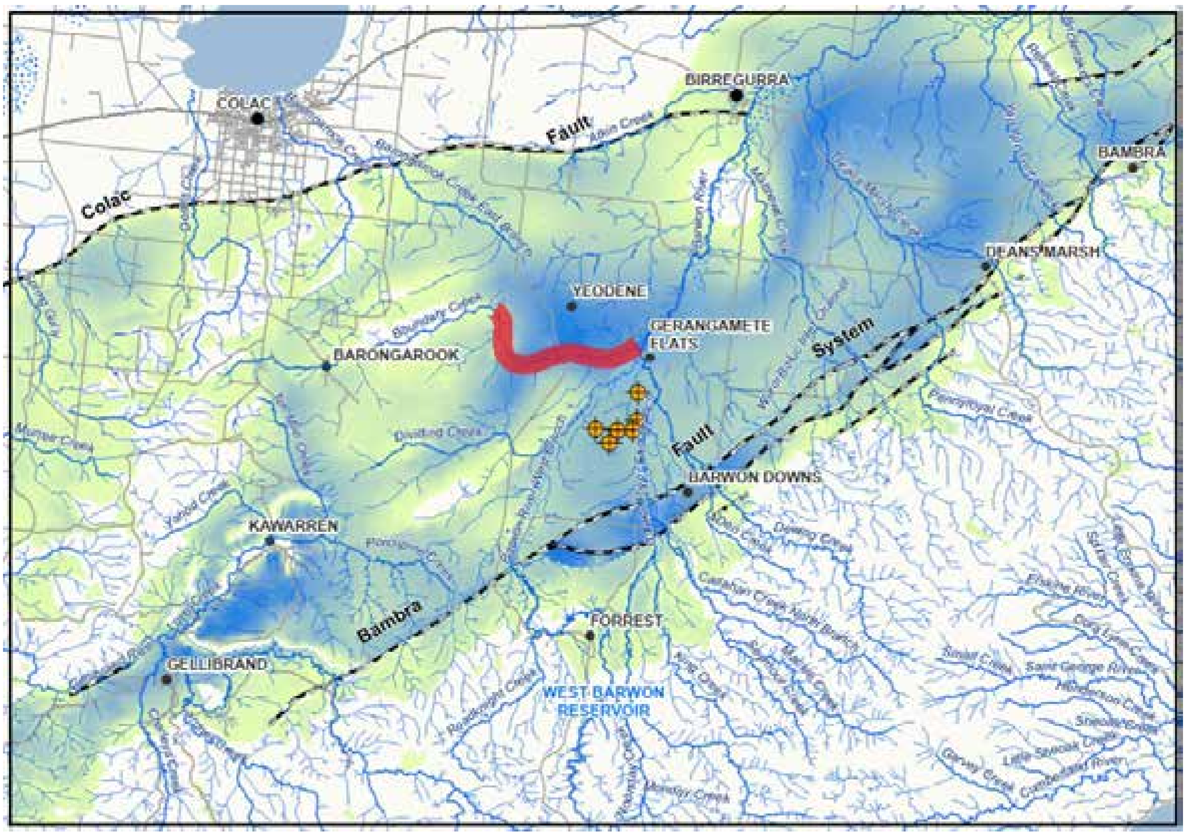


Figure 1: Area of confirmed impact (red area)

3.2.2 Surrounding environment investigation overview

The Surrounding Environment Investigation considers an extent of 480 km^2 (refer to Figure 2) as the starting point to identify other potentially impacted areas based on a systematic risk assessment framework (published in the revised scope of works submitted to Southern Rural Water in July, 2019).

This area was based on a whole of aquifer approach taking into consideration that the Barwon Downs Graben extends from the township of Gellibrand in the south-west to the Birregurra Monocline in the north-east (Blake, 1974). However, the Gellibrand Saddle to the east of Kawarren has been reported to act as a hydraulic barrier (Petrides and Cartwright, 2006), which may limit the connectivity of the far south-west of the graben from other areas.

This process resulted in the identification and prioritisation of areas ranked as '**high**' risk using the regional groundwater model. These areas include:

- Barwon River (East branch)
- Barwon River (downstream of the confluence)
- Gellibrand River
- Ten Mile Creek
- Yahoo Creek
- Groundwater dependent ecosystems west of the graben (near Yeodene)
- Groundwater dependent ecosystems east of the graben (Barwon Downs-Dean Marsh)
- Groundwater dependent ecosystems south of the graben (along the Gellibrand River)

While the groundwater model was able to narrow down sites at risk and give them a risk ranking, areas will require site specific investigations to 'ground-truth' and confirm if historical management of groundwater extraction from the Barwon Downs Borefield has had a measurable and environmentally significant adverse impact in that area. This will be the focus of the Surrounding Environment Investigation.

The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) were used to identify areas of potential risk that may require further investigations to validate the model results and confirm the presence of high value groundwater dependent ecosystems.

Where there is insufficient data to confirm the potential risk identified by the groundwater model, a site-specific study is recommended to investigate impacts and ground-truth the model predictions.

There is currently insufficient monitoring data to identify if historical groundwater pumping at Barwon Downs has caused any measurable impact to sensitive environmental receptors other than Boundary Creek and Big Swamp.

The additional data collected will also be used to update and refine the regional groundwater model prior to reassessing the risk to groundwater dependent ecosystems to confirm results from the initial risk assessment.

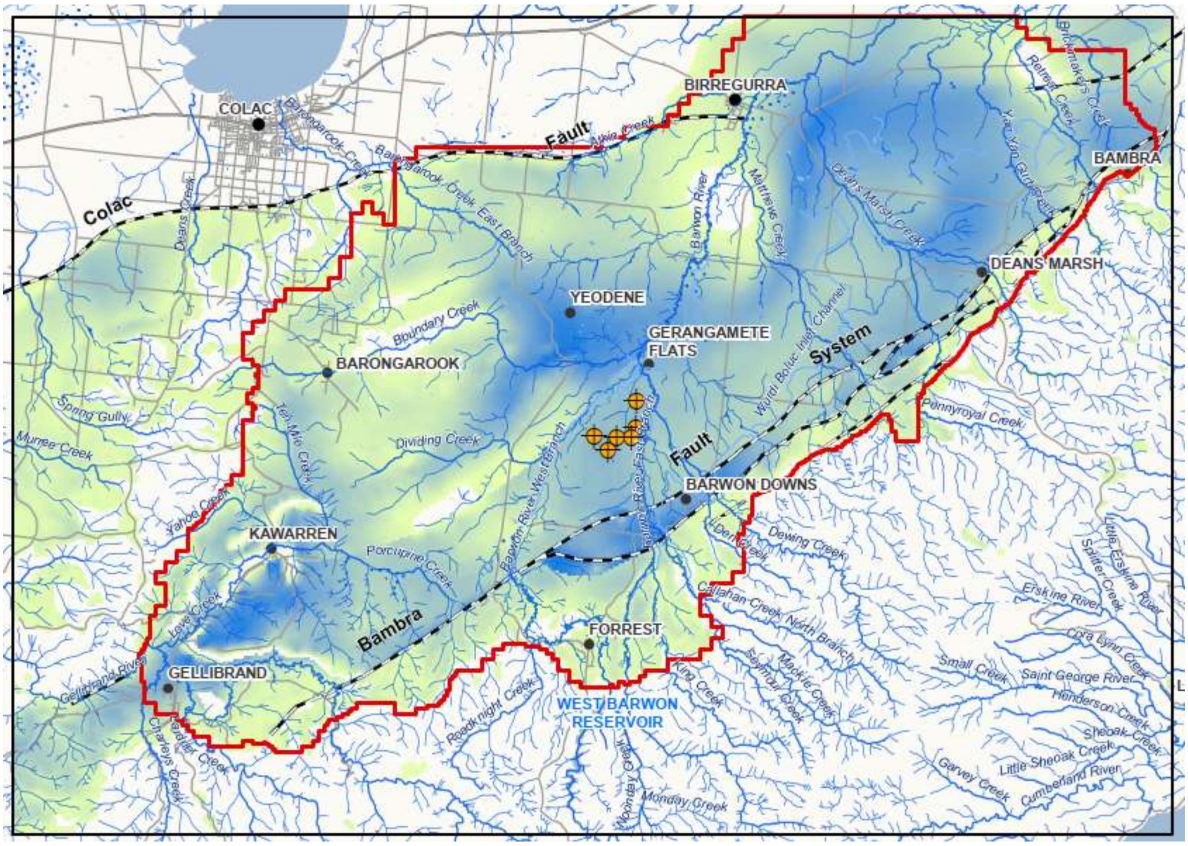


Figure 2: Area considered for further investigation

3.3 Definition of Remediation

The words river 'restoration', 'rehabilitation' and 'remediation' are often used interchangeably but have very different definitions with regard to environmental projects.

'Restoration

The ideal restoration project will restore a degraded river to its original condition. This includes restoring the natural range of water quality, sediment and flow regime, channel geometry, native aquatic plants and animals, and adjoining riparian lands. The goal of restoration is an admirable one, but it is important to acknowledge that it is often something to be aspired to, as it will seldom be possible to achieve.

This is because it is often impossible to establish what the 'original' condition was and, secondly, such restoration would mean replicating pre-European inputs and outputs into the system (e.g. water quality and quantity, animals and plants) from upstream, downstream and the riparian zone.

Rehabilitation

Although restoration may be impossible, this does not leave a degraded system without hope. By improving the most important aspects of the stream environment, you may create a stream that, although only resembling its original condition, is nevertheless an improvement on the degraded system and often a valuable environment in its own right.

Since restoration is usually impossible, rehabilitation is the more common goal for undertaking projects along rivers.

Remediation

In some cases, even rehabilitation is not possible because of irretrievable changes. In such a situation, the original state is no longer an appropriate aim for the stream because inputs from the catchment will never support that condition. **The aim of remediation is to improve the ecological condition of the stream, but the endpoint of that improvement will not necessarily resemble the original state of the stream.** In fact, it may not be possible to predict what that endpoint will be like.

Understanding that some of the changes in the catchment cannot be reversed (e.g. climate change, land clearing, channelisation and soil chemistry), rehabilitation and restoration are not reasonable and practicable conditions to aim for because inputs from the catchment will never support that original condition.'

(Edgar & Lovett, 2002)

Remediation has been defined in the s78 notice as the controls and actions that could be practicably carried out to achieve improved environmental outcomes.

Therefore, in order to address the requirements of the s78 notice and scientifically accepted definitions of remediation, the following has been adopted as the definition of remediation for the purposes of the REPP:

Remediation refers to the controls and actions that could be practicably carried out to improve the ecological condition and function of areas confirmed to have been impacted by historical management of groundwater pumping at Barwon Downs, noting that this is likely to be different to the original condition due to the extent of change since European settlement.

3.4 Adaptive management approach

Barwon Water has adopted the following definition of adaptive management for the REPP:

> **'a continuous cycle of improvement based on setting goals and priorities, developing strategies, taking action and measuring results, and then feeding the results of monitoring back into new goals, priorities, strategies and actions'**
>
> (Mackay, 2016).

An adaptive approach to remediation is considered best practice, whereby the REPP can be adapted in response to ongoing monitoring and measured changes. This approach allows Barwon Water to evaluate how systems are responding to interventions and take further action, such as implementation of contingency measures, if required.

An adaptive approach also aligns with feedback received from Southern Rural Water and its Independent Technical Review Panel which highlighted that the setting of indicators and measures of success would be dependent on the periods and seasonality of monitoring, and therefore a full seasonal cycle of data should be collected as a minimum to better inform long-term remediation. This approach allows for ongoing monitoring and collection of data to inform further actions.

The effectiveness of an adaptive management approach relies on appropriately designed management interventions and related monitoring and assessment programs. Adaptive management requires periodic review and if needed, the adjustment of the:

- **conceptual understanding**
  Constantly evolving improvements to the understanding of the system, its drivers and relationships based on collection of longer periods of monitoring data and the update of supporting models;

- **vision and objectives**
  If management strategies cannot achieve the vision and objectives against SMART success measures or targets, then the vision and objectives may need to be modified as more information becomes available as to what is achievable;

- **management strategies**
  Using the monitoring program to determine if the management strategies are working as expected and embrace innovation as newer technologies develop, and

- **monitoring**
  Based on observed 'on-ground' changes revisions to the monitoring program may be required.

Barwon Water proposes that any changes made to the REPP in light of the adaptive management approach would need to be considered and subsequently, approved by SRW.

4 Background & Context

Table 4 summarises the key regulatory mechanisms, technical inputs and community and stakeholder engagement activities that led to the development of the REPP.

An overview of the timeline in relation to the s78 notice is captured in Figure 3.

Table 4: Inputs that informed the development of the REPP

Time	Event
June 2017	**Environmental impact caused by historical management of groundwater pumping acknowledged** Barwon Water acknowledged publicly that the historic management of groundwater pumping from the Barwon Downs Borefield had environmentally significant impacts in the Boundary Creek catchment.
December 2017	**Yeodene (Big) Swamp Study drafted** A draft technical report was prepared to improve the understanding of chemical and physical processes in and around Big Swamp and on this basis, six possible remediation strategies for Boundary Creek and Big Swamp. This draft report was shared publicly.
May 2018	**Remediation Working Group established** The Remediation Working Group nominated three independent technical experts to provide input into the development of the Boundary Creek and Big Swamp Remediation Plan.
July 2018	**Nominated technical experts appointed** The Remediation Working Group established their independent expert panel to provide technical support in the development of the Boundary Creek and Big Swamp Remediation Plan.
September 2018	**Section 78 Ministerial Notice issued** Barwon Water was issued with a Ministerial Notice under Section 78 of the Water Act 1989. The purpose of the Notice is to ensure that Barwon Water successfully remediates impacts caused by historic groundwater extraction. The section 78 Notice directs Barwon Water to undertake the following requirements: • Discontinue extraction, other than for maintenance and emergency response purposes while the assessment is being completed and until all remediation work required under the remediation plan has been completed, and • Prepare and implement a remediation and environmental protection plan for Boundary Creek, Big Swamp and the surrounding environment. The preparation and implementation of the plan requires the: • Submission of a scope of works for developing the Remediation Plan by December 2018; • Submission of the Remediation Plan by 20 December 2019; and • Implementation of the Remediation Plan by 01 March 2020

Time	Event
December 2018	**Scope of works submitted** Barwon Water submitted the scope of works which outlined the area covered by the Plan, the environmental values to be included, and the necessary environmental assessments and methodology for how Barwon Water proposed to develop the Plan.
February 2019	**Southern Rural Water feedback on scope of works received** In early 2019, Southern Rural Water and its Independent Technical Reference Panel reviewed the 'scope of works'. Feedback included: • The use of a risk assessment framework to identify and confirm areas for remediation; • Broadening out the geographical extent beyond the Boundary Creek catchment; and • Broadening the ecological values beyond the emphasis on acid sulfate soils to address all beneficial uses under the State Environmental Protection Policy (Victorian Waters). • Data collected will be seasonally variable and vary between years depending on climatic conditions and therefore the setting of indicators and measures of success will be dependent on the periods and seasonality of monitoring Feedback was also received from the Remediation Working Group and their nominated expert panel and was consistent with what was provided from Southern Rural Water.
March 2019	**Field program and environmental assessments commenced** With approval from Southern Rural Water and support from the Remediation Working Group, Barwon Water initiated: • a field program and site specific environmental assessments to inform the development of the REPP, and • subsequently undertook additional monitoring as described in the scope of works to improve the conceptual understanding of current system conditions.
April 2019	**Community information sessions held** Community information sessions were held at Winchelsea, Birregurra and Colac to provide an update on the Remediation Plan to the broader community. Around forty people attended the information sessions with discussion centering on the process for developing the remediation plan, investigating whether there have been impacts in other areas and plans to secure future water supplies.
April 2019	**Soil testing and analysis commenced** A specialist consultant was engaged to undertake static and kinetic (incubation) soils testing to subject soils to a variety of treatments to assess the dominant hydro-geochemical processes occurring within the swamp and how theses might respond to changing hydro-geochemical conditions. Static testing was complete and five soil types were categorized, including: burned, unburned, wet and dry sediment. These soil types underwent further analysis using

Time	Event
	standard methods according to the national acid sulfate soils identification and laboratory methods manual. Results of the static testing informed the incubation testing by ensuring that the soils used in the incubation tests are representative of Big Swamp. Incubation test samples were sacrificed in a times series of 1,2,4,8,16,32,64 and 128 days (note, the final time step of 200 days won't be completed until after submission of this REPP) to determine if neutralisation of actual and potential acidity is viable via different treatment methods.
July 2019	**Revised scope of works submitted** Barwon Water submitted a revised scope of works on 31 July 2019 that addressed all feedback received from Southern Rural Water and its Independent Technical Review Panel, as well as the Remediation Working Group and their nominated experts.
October 2019	**Southern Rural Water feedback on revised scope of works received** After review, Southern Rural Water and its Independent Technical Review Panel considered the scope of works complete conditional to addressing recommendations and feedback through the submission of the Remediation Plan.
October 2019	**Community information sessions held** Community information sessions were held at Winchelsea and Colac to provide another update on the Remediation Plan to the broader community. Fifteen people attended the information sessions with focus on what would be included in the Remediation Plan and how the field program and environmental assessments were progressing.

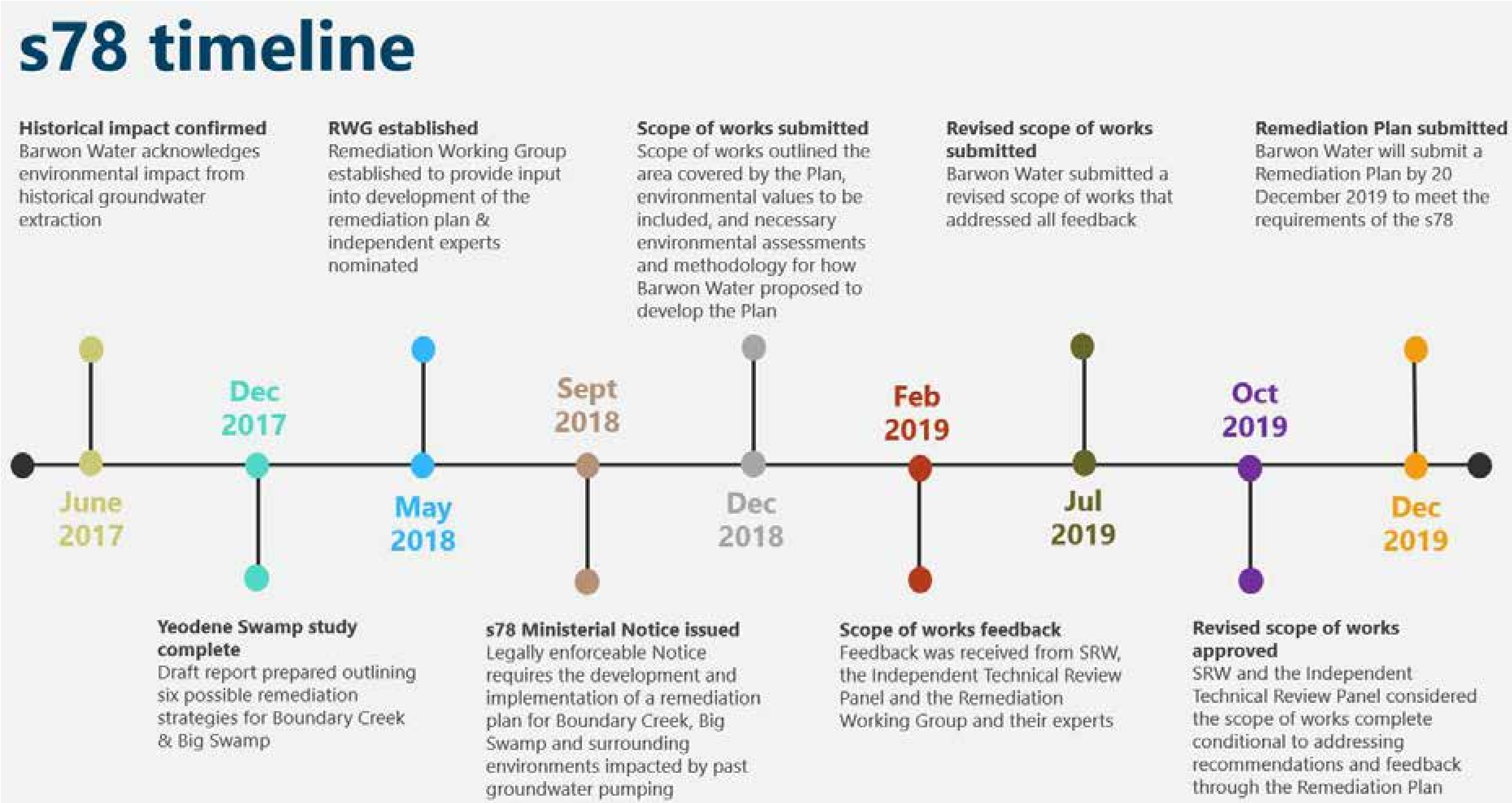


Figure 3: Summary of s78 notice and requirements

4.1 Why is remediation necessary?

Although many factors (described in section 6.1.2) have contributed to changes in the Boundary Creek Catchment, the two variables that have had the greatest influence are the management of historical groundwater extraction and climate due to their impact on flows.

Hydrogeological investigations found that "operation of the borefield over the past 30 years is responsible for two thirds of the reduction of base flow into Boundary Creek" (Jacobs, 2018a). Furthermore, the investigation concluded that "pumping had increased the frequency and duration of no flow periods in the lower reaches of Boundary Creek" (Jacobs, 2018a).

Compounding this, was the ineffective management of the supplementary flow condition. This was confirmed by investigations (Jacobs, 2018b) which showed that passing flows including the release of 2 ML/day in supplementary flows to counter expected streamflow losses in the lower reach of Boundary Creek were not passed in full in accordance with dam licence WLE043336.

This has resulted in several environmental impacts, including:

- Oxidation of acid sulfate soils in Big Swamp, leading to release of acidic water (i.e. water with low pH, low alkalinity, high acidity and elevated concentration of metals) into Boundary Creek and Barwon River;
- Encroachment of plant species relying on deeper groundwater levels within Big Swamp, and
- Increased occurrence of days with 'no flow' (i.e. flow rate below detection at the Yeodene stream gauge) in Boundary Creek downstream of Big Swamp (Reach 3).

Refer to Figure 4 and Figure 5.

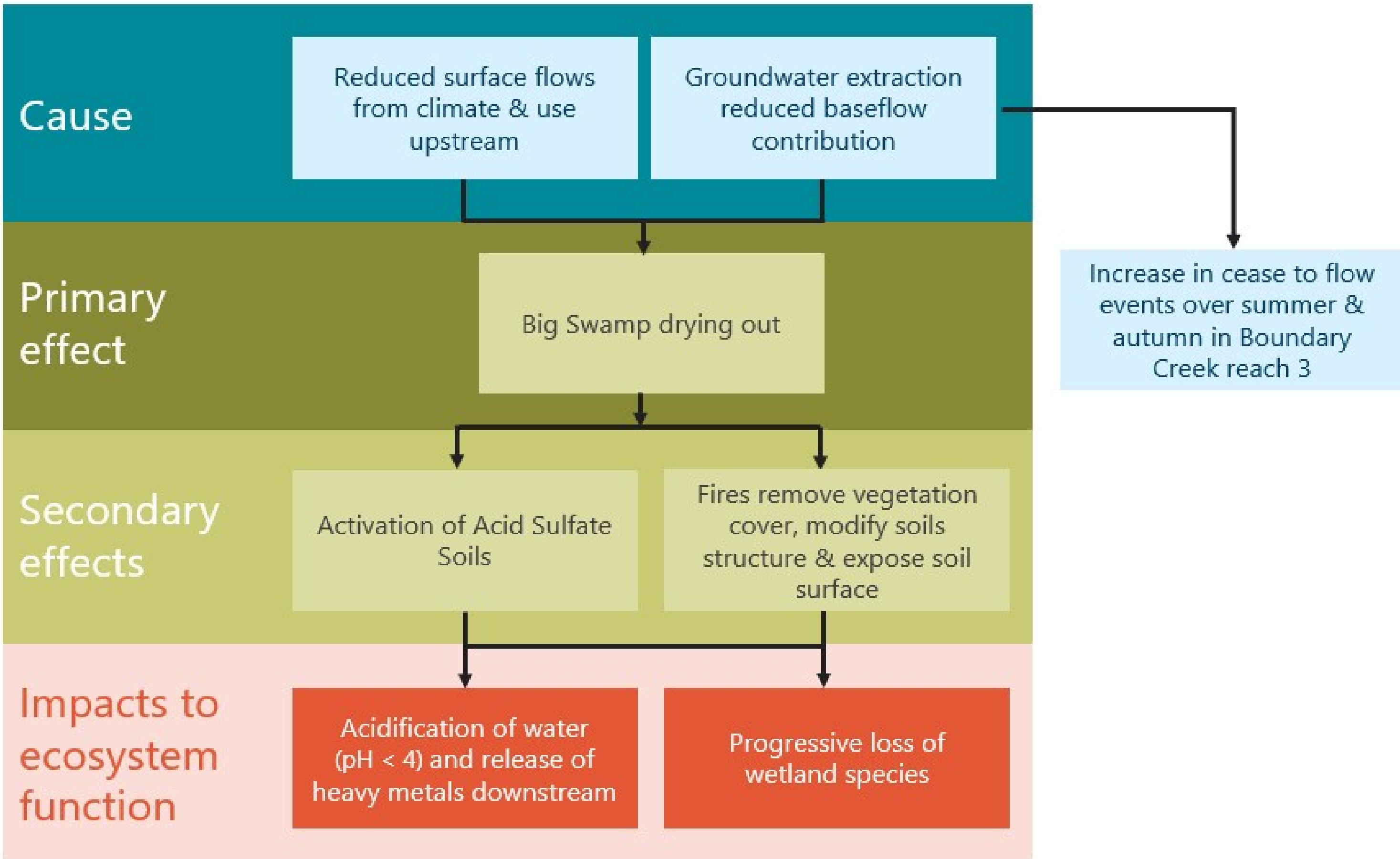
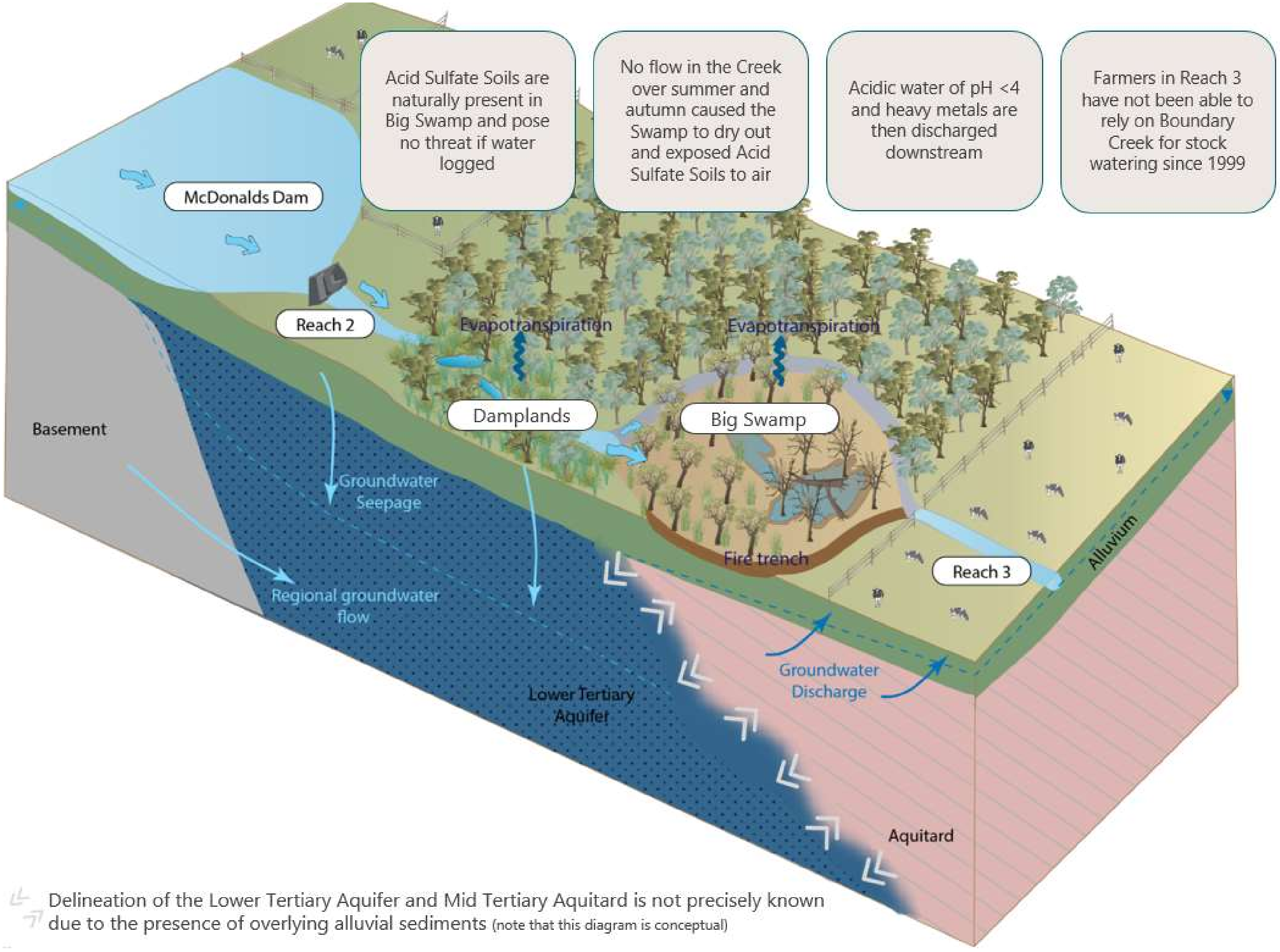


Figure 4: Cause and effect relationship in the Boundary Creek catchment



Water quality in Boundary Creek

Pre-1990

Median pH was 6.5 although readings around 5 were recorded under low flow conditions in Boundary Creek.

1990-1992

Monthly pH readings were median 5.1. Readings below pH 4 were recorded over summer and autumn when flows in Boundary Creek were reduced.

1992 – 1999

The median pH reading increased to 5.9 with only two readings below 4.0.

Since 1999

The median pH reading has fallen to 3.8 and has rarely been above 5. Cease to flow events have occurred annually after a step change of reduced flow in the creek. Over this time, pH has fallen and has not recovered.

Figure 5: Changes in water quality in Boundary Creek

Figure 6 provides a simplified conceptual illustration of the water balance for Boundary Creek, including the release of supplementary flows, reduced releases from 'McDonalds Dam' and surface water-groundwater interactions along each reach of Boundary Creek.

Figure 7 provides a simplified conceptual illustration of the chemical processes occurring at Big Swamp leading to the oxidation of acid sulfate soils and subsequently causing the discharge of low pH water downstream.

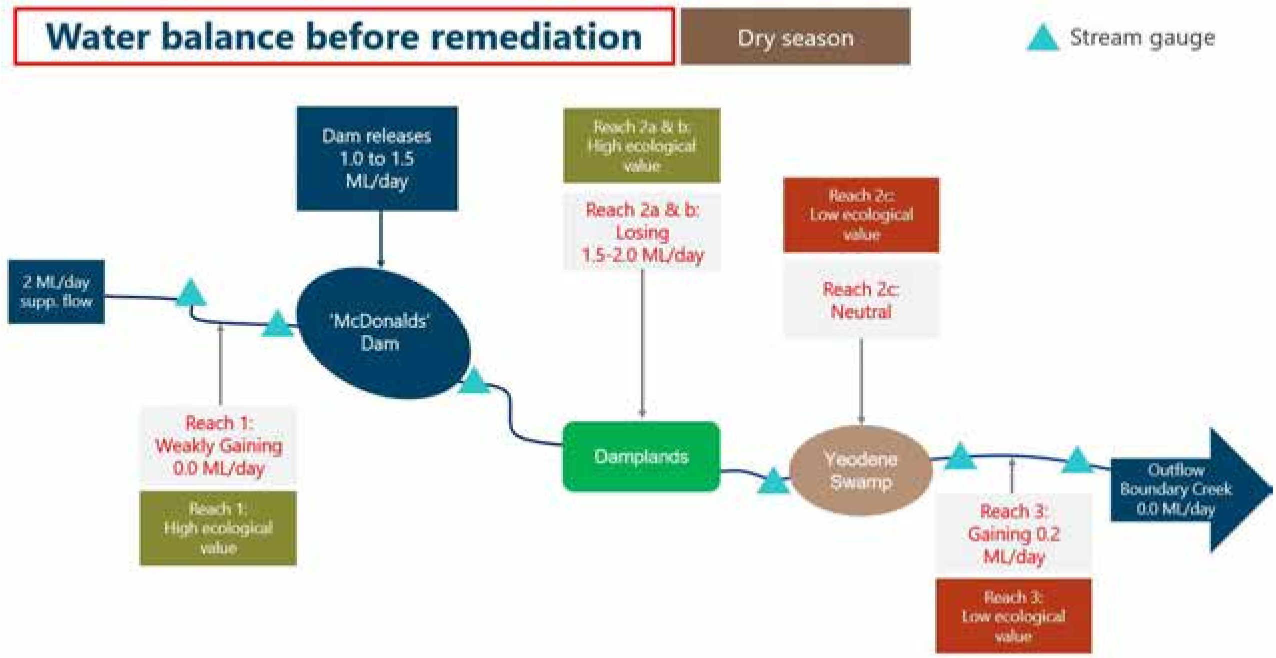


Figure 6: Conceptual water balance of Boundary Creek during the summer dry period prior to remediation

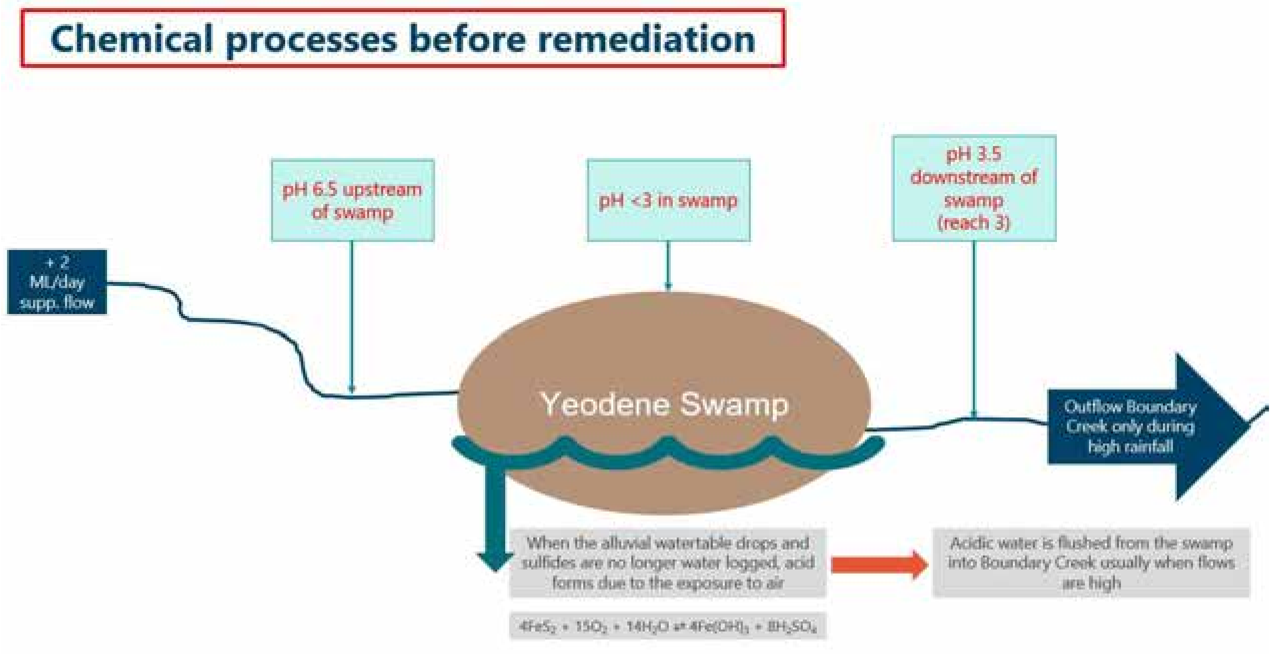


Figure 7: Conceptual chemical process occurring in Yeodene (Big Swamp) without remediation

4.2 What informed the development of the Remediation Plan

4.2.1 Community & stakeholder engagement

In May 2018, the Boundary Creek and Big Swamp Remediation Working Group was established to actively engage with Barwon Water in the design of a remediation plan for Boundary Creek and Big Swamp.

The working group is made up of representatives from the Corangamite Catchment Management Authority, Colac Otway Shire Council, Traditional Owners, Land and Water Resources Otway Catchment, Environment Victoria, Upper Barwon Landcare Group, Boundary Creek landowners and other interested community members.

The working group nominated their own independent technical experts to provide specialist advice and support. The experts are:

- **Dr. Vanessa Wong** (Monash University, Senior Lecturer, School of Earth Atmosphere and Environment)
- **Prof. Richard Bush** (Monash Sustainable Development Institute) (Global Innovation Chair, International Centre for Balanced Land Use Office)
- **Dr. Darren Baldwin** (Independent Consultant) (Charles Sturt University, Visiting Adjunct Professor, School of Environmental Sciences)

Ten meetings were held to consider how best to incorporate the community's vision and values for remediation as well as address any concerns they had about the remediation option. An eleventh and final meeting will be held with the group in early 2020 to provide the group with Southern Rural Water's feedback on the REPP.

A summary of meetings is provided in section 9.

Subject to the following considerations, the REPP was supported by the Remediation Working Group and their nominated technical experts:

- Desire to see Barwon Water's support for recovery of groundwater levels in the Lower Tertiary Aquifer articulated as a principle;
- Success measures for remediation need to be specific and measurable;
- Preference for minimal active treatment interventions unless required to be implemented as a contingency;
- Appropriate contingency measures developed to mitigate any unforeseen impact from the implementation of remedial works for Boundary Creek and Big Swamp, and
- Confirmation of impacts associated with the Surrounding Environment Investigation needs to be based on observable data and field studies to validate the predictions of the regional groundwater model.

4.2.2 Field program and environmental assessments

The revised scope of works that Barwon Water submitted in July, 2019 outlined a range of monitoring and environmental assessments to improve the understanding of the current system conditions of the Boundary Creek catchment. Activities under the scope of works have informed the development of the REPP.

The scope of works, of which some activities are still in progress, has included:

- Installation of 17 groundwater monitoring bores and data loggers within Big Swamp;
- Monitoring of groundwater levels in the 17 bores within Big Swamp;
- Monitoring of groundwater quality in the 17 bores in Big Swamp;
- Installation of two new stream gauges upstream and downstream of Big Swamp to monitor surface water flows in and out of the swamp, as well as monitor pH and EC;
- Light Detection and Ranging (LIDAR) Survey captured for Boundary Creek and Big Swamp
- 181 soil samples collected to depths of six metres from Big Swamp with cores logged for grainsize, colour, moisture content, organic material, odour, plasticity, cohesion, peat and burnt condition;
- 250 kg soil samples from Big Swamp sent for static laboratory analysis of acidity, potential acidity, acid neutralising capacity, net acidity, organic matter, and moisture content;
- Commencement of soil incubation testing of five soil types at the Monash University soils laboratory, including treatment with:
    1. No addition (anoxia)
    2. Bioavailable carbon
    3. Lime
    4. Lime and bioavailable carbon
    5. Sulfate

  A total of 675 analytical points will be collected over a sampling period of 1, 2, 4, 8, 16, 32, 64, 128, 200 days (underway with completion due early 2020);

Figure 8: Soils incubating in lab

- Vegetation survey undertaken within Big Swamp, and
- Water quality, sediment and macroinvertebrate sampling along Boundary Creek and the Barwon River.

4.2.3 Modelling to inform the Remediation of Boundary Creek and Big Swamp

Modelling to inform the feasibility assessment of remediation options, potential risks and other issues was informed by data collected through the field program and associated environmental assessments.

Groundwater, surface water and geochemical models were used to simulate the Boundary Creek system and predict responses to physical processes such as groundwater and surface water flows, soil chemistry and water quality changes. Key outcomes included the quantification of acid in Big Swamp, the water balance within the swamp and understanding of changes in geochemistry that could result as a consequence of implementing various remediation options.

A surface water model (including a flood model) and a groundwater model were developed and 'loosely' coupled to enable prediction of the impact of surface water flows and influences of localised groundwater levels within Big Swamp. Various scenarios were assessed, including different flow rates, timeframes and the feasibility of a hydraulic barrier to maintain water levels and re-wet the swamp. The models were limited by a short period of data collection and therefore further refinement and calibration will be required as ongoing monitoring continues. The collection of a full seasonal cycle of data was a recommendation provided by Southern Rural Water and its Independent Technical Review Panel on review of the revised scope of works.

A conceptual level hydro-geochemical model for Big Swamp was also developed to identify the key chemical processes responsible for the generation of acid, and estimate the current load and concentration of key analytes discharging from the swamp under different flow conditions and how analytes are likely to change over time.

Note that the geochemical model is thermodynamic, not kinetic in nature due to the recent installation of monitoring assets that haven't yet captured a low flow period. Development of a kinetic model will require a longer period of data to allow refinement of the model.

4.2.4 Approach adopted to develop the Boundary Creek and Big Swamp Remediation Plan

The approach adopted for development of the Boundary Creek and Big Swamp Remediation Plan was adapted from a nationally recognised 12 step stream rehabilitation planning process developed by the Cooperative Research Centre for Catchment Hydrology that provides guidance on how to conduct a stream rehabilitation – or in this case – a remediation project (LWRRDC & CRCCH, 2000).

Figure 9 summarises the 12 step planning process with more detail provided in section 9.

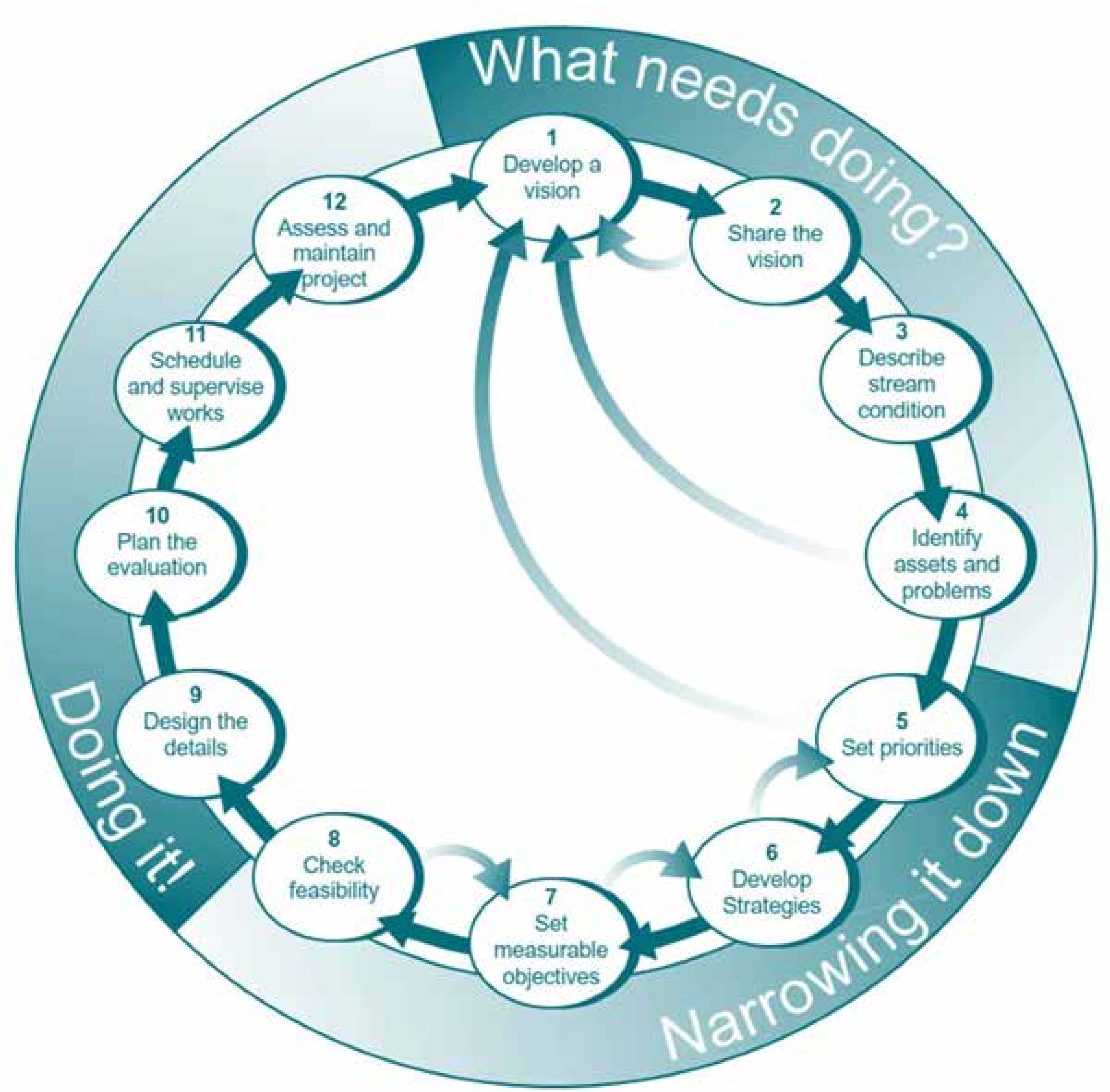


Figure 9: 12 step stream rehabilitation/remediation planning process (LWRRDC & CRCCH, 2000).

5 Remediation and Environmental Protection Plan summary

5.1 REPP Vision

Implementation of practical remediation actions and controls that achieve an improvement to the environment and the community, where measurable and evidence-based scientific methodologies conclude that historical groundwater pumping by Barwon Water at Barwon Downs Borefield has caused an environmentally significant adverse impact in that area.

5.2 Remediation of Boundary Creek and Big Swamp

5.2.1 Vision for Remediation of Boundary Creek and Big Swamp

Implementation of a practical remediation strategy that achieves an improvement to the environment and the community, so that:

- Big Swamp and Boundary Creek have healthy and sustained ecological systems;
- The impacts to the Barwon River are minimised and monitored, and
- Fire risks/threats are mitigated.

5.2.2 Priority outcomes for remediation of Boundary Creek and Big Swamp

Priorities were based on the protection of assets with the highest ecological values as well as consideration of the level of effort required to not only remediate damaged reaches but realise the benefits of remediation.

Priorities agreed to by the Remediation Working Group and experts involved are:

- **Protect** Barwon River (major asset) water quality and ecological values.
- **Improve** Boundary Creek stream flow and water quality.
- **Improve** Big Swamp ecological values.

To assist in realising the project vision, the following **six project objectives** were developed and agreed with the Remediation Working Group and experts involved:

1. Maintain groundwater levels above the top of the non-oxidised sediments in Big Swamp (to prevent oxidisation of deeper sediments within the swamp).
2. Control of the acid discharge (i.e. pH, sulfate and metals) from Big Swamp into Boundary Creek.
3. Maintain at least minimum flows in Reach 3 of Boundary Creek all year round.
4. Manage potential formation of acidity downstream of Big Swamp, which may be triggered as a result of implementation of some remediation options (i.e. swamp inundation).
5. Preserve/improve the ecological values of Big Swamp and Boundary Creek.
   This objective is focused around addressing the changes to the vegetation assemblages within the swamp post the initial acidic event and fire. The result is a drying of the swamp, creating a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities.
6. Reduce the peat fire risk in Big Swamp.

5.2.3 Remedial actions for Boundary Creek and Big Swamp

The Boundary Creek and Big Swamp Remediation Plan outlines an adaptive approach to improve flows and water quality, as well as vegetation and ecology in Boundary Creek and Big Swamp so that downstream impacts to the Barwon River are minimised.

An adaptive approach was recommended by all the experts and specialists involved in the remediation options assessment and they concluded that a combination of remediation options will be required to meet the vision and priorities.

Actions to be implemented for rewetting the swamp include the:

- **continued delivery of a supplementary flow** to meet the objective of maintaining minimum flows in Reach 3 of Boundary Creek all year round (recording a flow of at least 0.5 ML/day at the Yeodene stream gauge).

- **construction of a series of hydraulic barriers** to effectively distribute flows across the swamp to allow for a greater area to be inundated, increasing surface water flow connectivity across Big Swamp and preventing progressive water table decline in the perched alluvial aquifer.

- **infilling the existing fire trenches and agricultural drain** at the eastern end of the swamp to allow the swamp to retain more water over the winter months.

- **preventing the encroachment of dry vegetation classes** (e.g. Swamp Gum) in Big Swamp to provide suitable conditions for wetland species to recolonise disturbed areas.

- **ongoing data collection to inform the adaptive monitoring approach** including monitoring or surface water flow, groundwater levels, water quality for both groundwater and surface water, vegetation monitoring, macroinvertebrate survey, etc.

- **additional data collection and testing to inform the feasibility of the other contingency options ('aerial liming', 'in-stream treatment' and 'limestone sand')** which is particularly important for the 'in-stream treatment' option in consideration of its higher complexity and financial implications. Subsequent refinement of the geochemical model will inform the feasibility, risks and trade-offs associated with the need for additional treatment as a contingency to manage low pH events while the re-wetting strategy takes effect.

Table 5 highlights the remediation objectives the proposed remediation strategy will meet when considered over the long-term, i.e. 10 years.

Table 5: Meeting the objectives

	Maintain minimum groundwater levels in Big Swamp	Protect Barwon River water quality & ecological values	Improve water quality in Boundary Creek	Maintain Boundary Creek Minimum Flow	Increase Melaleuca/ Swamp Ovata ratio	Reduce Peat Fire Risk	Estimated Costs over 10 years
Remediation Strategy	✓	✓*	✓*	✓	✓	✓	**$5M**

**subject to further data collection, additional modelling and detailed design; contingencies may be required in the short to medium-term*

Costs include initial constructions and ongoing monitoring

Figure 10 provides a simplified conceptual illustration of the water balance for Boundary Creek, including the release of supplementary flows, reduced releases from 'McDonalds Dam' and surface water-groundwater interactions along each reach of Boundary Creek following remediation with the most important change being that minimum flows are maintained all year round in reach 3.

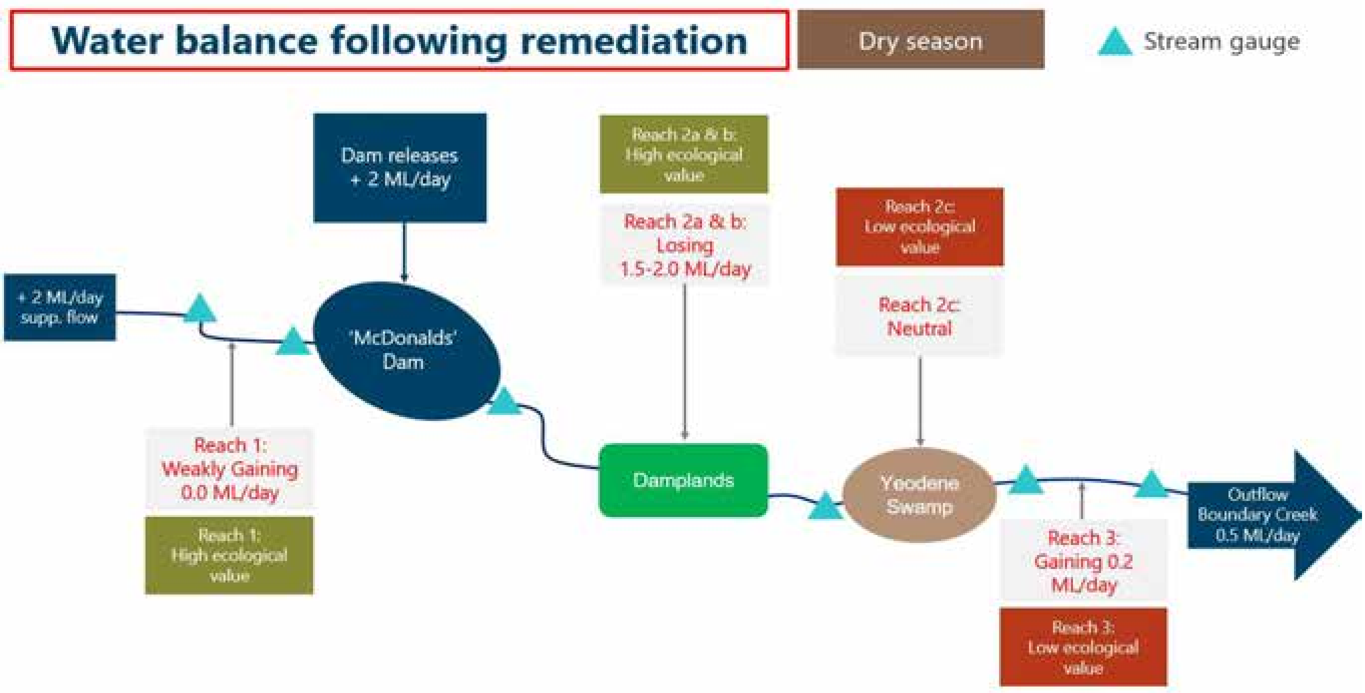


Figure 10: Conceptual water balance of Boundary Creek during the summer dry period following remediation

Figure 11 provides a simplified conceptual illustration of the chemical processes expected to occur following remediation which will see an increase in pH exiting the swamp.

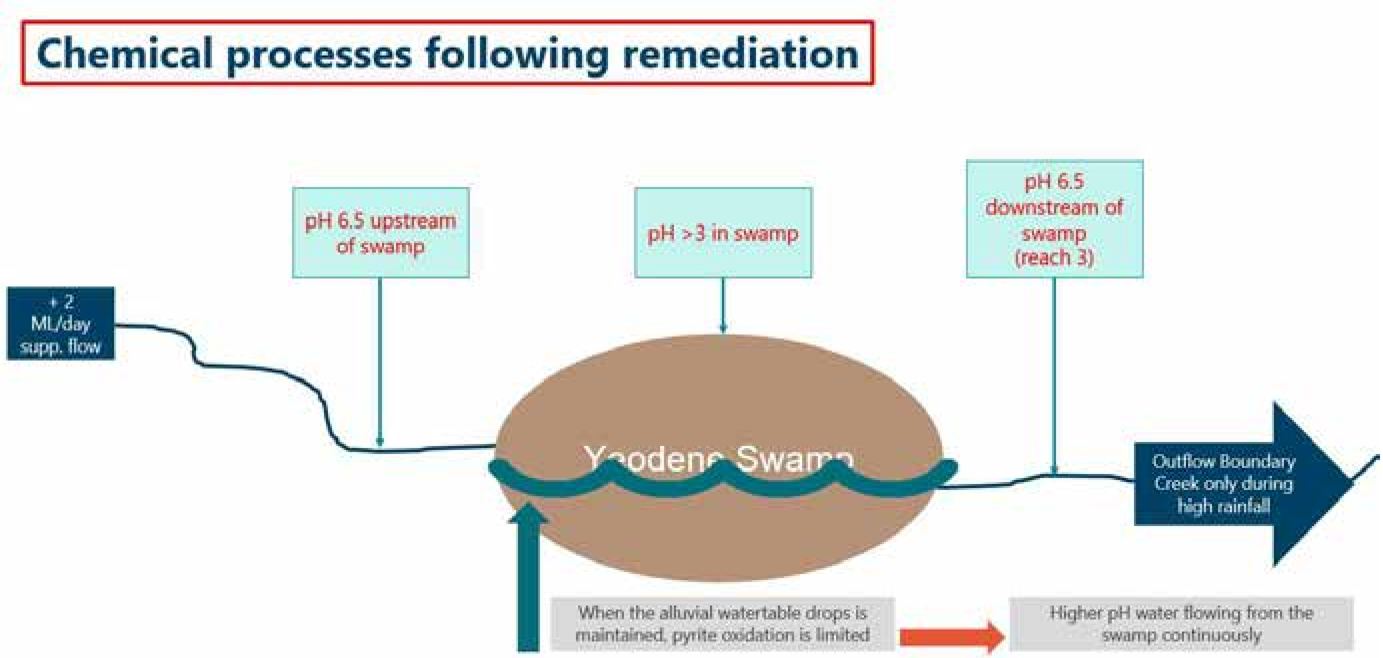


Figure 11: Conceptual chemical process occurring in Big Swamp following remediation

5.2.4 What does success look like for remediation of Boundary Creek and Big Swamp?

The development of success targets was informed by technical work and the vision, priorities and objectives for remediation.

They are based on SMART principles and are specific, measurable, achievable, relevant and time limited.

Consistent with these SMART principles, it is important that the success targets are set at a level that is achievable by the controls and actions being implemented.

Success targets are outlined in

Table 6 with further detail on how they were developed provided in section 6.5.1.

Table 6: Success targets for remediation of Boundary Creek and Big Swamp

Success Target	Measurement	Timeframe
Recovery trend for groundwater levels in the LTA (subject to median climate and no additional groundwater extraction above the current PCV limit)	Monitoring of groundwater levels in observation bores 64229, 64236, 82844 and 109131 to develop hydrographs to confirm a recovery trend line in LTA groundwater levels.	The term of the s78 notice
No further encroachment of terrestrial woodland into the swamp plain	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping to form the baseline for assessment of change along with condition scores.	Within 10 years of Implementation of hydraulic barriers
No encroachment of Lowland Forest dominant species into areas of Damp Forest	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping to form the baseline for assessment of change along with condition scores.	
No loss of structural or floristic diversity along the main channel and western end of the swamp.	Independent regular monitoring of quadrats to assess changes in species diversity over time, with a baseline assessment undertaken to form the basis for measuring changes in structural or floristic diversity along with condition scores.	
Increase diversity of understorey species within the swamp plain, with a focus on ferns and sedges	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping	

Success Target	Measurement	Timeframe
	to form the baseline for assessment of change along with condition scores.	
Big Swamp BH01 water table level less than 1.0 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH06 water table level less than 1.5 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH09 water table level less than 1.8 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH12 water table level less than 1.9 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH15 water table level less than 1.0 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
At least 0.5 ML/day flow maintained at site 233228 Boundary Creek @ Yeodene stream gauge maintained for a period of 2 years (Subject to passing flow conditions being enforced at 'McDonald's Dam' in accordance with its licence conditions - dam licence no. WLE043336)	Flow ML/day	Within 10 years of implementation of hydraulic barriers
Annual median pH equal to or greater than 6.5* at site 233228 Boundary Creek @ Yeodene stream gauge maintained for a period of 2 years To be refined pending completion of geochemical modelling (Dec 2020).	pH equal to or greater than 6.5* (annual median)	Within 10 years of implementation of hydraulic barriers*

**Additional data is required to be collected to enable the modelling of the hydrological and geochemical processes through the swamp and for this to be used to refine the forecast of the achievable target for this measure. The interim target of median pH of 6.5 has been selected based on the SEPP Guidelines. The interim target for water table levels for each bore have been set based on a very short period of data and depending on the final locations of the hydraulic barriers, the location of the water table level targets may be revised to ensure protection of key areas and vegetation.*

5.2.5 Boundary Creek and Big Swamp monitoring

An adaptive approach to remediation is considered best practice, whereby the Remediation Plan can be adapted in response to ongoing monitoring and measured changes. This approach allows Barwon Water to evaluate how systems are responding to interventions and take further action, such as implementation of contingency measures, if required.

Fundamental to an adaptive management approach is establishing an effective monitoring and assessment program to enable ongoing assessment of:

- Compliance with the requirements set out in the s78 notice;
- Progress towards meeting the vision, objectives and success targets;
- Monitoring environmental conditions, and
- Any unexpected high-risk conditions that require immediate management through a contingency action.

The monitoring and assessment program will follow the process of:

- Where needed, installation and construction of new monitoring assets and/or undertake appropriate environmental assessments;
- Collecting monitoring data;
- Refining models based on monitoring data to determine if action is required;
- Implementing action, and
- Evaluating the effectiveness of action.

Monitoring for the Boundary Creek and Big Swamp Remediation Plan will include:

- Standing water levels and groundwater quality at 17 monitoring bores within Big Swamp;
- Stream flow at six gauging sites along Boundary Creek;
- Vegetation assessments at five established transects every two years or as recommended based on monitoring results;
- Water quality monitoring along the Barwon River at 12 established sites quarterly or as recommended based on monitoring results;
- Sediment sampling along the Barwon River at 12 established sites every two years or as recommended based on monitoring results, and
- Macro-invertebrate sampling along the Barwon River at 12 established sites every two years (autumn and spring surveys) or as recommended based on monitoring results.

5.2.6 Boundary Creek and Big Swamp Remediation contingency planning

Contingency measures were identified should high-risk events be identified which may adversely impact environmental receptors. Detailed requirements for contingency measures will need to be informed by the final soil incubation test results anticipated to be available in early 2020, and the collection of additional geochemical data to obtain a full seasonal cycle.

This information will also inform establishment of triggers for implementation of contingency measures.

The implementation of contingency measures may be triggered by outcomes of the monitoring and assessment program to minimise or contain prolonged events like acid flushes or mobilisation of metals that may require additional management through intervention.

The Remediation Working Group supported the need for contingency options to be incorporated as part of remedial works for Boundary Creek and Big Swamp.

Subject to the outcomes of further geochemical modelling, final detailed design of hydraulic barriers and the refinement of assessment of risks, contingency measures may include:

- Increasing or reducing supplementary flows;
- Use of neutralising agents (either via aerial liming or placement of limestone sand) along established surface water flow paths to mitigate potential spikes in acidity promoted by increases in surface water and groundwater levels;
- Installation of a settling pond to protect Boundary Creek and the Barwon River from metal oxidation and precipitation;
- Installation of silt traps/barriers to protect Boundary Creek and the Barwon River from metal oxidation and precipitation;
- Instream treatment to control acid release and manage potential secondary precipitates being released into Boundary Creek and the Barwon River, and/or
- Use of treatment to supplement sulfate deficit in Big Swamp.

Progressive implementation of hydraulic barriers within Big Swamp will also provide an opportunity to calibrate the models (surface water, groundwater and geochemical) and reassess the potential occurrence and magnitude of any risks associated with increasing surface water flows and groundwater levels.

5.3 Surrounding Environment Investigation

The Surrounding Environment Investigation considers an extent of 480 km^2 (refer to Figure 2) as the starting point to identify other potentially impacted areas based on a systematic risk assessment framework (published in the revised scope of works approved by Southern Rural Water in October 2019).

The Surrounding Environment Investigation considers the whole extent of the Lower Tertiary Aquifer (LTA) and will focus on eight '**high**' risk areas identified through a risk assessment process adapted from the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015). This process was detailed in the revised scope of works submitted to and approved by Southern Rural Water.

The initial areas of further investigation include the following and are illustrated in Figure 12:

- Barwon River (East branch);
- Barwon River (West branch);
- Barwon River (downstream of the confluence of the east and west branches);
- Gellibrand River;
- Ten Mile Creek[2];
- Yahoo Creek[3];
- Groundwater dependent ecosystems near Yeodene;
- Groundwater dependent ecosystems near Deans Marsh, and
- Groundwater dependent ecosystems adjacent to the Gellibrand River.

[2] [2] Ten Mile and Yahoo Creeks feed into Loves Creek therefore outcomes for these creeks will also inform requirements for any further assessment of Loves Creek.

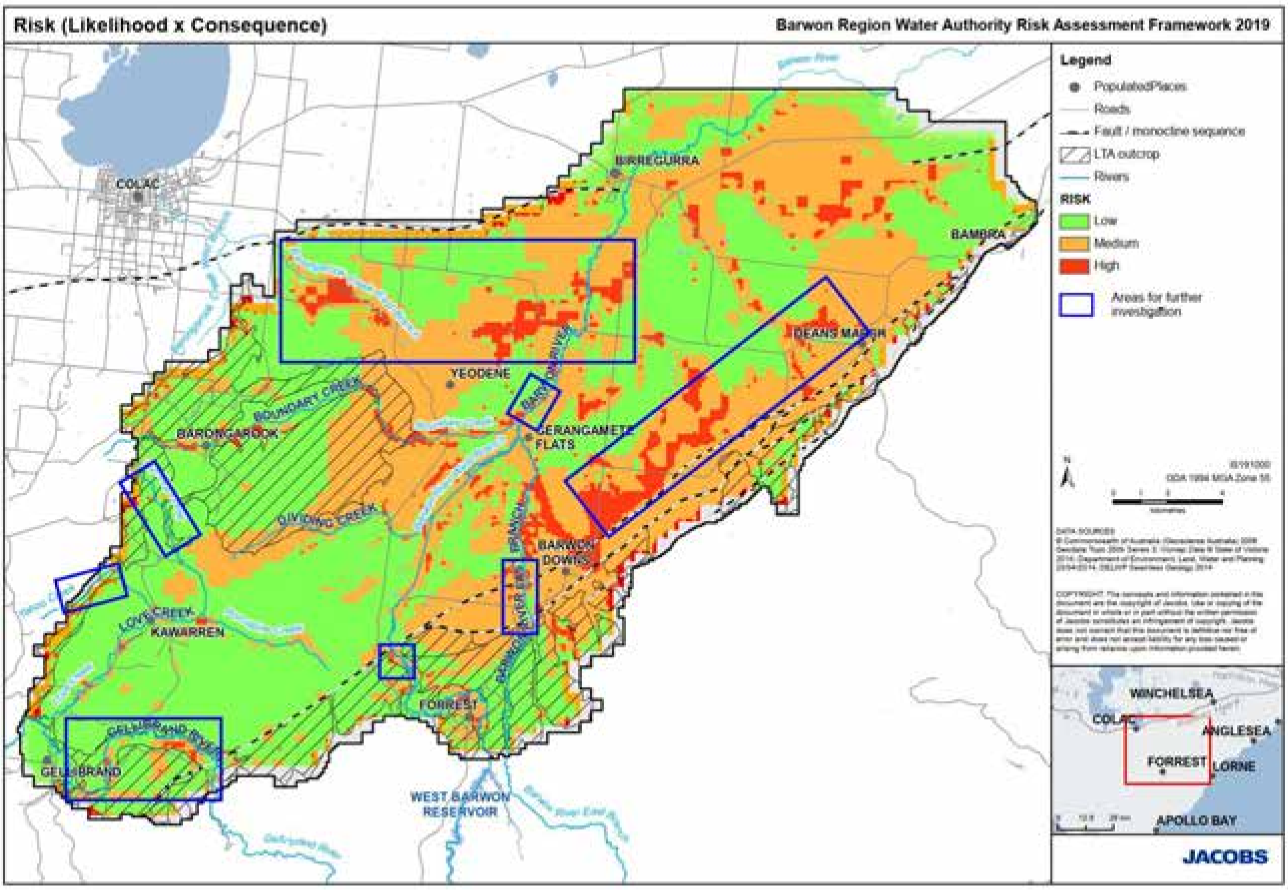


Figure 12: High risk area for further investigation

The regional groundwater model was used as the basis for informing a local scale conceptualisation of each of the eight '**high**' risk areas. Each conceptualisation seeks to represent current thinking (although in most cases, based on limited data-sets) in terms of hydrogeological setting (i.e. groundwater characteristics like recharge, discharge and flow) and processes like groundwater surface water interactions.

While the eight sites at risk are spread across the whole extent of the LTA, information gaps common to them all relate to answering the following questions:

- Has historic groundwater pumping caused a reduction in baseflow to rivers from the LTA (either directly or indirectly) in areas identified as high risk? If so, how much and is it significant?
- Has historic groundwater pumping caused a decline in watertable in areas where there a high value GDEs? And if so, how much and is it significant?

By answering these questions, the Surrounding Environment Investigation will be better placed to identify if there have been environmentally significant impacts in the surrounding environment which have been caused by historic management of groundwater pumping.

To resolve these questions, more data is required to validate the regional groundwater model and in turn, verify that the current risk ranking of '**high**' allocated to the eight areas are accurate. If the regional groundwater model is deemed unfit for purpose, Barwon Water will consider developing localised groundwater models to better represent site specific conditions.

Data-sets for these eight '**high'** risk areas are currently limited (either they don't exist, or the data is insufficient), therefore the recommended actions are to install the following monitoring assets:

- 22 groundwater monitoring bores;
- 5 surface water stream gauges, and
- 6 new vegetation monitoring sites (to confirm existence of groundwater dependent ecosystems).

The investigation has the potential to result in identifying additional areas that may need to be investigated further, or conversely the removal of areas where environmental indicators are not shown to have been impacted by the historic management of groundwater pumping.

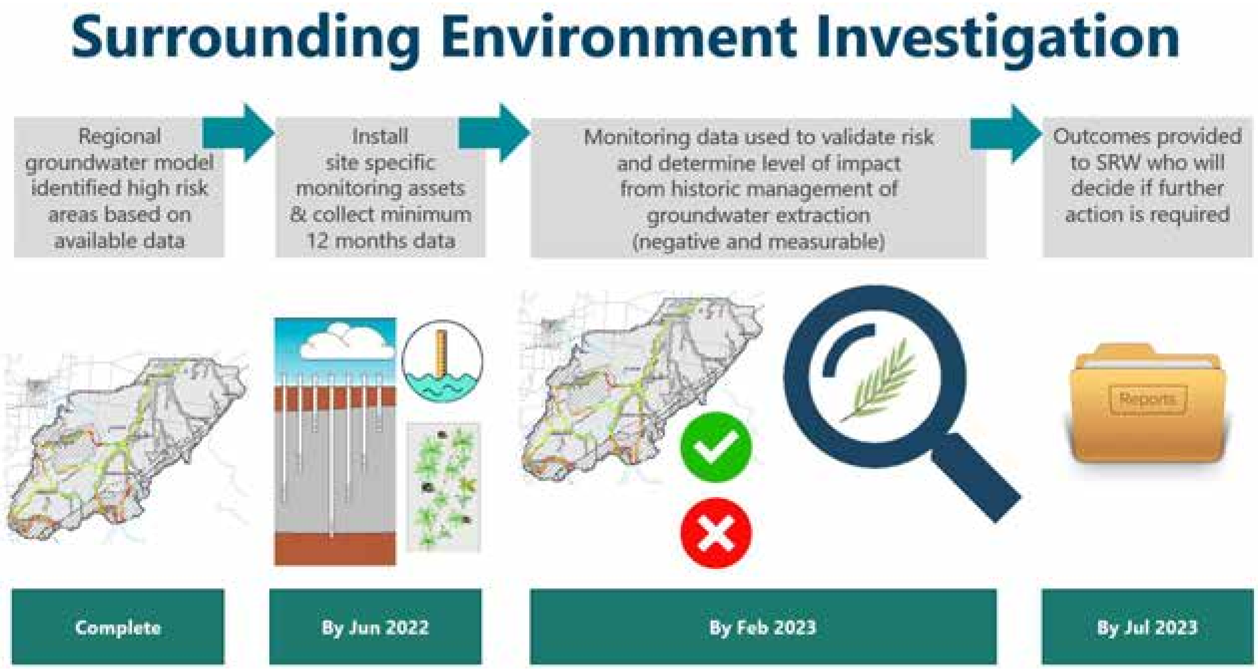


Figure 13: Process overview for the Surrounding Environment Investigation

Figure 13 highlights the time contingency built into the installation and data collection phase due to the fact that some monitoring assets may not be installed until the summer of 2020/21. This allows for approval of the REPP, permits to be obtained and accessibility requirements to install assets (i.e. stream gauges need to be installed during low flow periods).

Some sites such as the East Barwon River are scheduled to have assets installed this summer (2019/2020).

Barwon Water will progressively present outcomes from these investigations to Southern Rural Water as data becomes available to validate risk and determine level of environmental impact from historic management of groundwater extraction. The entire process to confirm if further remediation action is required is expected to conclude by July 2023.

Barwon Water will continue to monitor the regional network of groundwater monitoring bores and stream flow gauges within the Gerangamete and Gellibrand Groundwater Management Areas to refine and update existing surface water, groundwater and geochemical models as required.

Data from new monitoring assets will also be fed back into the regional groundwater model to reassess risks and ensure any new at risk areas are captured for investigation or alternately deemed low risk with no further remediation action required.

In carrying out the Surrounding Environment Investigation, Barwon Water will engage with community and stakeholders to consider insights and other available technical or scientific information so that there is a robust process (for example, that the investigation is well resourced, that data is quality controlled and appropriate project management protocols are followed) for implementing the Surrounding Environment Investigation.

Costs for the Surrounding Environment Investigation are estimated to be in the order of $1.6M.

5.4 Timeframes

High level timeframes for implementation of the Boundary Creek and Big Swamp Remediation Plan are outlined in Figure 14 (over-leaf).

Ongoing activities will include the continued delivery of supplementary flow to meet the objective of maintaining minimum flows in Reach 3 of Boundary Creek all year round (minimum flows means recording a flow of at least 0.5 ML/day at the Yeodene stream gauge) and monitoring and environmental assessments which will be refined based on monitoring outcomes.

Monitoring data will inform the update of the surface water, groundwater and geochemical models, which in turn will feed into the detailed design of the hydraulic barriers. Additional monitoring is necessary for collection of a full seasonal cycle to inform the setting of indicators and measures of success as recommended by Southern Rural Water and its Independent Technical Review Panel in review of the scope of works.

Detailed design is expected to be complete in 2021 to allow adequate time for approvals of permits. During this time, it is expected that the fire trenches will be infilled to enable more water to be retained in the swamp.

Further work will be undertaken in parallel to inform the feasibility and requirements for 'last resort' instream treatment contingency options.

The progressive installation of hydraulic barriers is anticipated to commence early 2022. Trigger levels for contingency measures will be reassessed based on how the system is responding to the hydraulic barriers taking into consideration any potential side effects associated with increasing surface water flows and groundwater levels within Big Swamp.

Barwon Water acknowledges that it may take a decade to realise improvements from remedial works for Boundary Creek and Big Swamp, particularly an increase in median pH values. However, this needs to be balanced with practicality as is required under the s78 notice, along with the environmental implications, costs, risks and trade-offs associated with implementing ongoing artificial treatment.

Beyond implementation, regular assessment of monitoring results, controls and trigger levels will continue to assess if progress is being made towards achieving success targets.

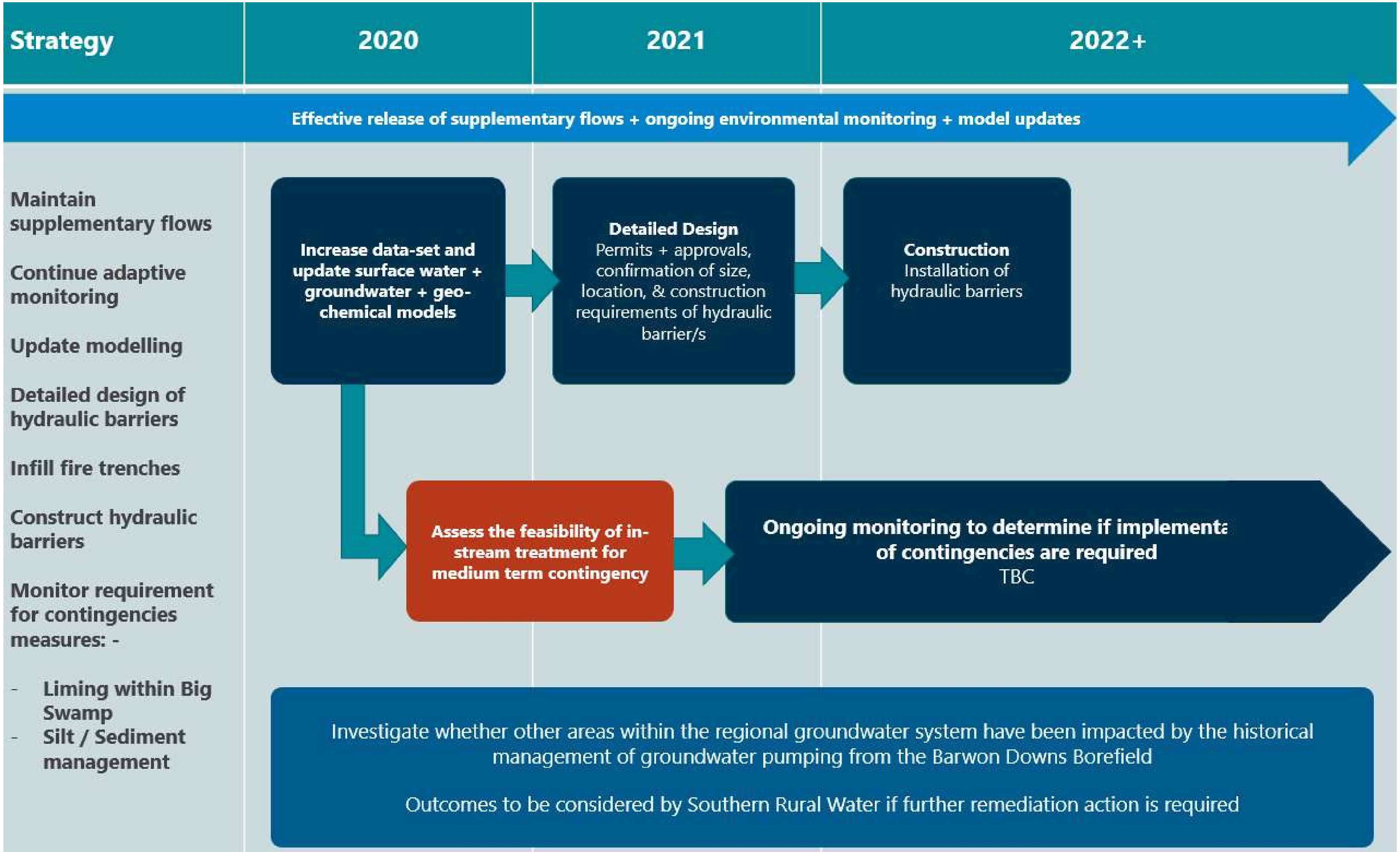


Figure 14: Timeframes for implementation of the REPP

5.5 Reporting Schedule

The schedule outlined in Table 7 proposes that Barwon Water provide a quarterly update and an annual report to Southern Rural Water to meet the requirements of the s78 notice.

The reporting schedule will be reviewed and if necessary, readjusted, at the conclusion of the implementation of the REPP, anticipated for 2023.

Table 7: Reporting schedule for the REPP

Date	Reporting requirement
30 June 2020	Quarter 1 update
30 September 2020	Quarter 2 update + Annual Report*
31 December 2020	Quarter 3 update
31 March 2021	Quarter 4 update
30 June 2021	Quarter 1 update
30 September 2021	Quarter 2 update + Annual Report*
31 December 2021	Quarter 3 update
31 March 2022	Quarter 4 update
30 June 2022	Quarter 1 update
30 September 2022	Quarter 2 update + Annual Report*
31 December 2022	Quarter 3 update
31 March 2023	Quarter 4 update
30 June 2023 +	Quarter 1 update

**Barwon Water proposes that any improvements made to the REPP in light of the adaptive management approach is put forward and approved by SRW as part of the annual reporting process for the s78.*

5.6 Community & Stakeholder Engagement

Recognising the important role the community, local environmental groups, technical experts and key stakeholders played in the development of the REPP, Barwon Water remains committed to continuing an open and transparent relationship during the upcoming implementation of the REPP.

Barwon Water wants to ensure that local insights and knowledge that the community and stakeholders bring are considered as progress is made in delivering the outcomes of the REPP for both remediation of Boundary Creek and Big Swamp, and the Surrounding Environment Investigation.

Barwon Water has designed a high level engagement approach that is aligned with the International Association for Public Participation (IAP2) public participation spectrum.

Figure 15 provides an overview of Barwon Water's proposed approach to the continued involvement of community and stakeholders following approval of the REPP.

Barwon Water anticipates that the Remediation Working Group will reconvene in March 2020 so that feedback on the REPP from Southern Rural Water and its Independent Technical Review Panel can be shared, and if updates to the REPP are required that the Remediation Working Group is involved prior to a resubmission.

Post approval of the REPP, Barwon Water will continue to share progress updates with key stakeholders, interested community groups and the broader community while implementation is underway.

Like the REPP itself, the approach to engagement will be adaptive to suit the needs of the community and stakeholders.

A dedicated communications and engagement strategy will be developed following approval of the REPP. Barwon Water will share community insights as well as outcomes from its communication and engagement activities through the quarterly and annual reporting requirements with Southern Rural Water.

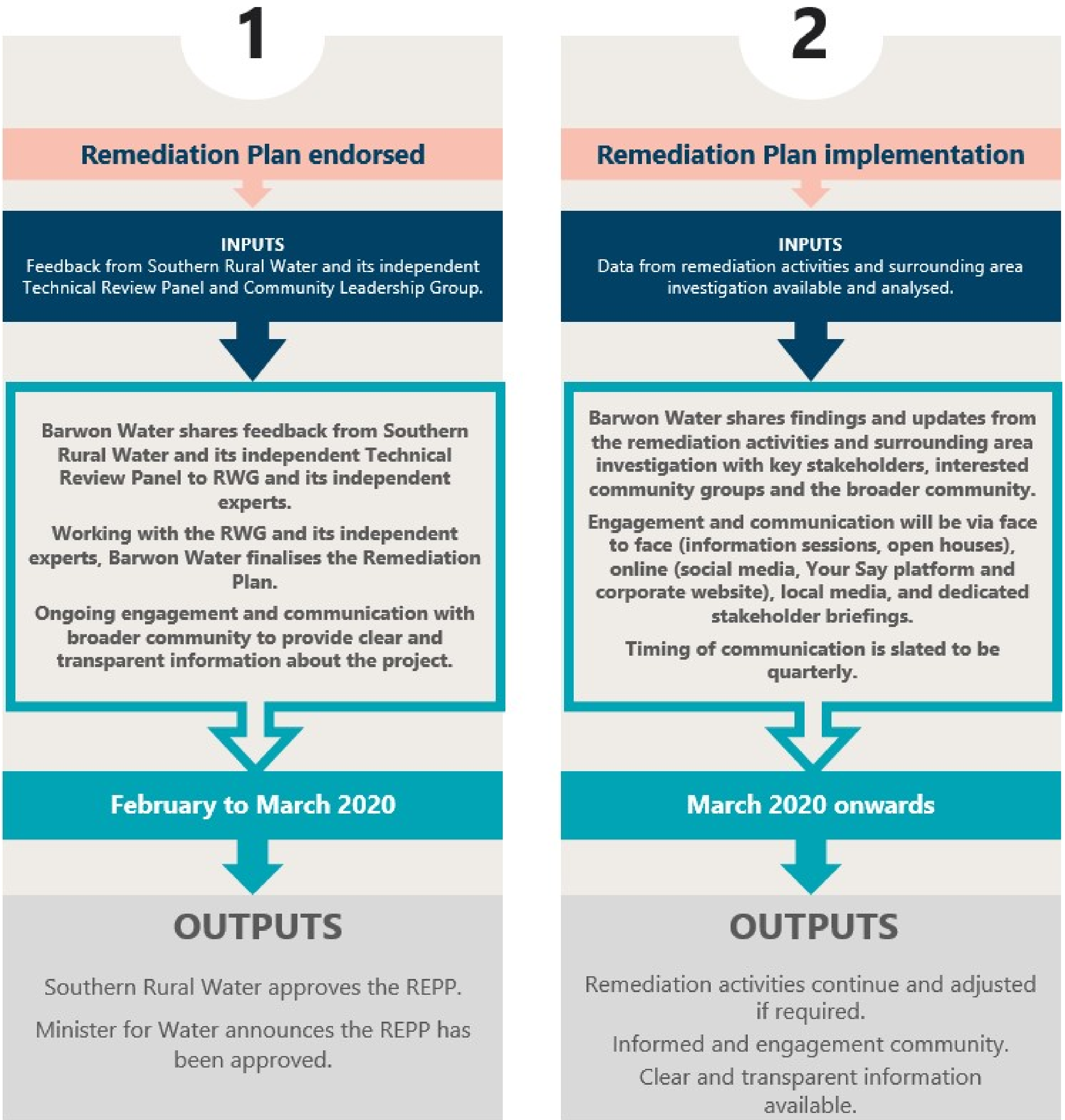


Figure 15: Overview of community and stakeholder engagement

Part 2

Technical Response to s78 notice

6 Background

Barwon Water operated the Barwon Downs borefield under groundwater extraction licence BEE032496 (formerly #893889) which has now expired. Under its licences, Barwon Water extracted a total of 115,676 ML between 1983 and 2016.

Hydrogeological investigations commissioned by Barwon Water found that the "operation of the borefield over the past 30 years is responsible for two thirds of the reduction of base flow into Boundary Creek" (Jacobs, 2018a). Furthermore, the investigation concluded that "pumping had increased the frequency and duration of no flow periods in the lower reaches of Boundary Creek" (Jacobs, 2018a).

Additional technical works subsequently found that passing flow conditions, including Barwon Water's release of the 2 ML/day supplementary flow as stipulated by the groundwater extraction licence was not passed in full (Jacobs, 2018b), in accordance with dam licence WLE043336 to the lower reaches of Boundary Creek and Big Swamp.

The reduction in flows led to the drying and oxidation of acid sulfate soils that exist within Big Swamp. This has resulted in the release of acidic water downstream of Big Swamp and has caused a measureable negative environmental impact on Boundary Creek and Big Swamp, and at times, reaches of the Barwon River up to Winchelsea.

In response to this, Southern Rural Water as a delegate for the Minister for Water, issued a notice (under section 78 of the Water Act, 1989 (Vic)) requiring Barwon Water to:

a) Continue no groundwater extraction, other than for maintenance and emergency response;
b) Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and
c) Describe the environmental outcomes for the waterways to be achieved by the remediation plan.

The following sections describe outcomes as required by points (b) and (c) outlined above.

6.1 Clause 2.5a: A description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment

This section provides a synthesis of the technical data and analysis that was undertaken to inform the REPP. The section is not intended to provide an exhaustive description of the methods, results and findings associated with all technical works, but rather draws on the key findings and outcomes of the technical works completed to provide a description of the "current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment" as required by Clause 2.5a.

The objective of the section is to synthesize a sound understanding of the Boundary Creek system in such a way that can inform the Boundary Creek and Big Swamp Remediation Plan. Full details of the methods and results of technical works undertaken as part of this program can be found in section 9.

6.1.1 Climate

The distribution of rainfall across the Otways and Barwon Downs region is shown in Figure 16 below. Accordingly, this illustrates an average annual rainfall of greater than 1,800 mm/yr throughout the southern Otway Ranges. These rates are consistent with some of the wettest areas in Victoria. Trends in rainfall decline inland of these areas, falling to less than 800 mm at Colac and Aireys Inlet.

Figure 16 also shows the location of five rainfall gauges in the area surrounding the Barwon Downs borefield. These are monitored by the Bureau of Meteorology (BOM) as part of the national rainfall monitoring network. Of the seven gauges shown in this figure, Burtons Lookout and Colac (Elliminyt) are no longer operational.

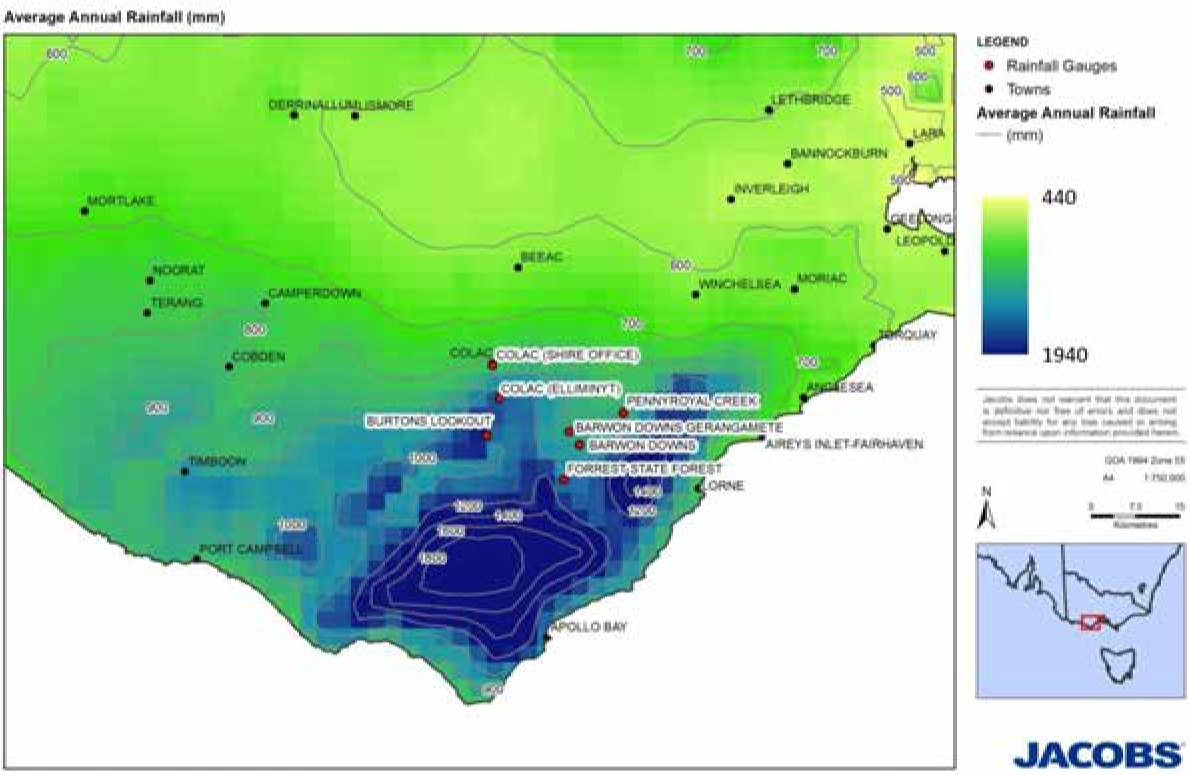


Figure 16: Spatial trends in average annual rainfall in Victoria based on 1960-1991, 30 year period. Data sourced from the Bureau of Meteorology (2010).

As the Forrest State Forest and the Barwon Downs rainfall gauges are centrally located to the Barwon Downs Graben and offer long and complete records, these rainfall gauges were selected for analysis of temporal trends in rainfall to the area. The other rainfall gauges continue to be monitored by BOM.

Temporal trends in rainfall have been represented in Figure 17 for 1900-2016. This figure plots the cumulative deviation from the mean monthly rainfall at the Forrest State Forest and the Barwon Downs rainfall gauges. This highlights periods of below average rainfall conditions (e.g. drought) as declining trends and periods of above average rainfall as rising trends.

The grey shaded area in Figure 17 highlights the Millennium Drought. This represents a 13-year period with a deviation from the mean monthly rainfall of ~1,250 mm, or an average decline of 96 mm/yr (based on the Forrest State Forest gauge). The same gauge exhibited a decline of ~4,000 mm between 1910 and 1945, or an average decline of 114 mm/yr. This provides context for the kind of climatic variability experienced within the Barwon Downs region and the historical conditions to which the region has been subject to.

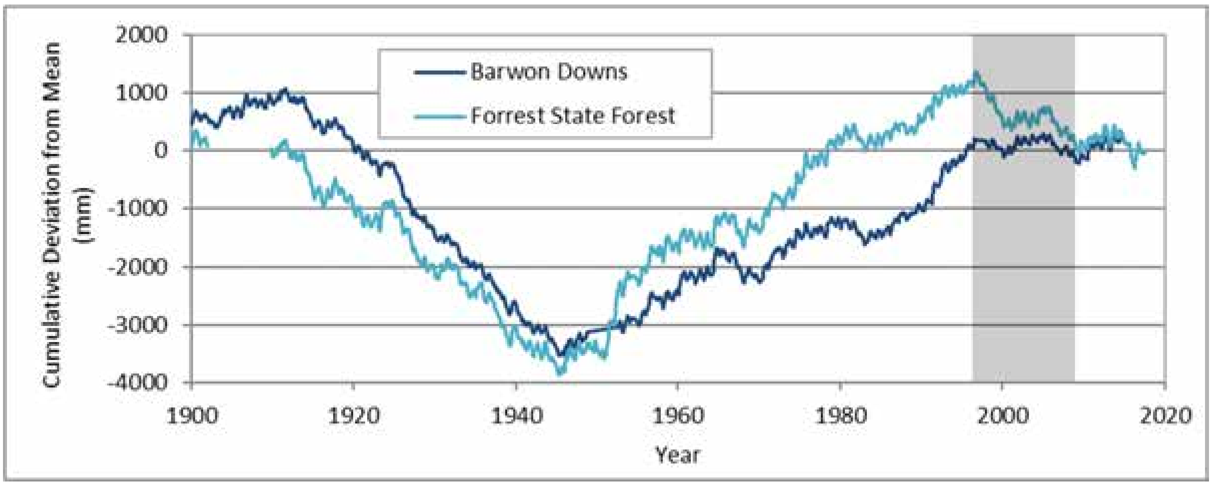


Figure 17: Cumulative deviation from mean rainfall for Forest state Forrest and Barwon Downs rainfall gauges 1900 – 2017 (BOM, 2019)

6.1.2 Boundary Creek catchment description

Boundary Creek rises south of Colac, near Barongarook West, and flows in an easterly direction for approximately 18 km, before joining the Barwon River east of Yeodene.

The Boundary Creek catchment has been highly modified over the last century. Changes to the catchment, some of which are permanent and irreversible, have significantly altered the natural hydrological flow regime of Boundary Creek. These changes include a range of natural and human factors which are outlined below: -

- Figure 18 illustrates the estimated distribution of different vegetation classes in 1750 (DELWP, 2017) prior to European settlement. Land use changes claimed about 800 acres (Jennings, 2008) of low lying land for agricultural production and required the removal of large sections of low land forest and grassy woodlands as shown in Figure 18 . Much of the lower reach of Boundary Creek was cleared over the last century to support agriculture and farming practices which has likely changed runoff patterns and therefore streamflow.

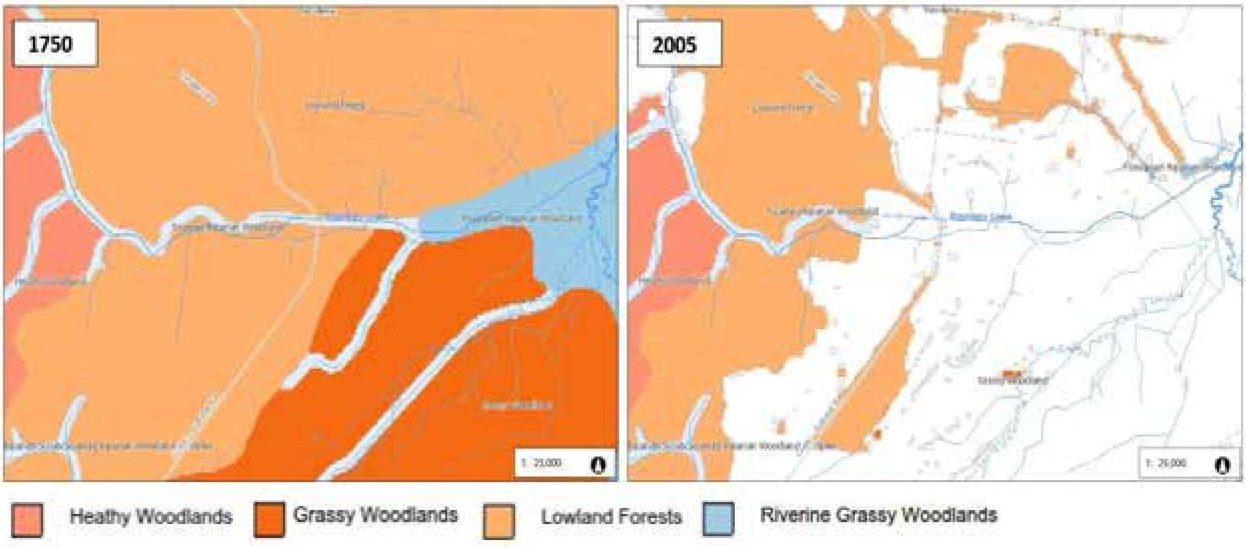


Figure 18: Ecological Vegetation Class mapping of the Boundary Creek catchment in 1750 and 2005

- The catchment has a number of private diverters and farm dams which collect rainfall before it reaches the creek (private diverters make up 91 ML, of which 86 ML are winter fill licences and 5 ML are for stock and domestic uses; SKM 2006).
- In 1979, an on stream private irrigation water storage (referred to as 'McDonalds Dam') was constructed in the central reach of Boundary Creek. The dam has a storage capacity of 160 ML and has a surface area similar to that of Big Swamp.
- Since 2003, Barwon Water has released a supplementary flow of 2ML/day when required under licence conditions to counter predicted losses of baseflow in Boundary Creek that landholders were reliant on for stock watering.
- All creek flow is captured by this dam and while the dam operates under licence from Southern Rural Water, streamflow monitoring gauges installed in 2014 confirmed that not all inflows, including Barwon Water's supplementary flows, were passed as stipulated outside the four month harvesting period.
- Groundwater extraction by Barwon Water occurred in 1983, 1985-1990, 1997-2001, 2005-2010 (Millennium Drought) and 2016 to supplement surface water storages during periods of low inflow. A total of 115,676 ML was extracted over a 30+ year period in accordance with licence conditions.
- Big Swamp is a swamp that is rich in organic soils with peat-like properties located in the middle of the Boundary Creek catchment (downstream of 'McDonalds Dam'). A fire was reported in the swamp on October 10 1997 with an area of approximately one hectare of peat involved in wildfire (Country Fire Authority, 2010). In 2010, fire once again broke out in Big Swamp and burnt an area approximately 80 hectares to the north of Boundary Creek. Fire investigators concluded that this fire was ignited from residual fire still remaining in the peat, which would appear to have been smoldering deep underground since 1997 (Country Fire Authority, 2010). A trench (refer to Figure 19) one km long and up to three m deep running east-west along the southern boundary of the swamp was excavated to prevent fire igniting significant peat deposits within the swamp in 2010. The drying, fire and trenching have had considerable impacts on both the quantity and quality of water flowing out of the swamp and has likely contributed to the lowering of the groundwater table.

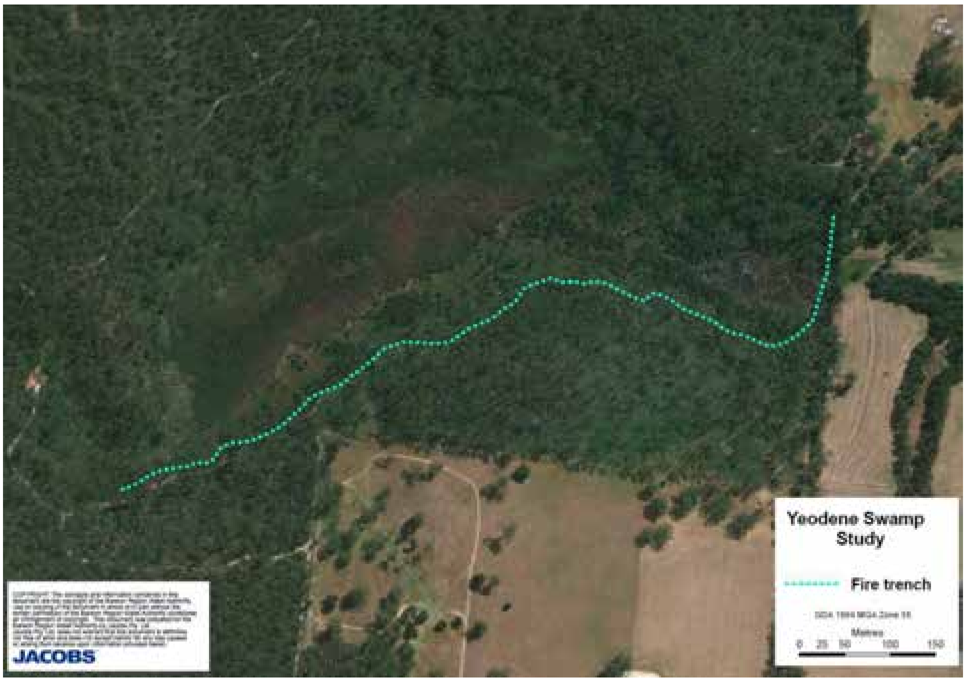


Figure 19: Approximate location of the fire trench excavated in 2010

- Significant changes in long term climatic conditions have resulted in a minimum 30% reduction of streamflow in some parts of the Otways.

By altering the natural hydrology of the creek, the changes outlined above (refer to Figure 20) are likely to have had an impact on the ecological values supported in the catchment.

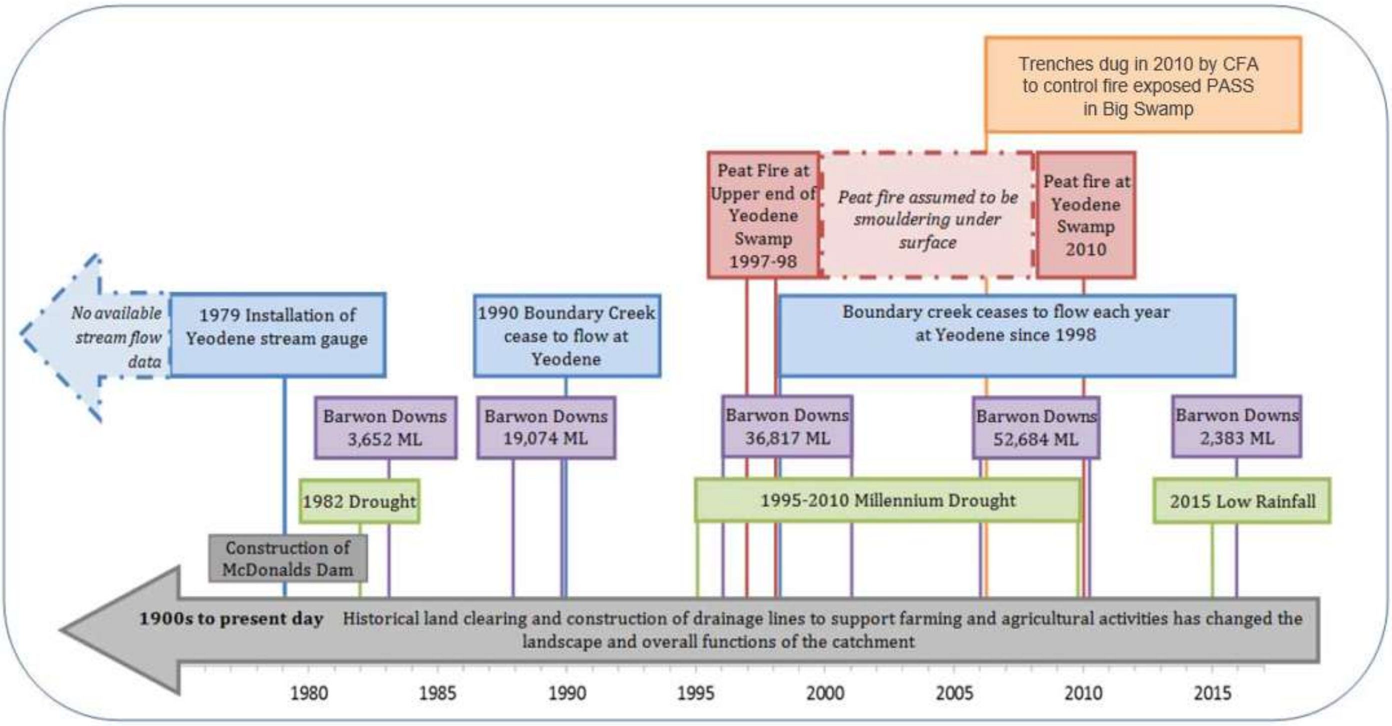


Figure 20: Changes in the Boundary Creek catchment

6.1.3 The reaches of Boundary Creek

For the purposes of this report, the different reaches of Boundary Creek have been defined by surface water features, hydrology and operational considerations, not by the underlying geology. The basis for this is that remediation efforts are intended to either maintain or improve ecological values at the surface as set out by the Remediation Plan's vision and objectives. While the surface water reaches of Boundary Creek do not accurately align with the underlying hydrogeological settings, for simplicity of explanation and consistency with previous reports, the classifications outlined below have been applied.

It is recognised that these reaches could equally be separated solely according to their hydrogeological characteristics. If this were the case, the boundary between Reach 1 and Reach 2 would be located approximately 600 m upstream of 'McDonalds Dam', at the boundary between the outcropping LTA and the Basement. However, to prevent confusion between naming conventions and to remain consistent with previous reporting, formal revision to the reaches as defined above has not been adopted in this document, recognising that a proportion of Reach 1 does in fact overly the LTA.

Therefore, Boundary Creek has been divided into three reaches (Jacobs, 2018a and 2018b), as described below:

- **Reach 1** – This is the upper reach of the creek, flowing predominantly over outcropping bedrock which comprises impermeable Paleozoic sandstone, siltstone and mudstone.

  The downstream end of Reach 1 is defined by 'McDonalds Dam', a large on-stream private irrigation water storage (160 ML capacity) that was constructed in 1979.

  Supplementary flows by Barwon Water are released into a small tributary that joins Boundary Creek in Reach 1, upstream of 'McDonalds Dam'.

- **Reach 2** – From the outlet of 'McDonalds Dam' to the downstream end of Big Swamp, flowing predominantly over the outcropping LTA comprising permeable sands of the Mepunga, Dilwyn and Pebble Point formations.

  This reach can be further subdivided into three sub-reaches:

  - Reach 2a, a likely artificial channelised section immediately downstream of 'McDonalds Dam'.
  - Reach 2b, a densely vegetated and marshy area known as the 'damplands' characterised by highly braided flow pathways and waterlogged conditions.
  - Reach 2c, corresponding to Big Swamp, a large peat swamp covering an area of approximately 11 hectares.

- **Reach 3**- Downstream of Yeodene Swamp to the confluence with the Barwon River, flowing over the outcropping Mid-Tertiary Aquitard (MTD) comprising the silty clays of the Gellibrand Marl. This reach has been modified to support agricultural activity.

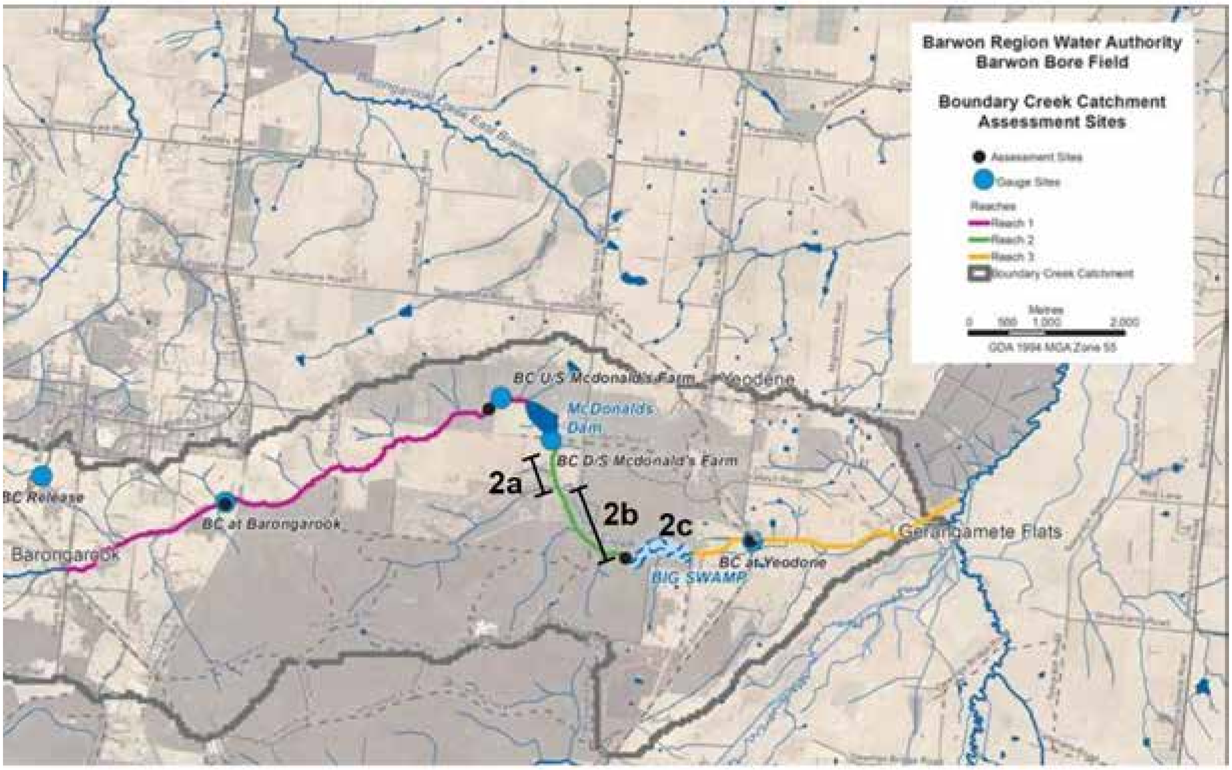


Figure 21: Location of reaches and key surface water features of Boundary Creek

Figure 22 also indicates presence of shallow Quaternary Alluvium sediments that are interpreted to occur locally along the Boundary Creel flow path, overlying the regional formations. Quaternary Alluvium includes the deposits and acid sulfate soils that occur throughout Big Swamp.

Figure 22: Simplified geology of Boundary Creek catchment

6.1.4 Hydrology

The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment (refer to Figure 23). Surface water features of regional importance within these catchments are the Barwon River and the Gellibrand River.

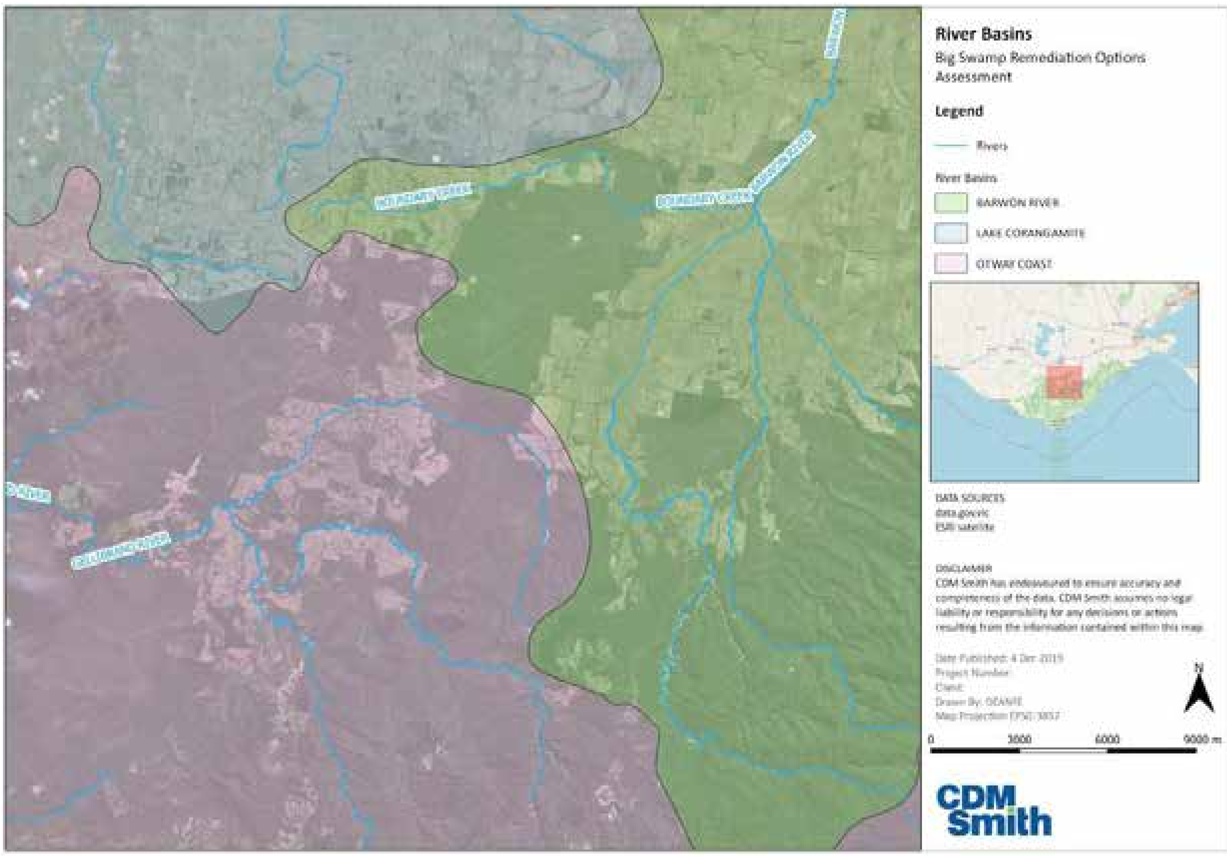


Figure 23: Surface water catchments in the Boundary Creek catchment

Streamflow gauging on Boundary Creek has occurred at four locations prior to 2017, with an additional two gauges installed in 2019 for Big Swamp. The location of streamflow gauges is illustrated in Figure 24 and their status summarised in Table 8 below. Figure 24 presents the most recent hydrographs for all gauges.

The hydrographs illustrate a reduction in streamflow through ‘McDonalds Dam’ and flow cessation at Yeodene during summer low flow periods. The average reduction in streamflow through the dam over the 2014/15, 2015/16 and 2016/17 low flow periods ranged between 1.0 and 1.4 ML/day (Jacobs, 2018b). This trend is consistent with observations from January to March 2019 in which an average reduction in streamflow of 0.8 ML/day was observed. These trends are also consistent with previous characterisation by Jacobs (2018b) and indicates a continuation of pre-existing conditions.

Figure 2.1: Topographic map showing the subcatchment boundaries and other key hydrological features along Boundary Creek, upstream of the Yeodene township

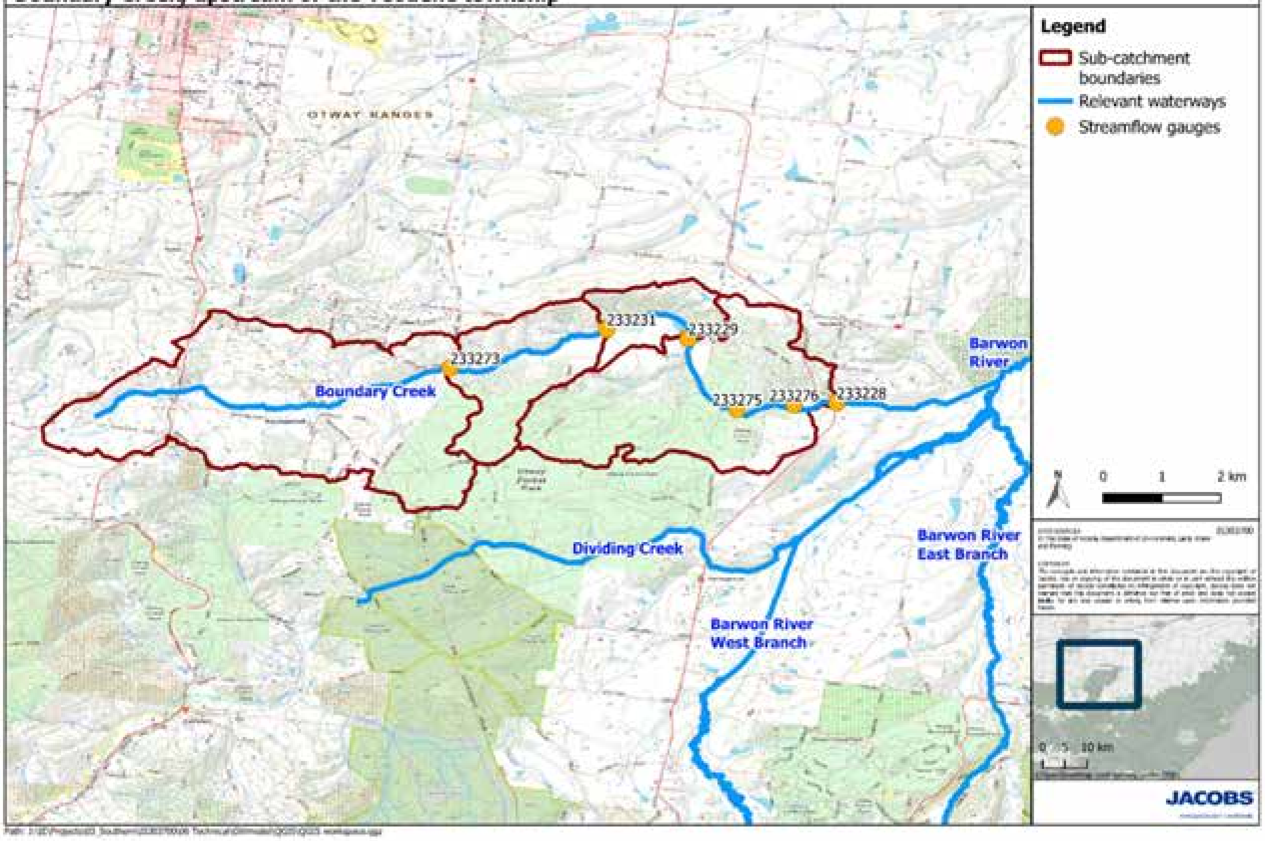


Figure 24: Boundary Creek Catchment and location of surface water flow gauges

The driver of the discrepancy of inflows and outflows has previously been reported to be a dysfunctional release valve at 'McDonalds Dam'. A new valve was installed in May 2018 to improve ease of operation of the valve and better facilitate water releases to align with passing flow requirements for the dam.

While this may, on appearance, suggest that this has not been fully effective based on the 2019 low flow data, it does not take into account the accuracy of instantaneous flow data in the short-term and subsequent correction of data during the quality control processes through the State Government's Regional Water Monitoring Partnership. As a result, passing flow adjustments at 'McDonalds Dam' are made based on instantaneous flow data which may be subsequently adjusted during the quality control process for establishing the long-term data record. This is an issue inherent with stream gauge data across the state and every effort is made to ensure real-time instantaneous data is as accurate as possible and requires minimal retrospective quality control correction.

Table 8: Status of surface water flow gauges on Boundary Creek

Gauge	Description	Active/ Inactive	Record length
bw763	Boundary Creek Release flow meter	Active	March 2015 to present
233273A	Boundary Creek at Barongarook	Active	June 2014 to present
233231A	Boundary Creek Upstream McDonald's Dam	Active	Dec 1989 to Feb 1994 June 2014 to present
233229A	Boundary Creek Downstream Macdonald's Dam	Active	Dec 1989 to Feb 1994 June 2014 to present
233275	Boundary Creek Upstream Big Swamp	Active	June 2019 to present
233276	Boundary Creek Downstream Big Swamp	Active	June 2019 to present
233228A	Boundary Creek at Yeodene	Active	June 1979 to present

Streamflow monitoring for 2019 including newly installed gauges both upstream (US) and downstream (DS) of Big Swamp is provided in Figure 25. The figure shows that during June-October 2019, streamflow at site 233228 Boundary Creek at Yeodene was generally higher than further upstream. It also shows that during flow recession, flow reduction is observed between the DS 'McDonalds Dam' gauge and the US Swamp gauge. While this reduction is variable and difficult to constrain for the period based on gaps in the data set, it suggests that reductions of 0.5 to 2 ML/day were observed.

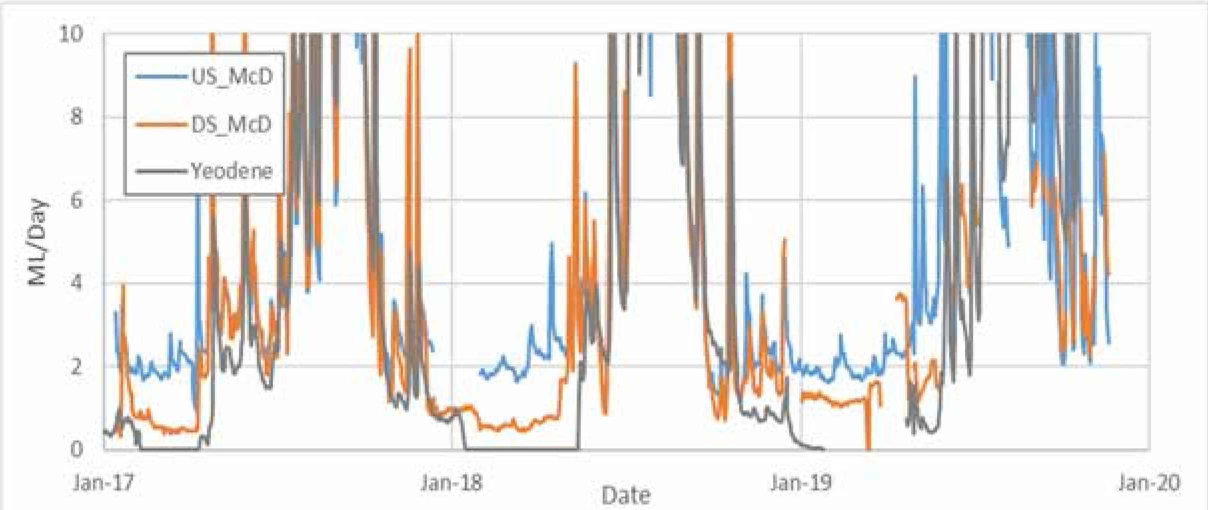


Figure 25: Boundary Creek Hydrographs 2017 – 2020

Figure 26 also illustrates that flow upstream and downstream of the swamp is similar for this period of data collection. The average monthly flow upstream and downstream of the swamp has been summarised in Table 9. It illustrates that for the June-October 2019 period, the net change in flow is <0.1 ML/day. For the same monitoring period, total rainfall and evapotranspiration (ET) was 266 mm and 281 mm, respectively (Mt Gellibrand station: BOM, 2019), indicating that direct rainfall and ET are unlikely to have significantly affected the water balance in the swamp during this period.

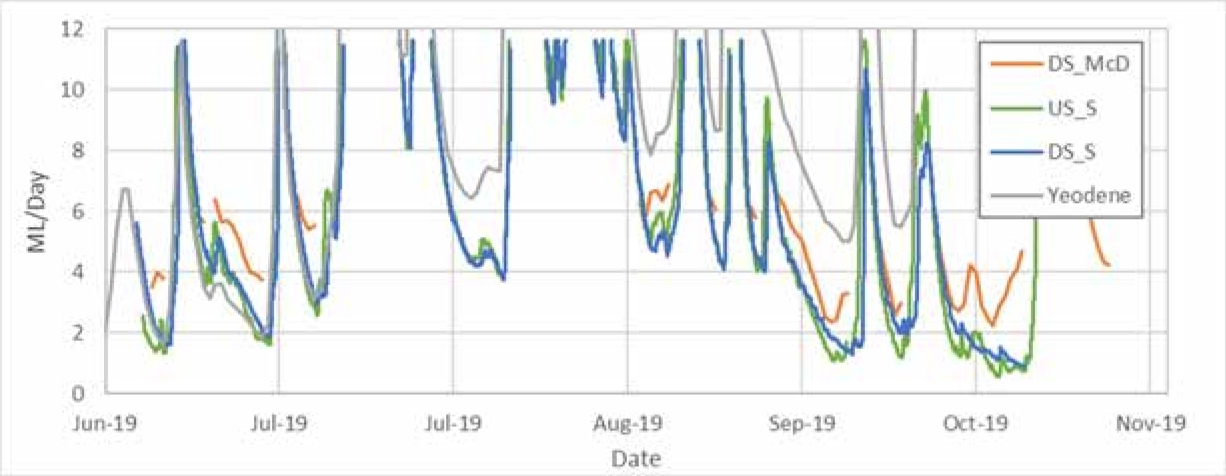


Figure 26: Boundary Creek Hydrographs 2019

This suggests that the net groundwater exchange at the swamp, either as inflow or seepage, was limited during this period. It is recognised that this characterisation is constrained to the available monitoring period and does not take into account runoff (although runoff from hillslope directly to the south of the swamp is likely to be intercepted by the fire trench). It does however, provide a reasonable indication that net groundwater exchange through the swamp is minimal during the June to October period.

Table 9: Average monthly flows on Boundary Creek in 2019 upstream and downstream of Big Swamp (ML/day)

Month	US_S	DS_S	Difference
Jun	3.70	3.90	0.20
Jul	6.56	6.61	0.04
Aug	7.37	7.35	-0.02
Sep	5.82	5.58	-0.24
Oct	3.18	3.24	0.06
Total	26.62	26.67	0.05

To better define flow paths in Boundary Creek and Big Swamp, surface water flow modelling was also undertaken using TUFLOW (Jacobs, 2019a). The model was based on high resolution LiDAR data obtained in 2019 and is described in section 9. The modelling indicates that with the release of 2 ML/day from 'McDonalds Dam', flows are predominantly contained within channels located along the northern portion of Big Swamp. As flow increases to 5 ML/day, a number of additional flow paths, including one through the centre of the swamp become active. This is illustrated in Figure 27 below.

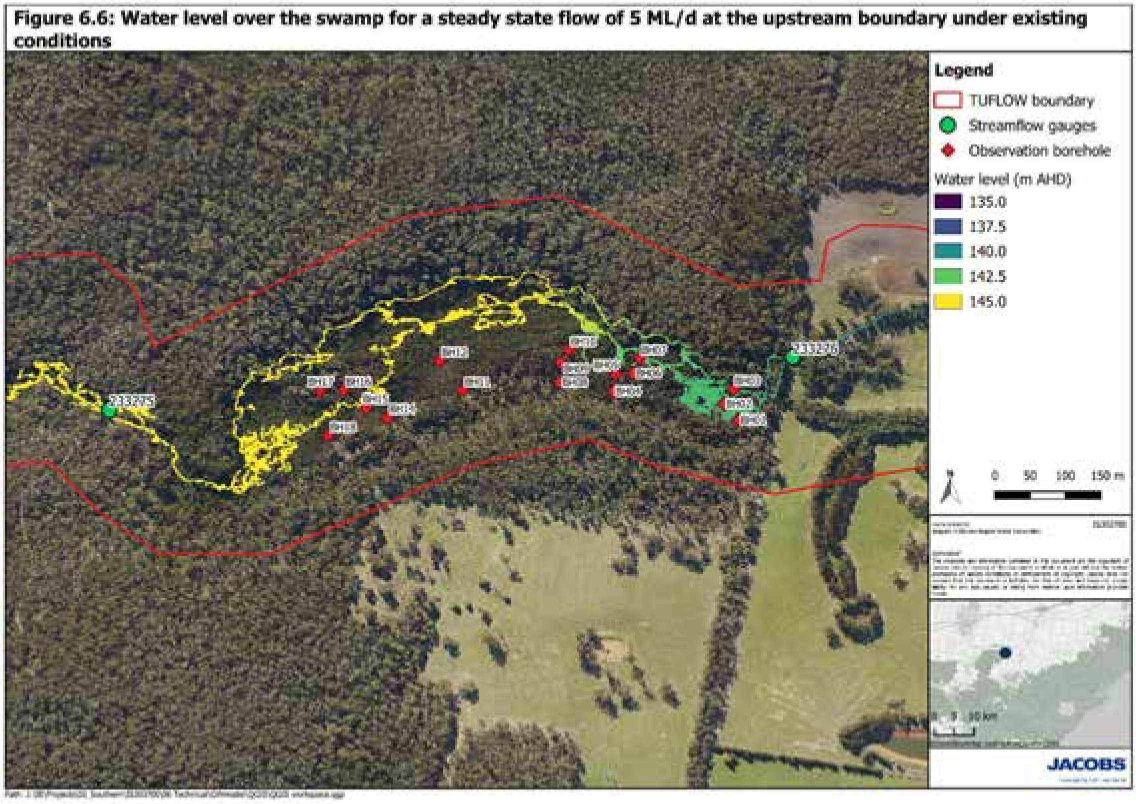


Figure 27: Water level over the swamp for a steady state flow of 5 ML/d at the upstream boundary under existing conditions (Jacobs, 2019a)

In conjunction with streamflow gauging, water quality monitoring in the form of salinity (as electrical conductivity or EC) and temperature (T) is currently logged at most gauges along Boundary Creek. In addition to EC, pH has been recorded at Yeodene since 1985. The recently installed gauges upstream and downstream of Big Swamp are monitored instantaneously (15 minute intervals) for field water quality (including EC, pH, T), while major ions, dissolved metals and nutrients are monitored on a monthly basis. A full summary of the monitoring suites, timing and records is listed in Table 10.

Salinity and pH monitoring on Boundary Creek between June and November 2019 is summarised in Table 11 below. This shows an increase in the average salinity of the creek from 450 µS/cm at both the DS McDonalds Dam and US Big Swamp gauges, to 650 µS/cm at the DS Big Swamp gauge and 680 µS/cm at the Yeodene gauge.

Median pH values increase from 6.3 at the DS McDonalds Dam gauge to 6.6 at the US Swamp Gauge. Median pH declines to 3.6 through the swamp, before increasing to 3.7 at the Yeodene Gauge. The pH and EC trends observed are consistent with leaching of acid and metalliferous soils in Big Swamp.

Longer term pH monitoring in Boundary Creek is illustrated in Figure 28, which shows monthly spot pH measurements at the Yeodene Gauge. It shows that while pH values of <5.5 have been recorded historically (prior to 1990) these were sporadic and the median pH prior to 1990 was 6.5. A step change in pH is observed from 1990, with highly variable pH values and a median pH of 5.8 recorded between 1990 and 1999. A third step change has been observed since 1999, with a less variable median pH of 3.8 recorded between 2000 and present.

Table 10: Water quality monitoring on Boundary Creek

Gauge	Description	Active/ Inactive	Parameters	Record length
233273A	Boundary Creek at Barongarook	Active	T, EC	August 2018 to present
233231A	Boundary Creek Upstream McDdonald's Dam	Active	T, EC	August 2018 to present
233229A	Boundary Creek Downstream McDonald's Dam	Active	T, EC, pH	August 2018 to present
ME735	Boundary Creek Upstream Big Swamp	Active	T, EC, pH Majors, metals, nutrients	June 2019 to present June 2019 to present (monthly)
ME736	Boundary Creek Downstream Big Swamp	Active	T, EC, pH Majors, metals, nutrients	June 2019 to present June 2019 to present (monthly)
233228A	Boundary Creek at Yeodene	Active	T, EC, pH	1985 to present

[1] Majors, metals and nutrients suite is as follows: Ca, Mg, K, Na, Cl, SO4, Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Sr, Tl, Sn, Ti, V, Zn, NH4, NO3, NO2, TKN, TCN, P, BOD, COD, TOC, Alkalinity
NB: Spectated Fe^{2+} and Fe^{3+} added after November monitoring.

Table 11: Summary of water quality in Boundary Creek June to November 2019

Gauge	EC[1] (µS/cm)	pH[2] (units)
DS McDonalds	450	6.3
US Swamp	450	6.6
DS Swamp	650	3.6
Yeodene	680	3.7

[1] EC represents average EC value for monitoring period.
[2] pH represents median value for monitoring period.

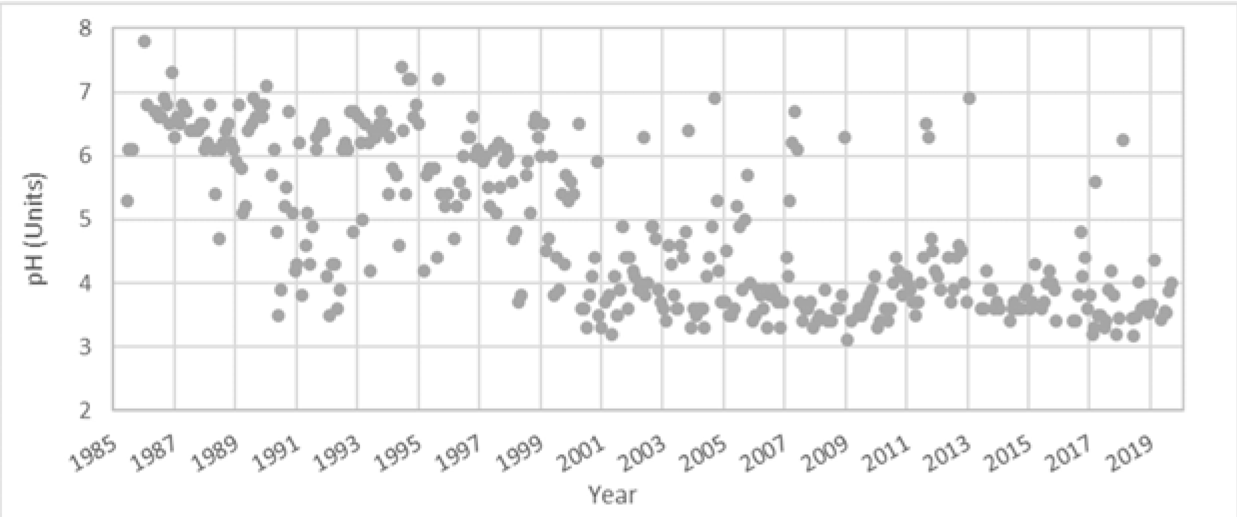


Figure 28: Water pH in Boundary Creek at Yeodene

6.1.5 Hydrogeology

The hydrogeology of Boundary Creek is well understood compared to other waterways in the Barwon Downs Graben. This has been illustrated in long section in Figure 29.

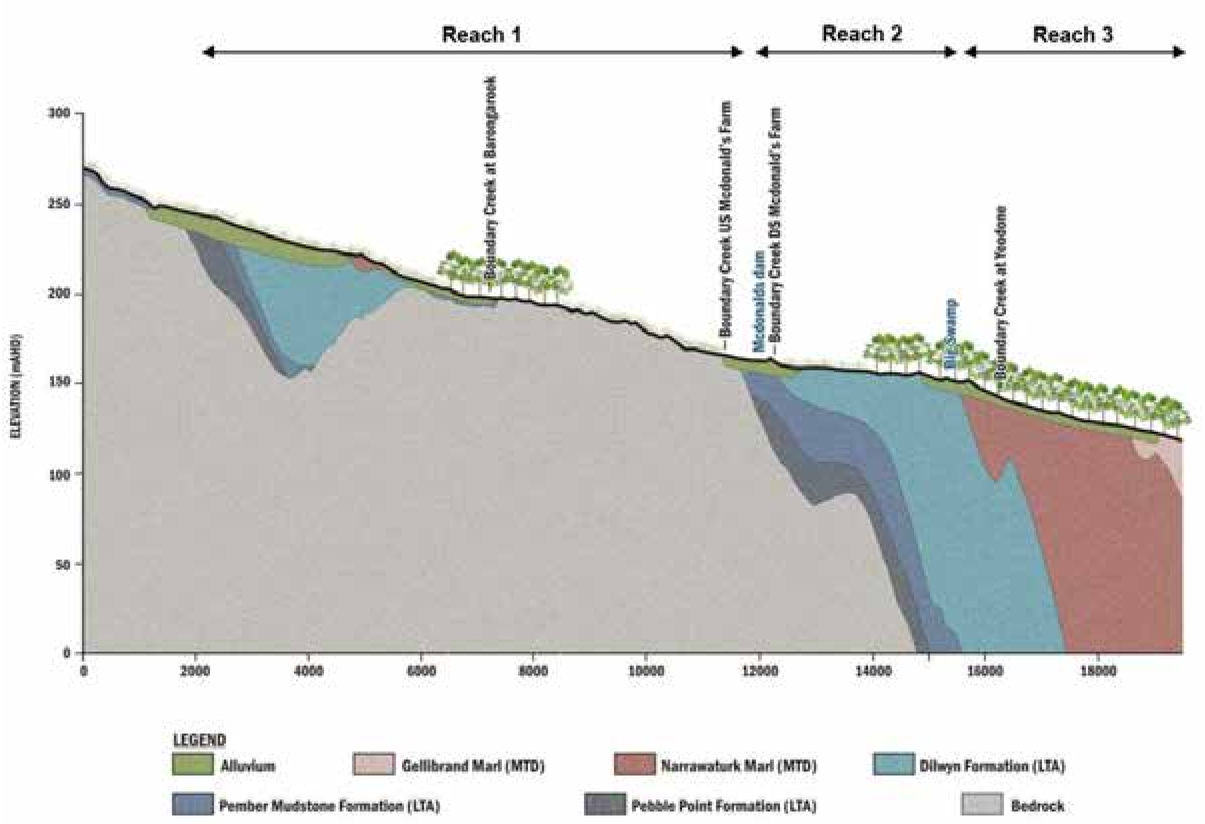


Figure 29: Geological long section along Boundary Creek

Monitoring bores in the basement (bedrock) indicate that Boundary Creek receives groundwater discharge from the basement in Reach 1. However, due to the low permeability of the basement, inflow volumes to Boundary Creek in Reach 1 are small (Jacobs, 2018b). The limited exchange between groundwater and surface water in this reach is supported by streamflow monitoring in Figure 25 which shows that under low flow conditions, the supplementary flow release of ~2 ML/day reaches 'McDonalds Dam', but flows do not consistently increase or decrease in Reach 1, as would be expected for a highly gaining or losing system.

In the LTA, historical monitoring indicates a significant decline in regional groundwater levels in Reach 2 of Boundary Creek. This is predominantly attributed to borefield operation and changes in climate. This decline has resulted in groundwater levels falling below the streambed elevation in Reach 2 (Figure 30) and a transition from a system that receives groundwater, to one that loses water via seepage.

Where Boundary Creek intersects the aquitard in Reach 3, groundwater levels are above the streambed, indicating that Boundary Creek receives groundwater through this reach. However, groundwater discharge volumes are limited by the low permeability of the aquitard (Jacobs, 2018b).

Groundwater exchange in Reach 2 of Boundary Creek has been estimated previously using the numerical groundwater model for the Barwon Downs Graben (Jacobs, 2018a). This has been illustrated in Figure 31) below. Model predictions have indicated that “operation of the borefield over the past 30 years is responsible for two-thirds of the reduction in baseflow into Boundary Creek; while the dry climate experienced during the same period accounts for the remaining one third” (Jacobs, 2018a).

The numerical model assumes a constant head in the creek 0.5 m above the base of the creek bed. Further, when the groundwater level in the underlying aquifer falls below this level, the creek becomes losing, with losses predicted according to the difference in head and hydraulic conductivity of the aquifer (Jacobs, 2018a). The cells in the model are 50-100 m wide.

While this provides a good first pass assessment of the potential impact of pumping and climate on groundwater exchange, it is of relatively low resolution and doesn’t take into account a number of factors such as the presence of alluvial aquifers which can provide storage, clogging layers in streambeds which may limit seepage, or changes in the water level in the creek which would (comparatively) increase losses under high flow conditions and reduce losses under low flow conditions.

For these reasons, losses illustrated in Figure 31 (i.e. up to 40 L/s or 3.5 ML/day) are considered to be an overestimate. Historical flow monitoring supports this, as flows of >2ML/day into Reach 2 tend to yield flows in Reach 3 (see section 6.1.4).

Figure 30: Groundwater levels and streambed elevation in Reach 2 of Boundary Creek

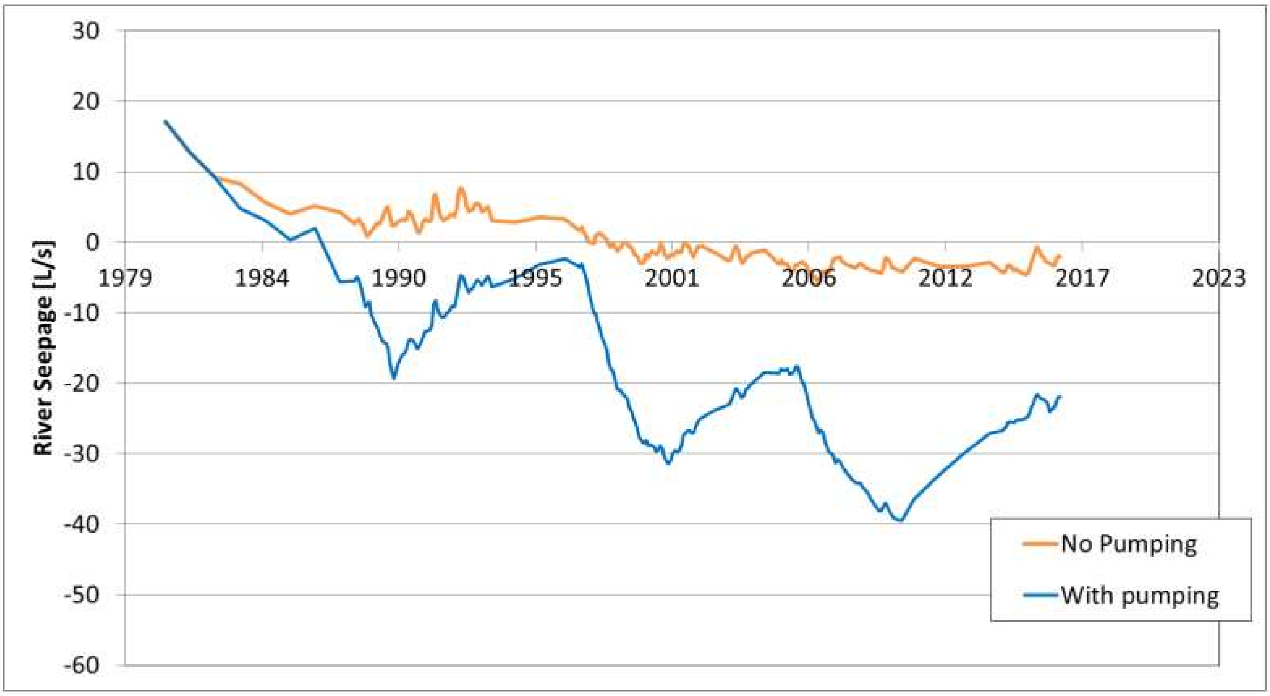


Figure 31: Groundwater flux estimates to Reach 2 of Boundary Creek in response to groundwater extraction

Big Swamp

Big Swamp is approximately 11 hectares in size and consists of surface sediments that are comprised of quaternary alluvial sediments dominated by clays and silts with sparse intervals of sand.

The swamp is located at the transition where the LTA and the MTD aquitard outcrop. However, due the presence of overlying alluvial sediments and access limitations, the nature and location of this contact has not been able to be clearly delineated.

In addition to surface water monitoring described above, a number of groundwater monitoring wells were installed at Big Swamp during site investigations in 2019, to better characterise the hydrogeology of Big Swamp (Jacobs, 2019a). The location of the boreholes is illustrated in Figure 32.

Lithological logs indicate the presence of silts, clays and discrete sands in the upper 6 m of the soil profile throughout Big Swamp (Figure 33) which is consistent with the occurrence of alluvial deposits. Hydraulic testing of these sediments yielded a median hydraulic conductivity of 0.15 m/day. These results suggest the presence of a relatively significant (>6 m) sequence of alluvial sediments in the swamp with a relatively low hydraulic conductivity. This is consistent with data from streamflow gauging (section 6.1.4) which indicates limited groundwater exchange within the swamp during the data period available.

Groundwater hydrographs from the monitoring bores for the June-November 2019 period have been provided in section 9. Groundwater level fluctuations and trends have been summarised in Table 12. Monitoring data indicates that the depth to water table in the swamp ranges between 0 and 2.1 m below ground level (bgl). Average fluctuations in water table levels between June and November 2019 were 0.6 m with most bores exhibiting increases between June and August 2019, followed by a decline from August to November 2019. It should be noted that this does not cover a full seasonal data range which would be likely to show further declines in water table levels over the drier summer period.

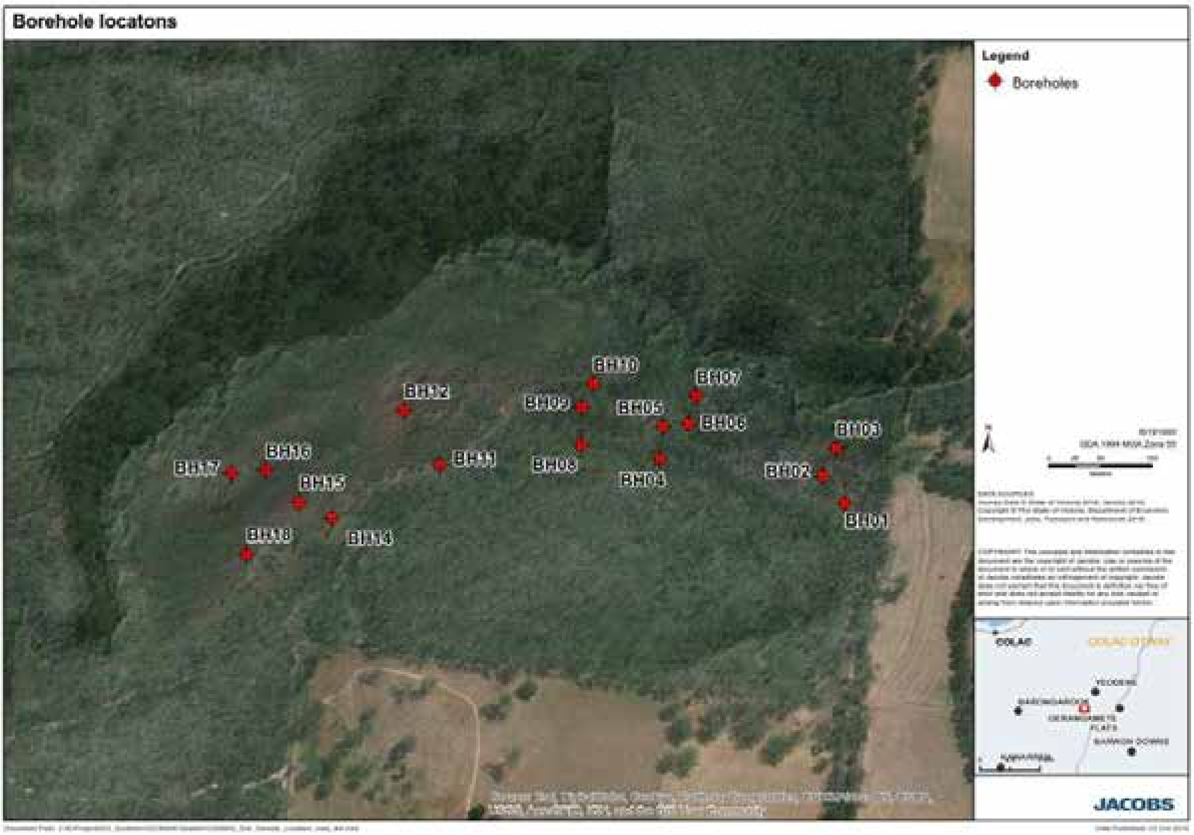


Figure 32: Location of groundwater wells in Big Swamp

Figure 33: Leapfrog geological model showing the primary constituents of SILT (grey), CLAY (light yellow) and SAND (orange) throughout the bore logs (Jacobs, 2019a)

Table 12: Groundwater level trends in Big Swamp

Bore	Groundwater Level Range (m bgl)				Trend
	Date	Higher	Date	Lower	
BH01	11-Aug	0.3	12-Jun	0.8	Increase June-August, decline August-November
BH02	11-Aug	0.6	12-Jun	1.1	Increase June-August, decline August-November
BH03	11-Aug	0.7	12-Jun	1.1	Increase June-August, decline August-November
BH04	31-Aug	0.8	12-Jun	1.2	Increase June-August, stable August-November
BH05	12-Aug	0.8	12-Jun	1.4	High fluctuations, increase June-August, decline August to November
BH06	11-Aug	1	12-Jun	1.5	Minor fluctuations
BH07	11-Aug	0	12-Jun	0.6	Increased June-August, stable August-November
BH08	09-Aug	1.2	04-Jul	1.7	Minor increase June-August, stable August-November
BH09	12-Aug	1.3	08-Aug	2.1	High fluctuations, decline October - November
BH10	12-Aug	1.2	06-Nov	1.9	High fluctuations, decline October - November
BH11	12-Aug	1.3	28-Jun	1.9	High fluctuations, decline October - November
BH12	12-Aug	1.5	12-Jun	1.9	Minor fluctuations
BH14	06-Sep	1.6	26-Jun	2.1	Increase June-August, decline August-November
BH15	09-Sep	0.5	07-Nov	1.9	Increase June-August, large decline August-November
BH16	09-Sep	1.1	06-Nov	2.1	Stable June-August, large decline August-November
BH17	06-Sep	1.2	05-Nov	1.9	Increase June-August, decline August-November
BH18	12-Aug	1.2	06-Nov	1.8	Stable August-September, decline September-November

The potentiometric groundwater surface within Big Swamp was interpolated and subsequently modelled for the September 2019 monitoring period (Jacobs, 2019a). This has been illustrated in Figure 34 below. Both the modelled and interpolated surface indicate a reduction in groundwater potentiometry from ~148 m AHD at the western end of the swamp to <142 m AHD at the eastern end of the swamp.

While general trends in the groundwater surfaces are consistent across the swamp, notable discrepancies are observed through the north-west portion of the swamp, where the modelled surface is ~2 m lower than the interpolated surface in some areas.

However, the level of agreement between the modelled and observed surfaces is reasonable given the limited groundwater monitoring record currently available for Big Swamp and that the model is based on synthetic flow data (for more detail, see Jacobs 2019a). Noting these limitations, the model is considered adequate for the purposes of understanding groundwater responses to surface water flow and recharge at a conceptual level. It is recognised that further refinement and calibration of the model using a larger dataset capturing a full seasonal cycle would be required to improve accuracy and transition the model beyond a conceptual level.

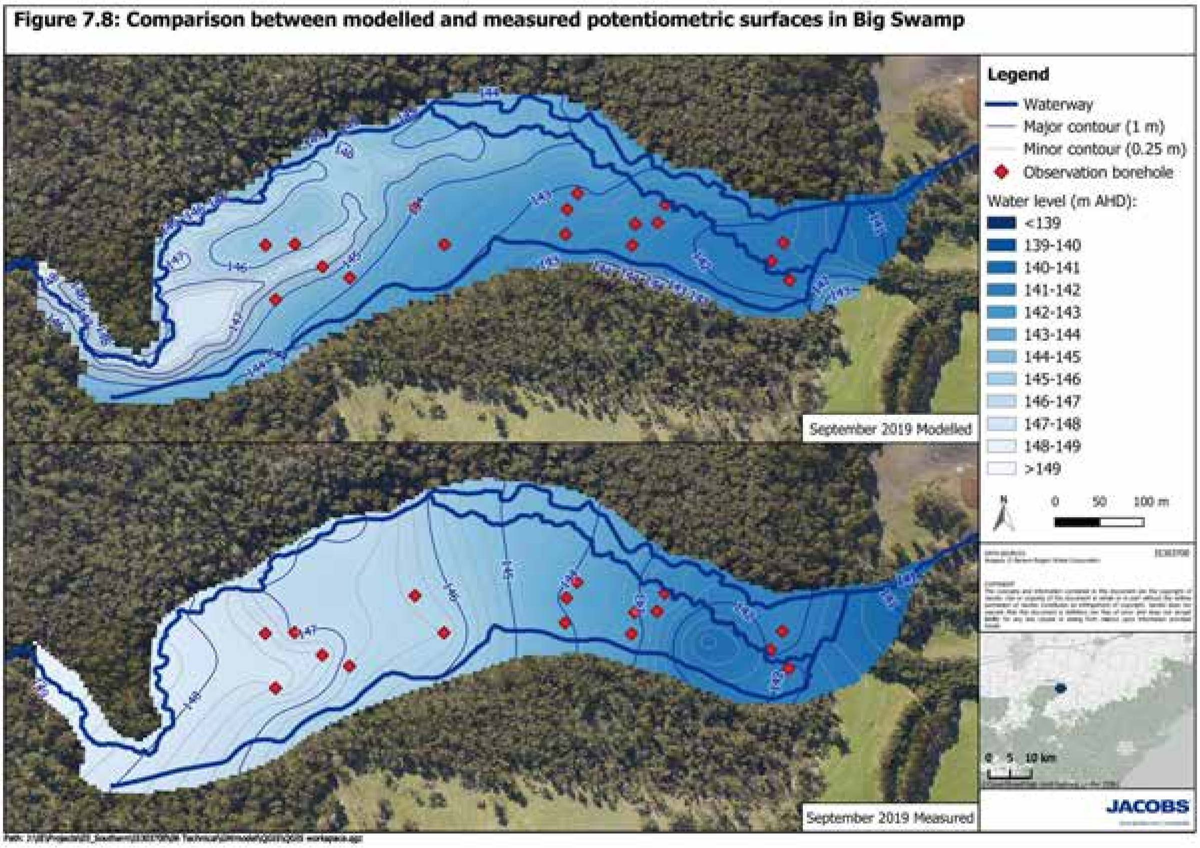


Figure 34: Measured and modelled potentiometric groundwater surface in Big Swamp (Jacobs, 2019a)

6.1.6 Acid sulfate soils

Regional occurrence of Acid Sulfate Soils (ASS)

Until relatively recently, the distribution of ASS in Australia was believed to be predominantly coastal, reflecting the extensive development of coastal areas. In contrast, the understanding of inland ASS in Australia has only developed since 1990, mainly in response to extensive drying of wetlands and river systems during the extreme dry conditions in the Millennium Drought (Glover, 2014). During this period, reductions in water levels in submerged or subaqueous soils, wetlands, areas of riverbank and lakes have exposed sulfidic sediments to oxygen, leading to the development of sulfuric material with pH levels below 4 (Fitzpatrick et al., 2008).

The majority of research on inland ASS in Victoria have focused on those in the Murray River Basin (e.g. Hall et al., 2006; Lamontagne et al., 2004; Fitzpatrick et al., 2008). To improve on this understanding, Glover (2014) focused on assessing the distribution of inland ASS that may occur over a regional scale within the Corangamite Catchment. Sampling and analysis of soils were undertaken in five areas including Boundary Creek, Anglesea River, Porcupine Creek, Pennyroyal Creek and Bambra Wetlands (Figure 35).

Within these areas, Glover found that seasonal fluctuations in the water table, due to variability in rainfall and temperature resulted in the loss of anaerobic conditions at the top of the soil profile. As such, it was asserted that seasonal drying of sediments in these areas was responsible for the partial oxidation of sulfides in the upper soil profile, which ranged between 0.3 and 1.5 m below ground surface at these sites.

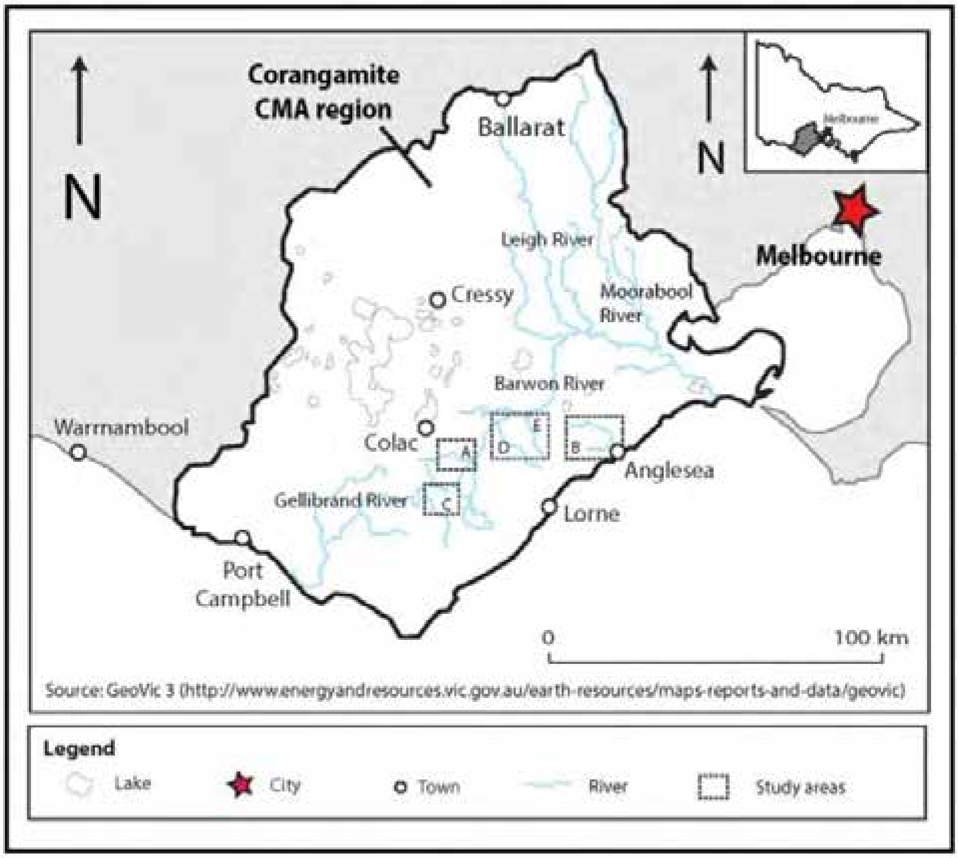


Figure 35: Location of ASS investigations (Glover, 2014)

Barwon Downs Graben

As part of the Barwon Downs groundwater licence application (withdrawn in March, 2019), Barwon Water investigated the presence of sulfidic soils within the regional groundwater catchment to assess the risk of future groundwater extraction to oxidation of sulfidic soils.

In 2013, a desktop review was undertaken to identify potential areas with ASS. The desktop assessment considered the physical landscape such as where swamp areas were known to exist, geology, geomorphology, topography and vegetation, as well as where groundwater is predicted to drawdown. This process identified nine locations with potential ASS (SKM, 2013). In addition to these nine locations, the Barwon Downs Groundwater Community Reference Group (BDGCRG) identified a further five sites for investigation. The location of the 14 sites are illustrated in Figure 36 with respect to the risk of being impacted by water table drawdown.

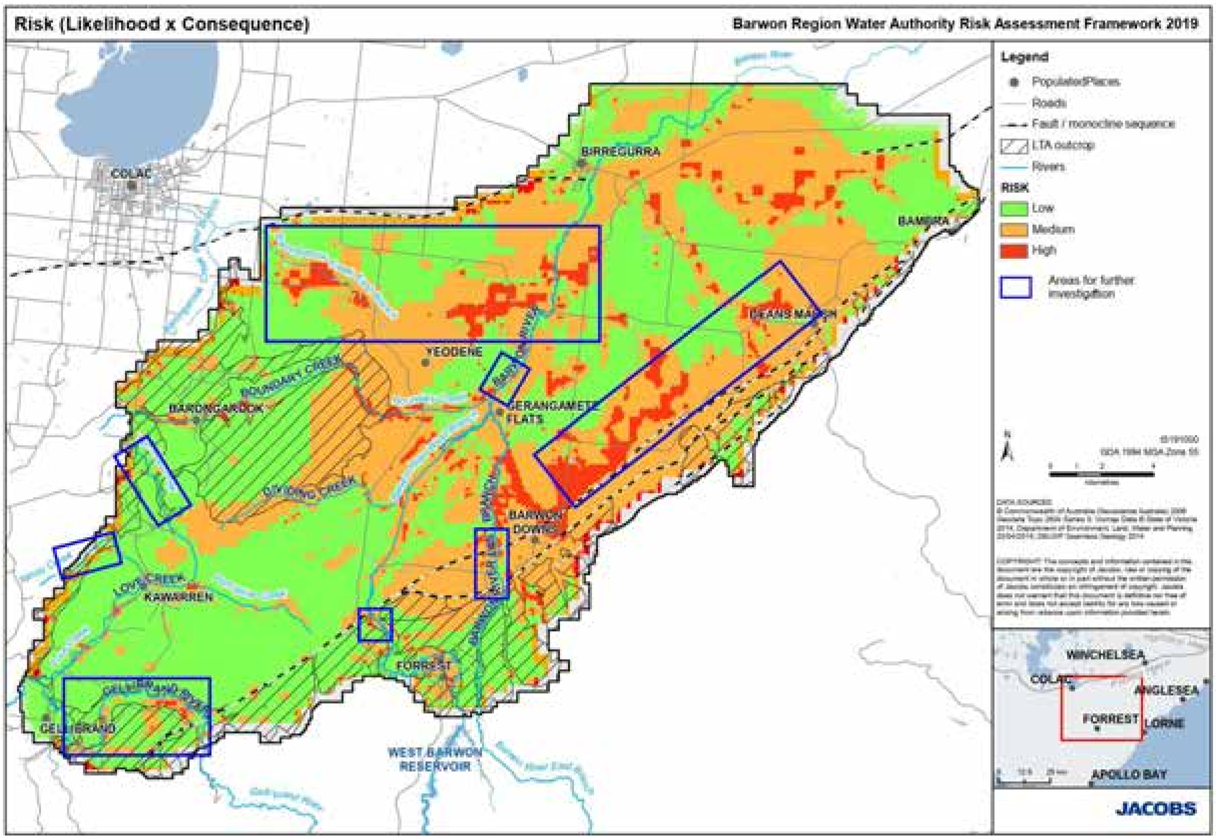


Figure 36: Risks related to drawdown and location of ASS sampling and monitoring

Eight sites were prioritised for field investigation (noting that Big Swamp was not included due to its known presence of ASS). Soil samples were collected at six of the eight sites (due to access) to confirm the presence or absence of ASS. All sites were found to have varying concentrations of sulfidic and sulfuric sediments. Of these sites, four sites were selected for ongoing monitoring of groundwater and surface water with the aim of providing a baseline condition assessment to understand key drivers in change.

Monitoring at each of these four locations found that groundwater levels were shallow (typically within 1 m of the surface) and displayed seasonal fluctuations of around 0.5 m, rising during the winter months and declining during the summer months (Jacobs, 2017).

Interestingly, the highest concentrations of both sulfidic and sulfuric material was found at bore PASS4, where artesian groundwater conditions were prevalent. These conditions are consistent with those characterised by Glover (2014), and indicate that the seasonal drying of sediments is driving the oxidation of sulfides in the upper soil profile.

Big Swamp

Big Swamp can be described as an inland acid sulfate soil system where sulfide minerals (mostly pyrite, FeS_2) formed through the reduction of available iron and sulfate under reducing conditions via the decomposition of organic matter.

The occurrence of ASS within Big Swamp has been well documented. This includes initial characterisation by Graham and Lancaster (2007) and subsequent work by Glover (2014), Jacobs (2017) and finally Jacobs (2019). Through these studies, a total of 34 locations have been sampled and analysed and identified the occurrence of both sulfuric and sulfidic material, yielding concentrations of net acidity in excess of 20%S in some samples.

While characterising the concentration and distribution of sulfuric and sulfidic material in Big Swamp is relatively straight forward (see section below), discerning the drivers of sulfide oxidation in a highly modified setting with a complicated history is less intuitive. Potential drivers of oxidation (and subsequent acidification) were assessed as part of the Yeodene Swamp Study (Jacobs, 2018). While it is likely that all of these factors have in some way contributed to the current state of ASS and water quality in Big Swamp and Boundary Creek, the cessation of flows appear to be the dominant factor driving sulfide oxidation and acidification (Jacobs, 2018a).

The timing of each of these factors is illustrated along with surface water pH downstream of Big Swamp at Yeodene in Figure 37 below. The correlation between acidification and flow cessation in this setting is intuitive as both flows in Boundary Creek and the drying/oxidation of sulfides in Big Swamp are likely to be controlled by a similar combination of factors. These factors include baseflow reduction, dry climate and flow reductions through 'McDonalds Dam'.

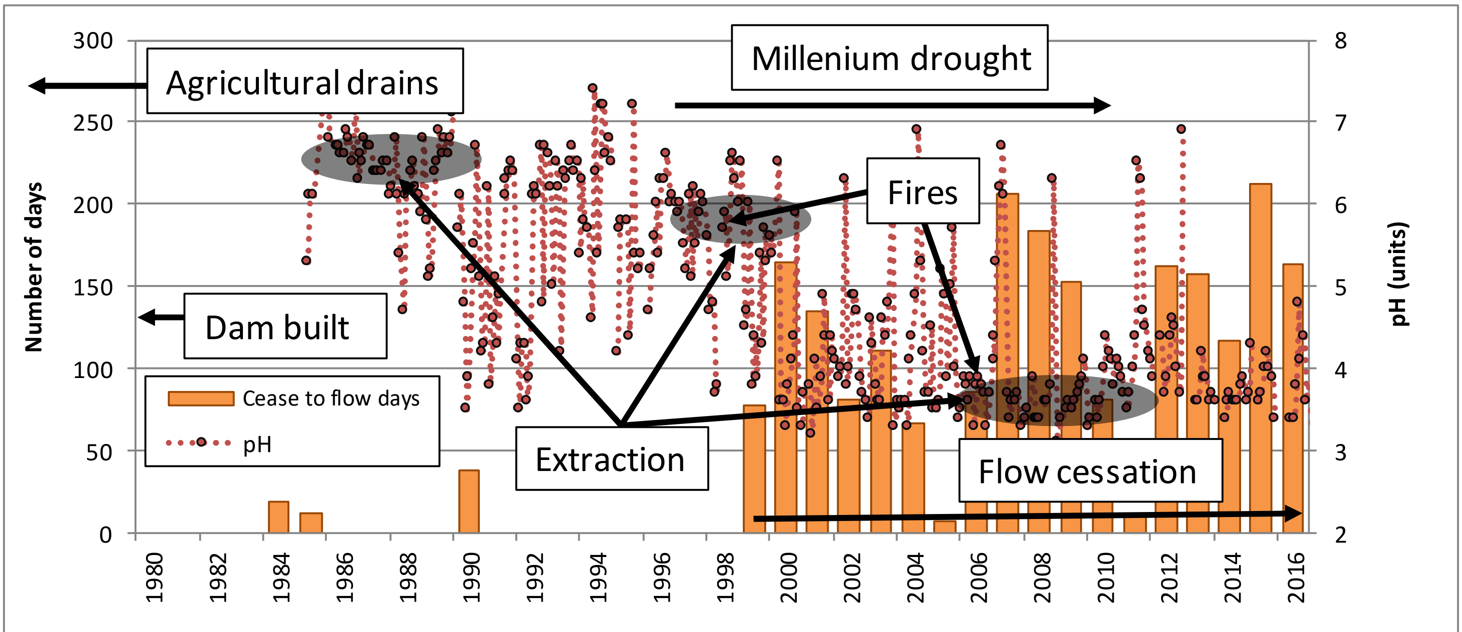


Figure 37: Timing of key events, flow cessation and surface water pH downstream of Big Swamp (modified from Jacobs, 2017c)

Distribution

As part of soil sampling and laboratory analysis of ASS within Big Swamp, characterization of the concentration of sulfides and acidity in the soil profile was undertaken. At a high level, trends in the concentration of both existing acidity and sulfide (both as %S) with depth have been illustrated in Figure 38 below. While such trends are spatially variable, this illustrates the elevated concentrations of existing acidity are relatively high (>0.5 %) in the upper 2 m of the soil profile within the swamp. Conversely, the average sulfide concentrations are comparatively low (0.1 %S) in the upper 0.5 m of the soil profile, but increase significantly at depth (>2 %S below 1.5 m depth).

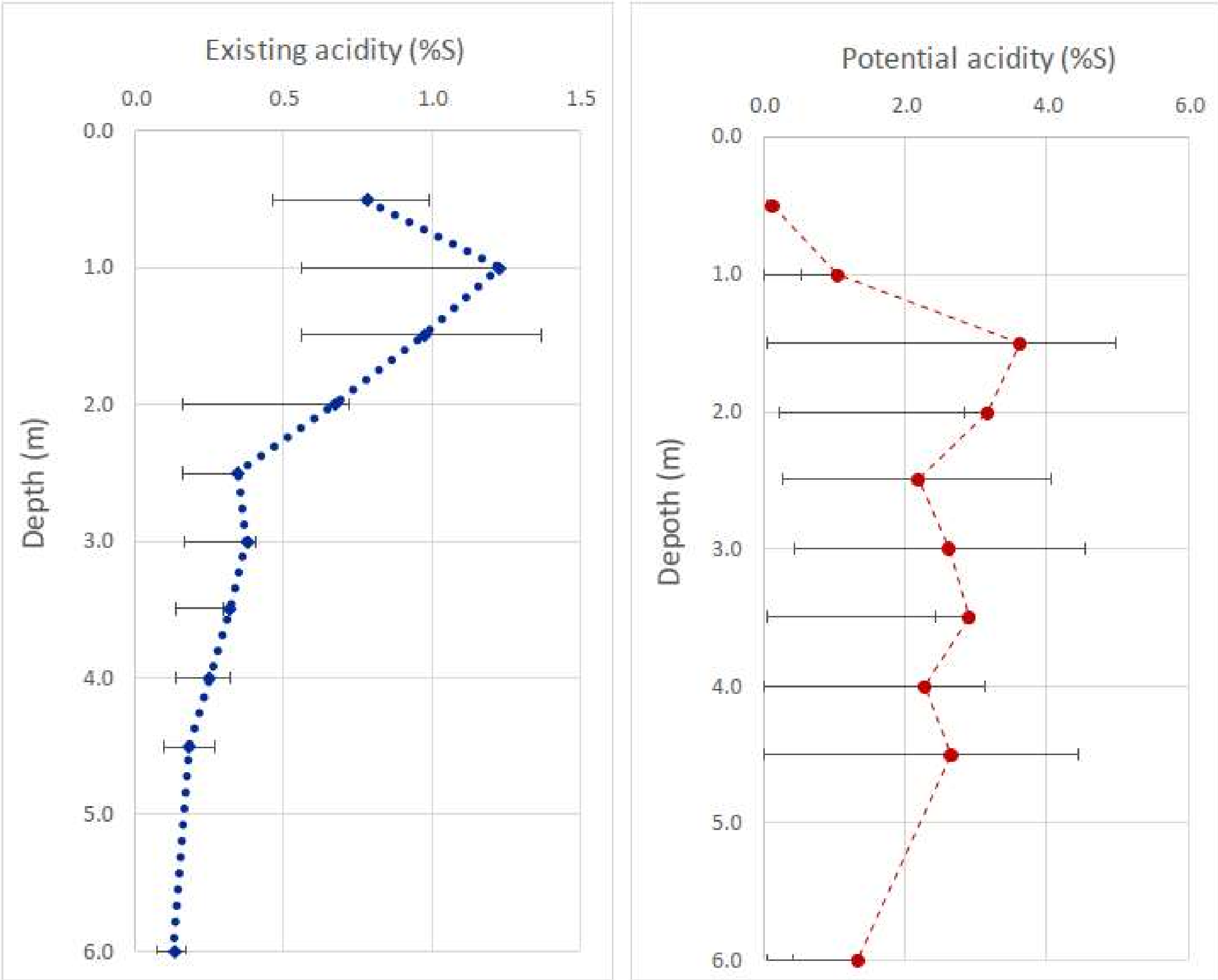


Figure 38: Average, 25th and 75th percentile (show as error bars) of existing and potential acidity with depth (aggregates from 0.5 m intervals) (Jacobs, 2019x)

The distribution of acidity throughout the swamp (as net acidity) has been mapped in more detail in 3D as part of subsequent geochemical assessment (GHD, 2019). The model is based on geospatial analysis and interpolation between soil sampling locations. It suggests that the highest concentrations of net acidity are distributed around BH14, BH15 and BH18 in the western end of the swamp and BH04 through to BH10 in the eastern end of the swamp.

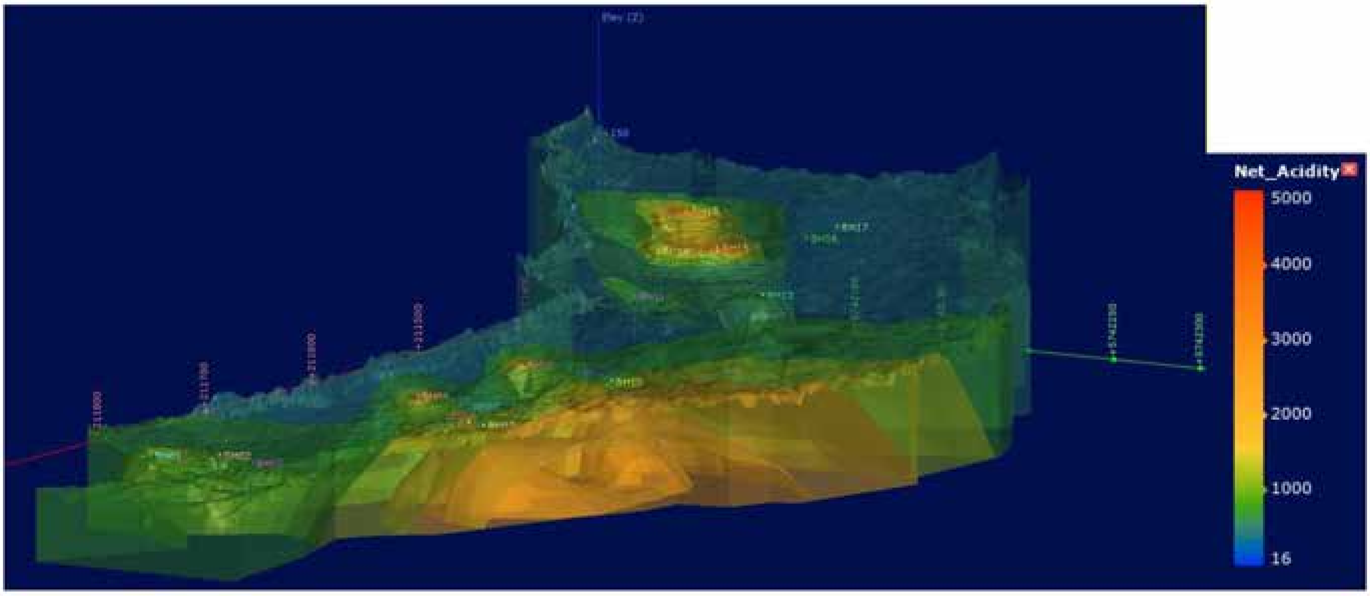


Figure 39: Distribution of net acidity throughout Yeodene Swamp (GHD, 2019)

6.1.7 Geochemistry

Geochemical laboratory analysis of sediments collected from Big Swamp has been undertaken by Cook (2019). Soils were subject to a variety of treatments to assess the dominant hydro-geochemical processes occurring within the swamp and how theses might respond to changing hydro-geochemical conditions. A full description of the experimental set up, treatments and results undertaken by Monash University are provided in section 9.

Soil cores were logged and initial analysis of the soil samples identified five key soil types with varying concentrations of organic carbon, sulfide, acidity and burnt condition. Soils were subsequently incubated in 160 ml serum vials and purged with Argon gas to simulate anoxia associated with inundation or water table recovery in the swamp. In addition, samples were also treated with the addition of acetate, lime and sulfate to assess the limitation of organic carbon, sulfate and effect of pH on biogeochemical processes.

Samples were subsequently sacrificed in a times series of 1,2,4,8,16,32,64 and 128 days (note, the final time step of 200 days won't be completed until after submission of this REPP anticipated for completion early 2020). At each time point, a water sample was taken of overlying water (100 ml) for analysis of pH, alkalinity, acidity, dissolved organic carbon, SO_4^{2-}, H_2S, Fe^{2+}, Mn^{2+}, NO_3^- and NH_4^+. The headspace was sampled for CH_4 and CO_2.

Soils collected below the water table, with a high concentration of sulfide and limited acidity did not show any clear trend in pH over time as the generation of alkalinity via reductive mechanisms would not be expected given their pre-existing reduced condition. In contrast, soils containing shallow, oxidised material exhibited a pH increase of between 0.5 and 1.5 units over the 128 days.

The increase in pH shows a strong correlation with dissolved inorganic carbon production and dissolved iron concentrations, indicating that alkalinity is being generated by the metabolism of organic material and subsequent reduction of iron via reaction (1) below. Dissolved sulfate concentrations did not decline during incubation, indicating that subsequent sulfate reduction and sulfide formation (reactions 2 and 3) has not yet taken place.

Interestingly, dissolved iron concentrations decreased substantially at day 128 in the shallow, oxidised soils that were both untreated and treated with sulfate. The exact mechanism responsible for the removal of iron from the water column is yet to be determined, however preliminary review suggests that adsorption or occlusion may be responsible. This suggests that under prolonged reducing conditions, the mobility of Fe(II) in surface or groundwater may be reduced.

$$4Fe(OH)_3 + CH_2O + 8H^+ \rightarrow CO_2 + 4Fe_2+ + 11H_2O \quad (1)$$

$$2CH_2O + SO_4^{2-} + 4H^+ \rightarrow 2CO_2 + H_2S + 2H_2O \quad (2)$$

$$3SO_4^{2-} + 6C_{org} + 2Fe(OH)_3 \rightarrow 2FeS + S^0 + 6HCO^{3-} \quad (3)$$

In conjunction with the above laboratory test work, a series of geochemical models were run using the thermodynamic equilibrium model (MINTEQ), to assess the geochemical processes occurring within the swamp and how these might change over time and with the implementation of management strategies (GHD, 2019). To inform this, initial analysis was undertaken to assess the key drivers of acidification occurring within Boundary Creek and Big Swamp. The relationship between pH, iron and sulfate suggests that iron sulfide minerals are the primary acid source minerals, and that the ratio of iron to sulfate in water suggests that this is mainly in the form of pyrite (Figure 40). Further, while the oxidation of reduced Fe^{2+} was highlighted as a potential mechanism for acid release during the incubation experiments, the ratio of iron to sulfate suggests this is not the case currently. If it was, the ratio of iron to sulfate would be expected to be higher.

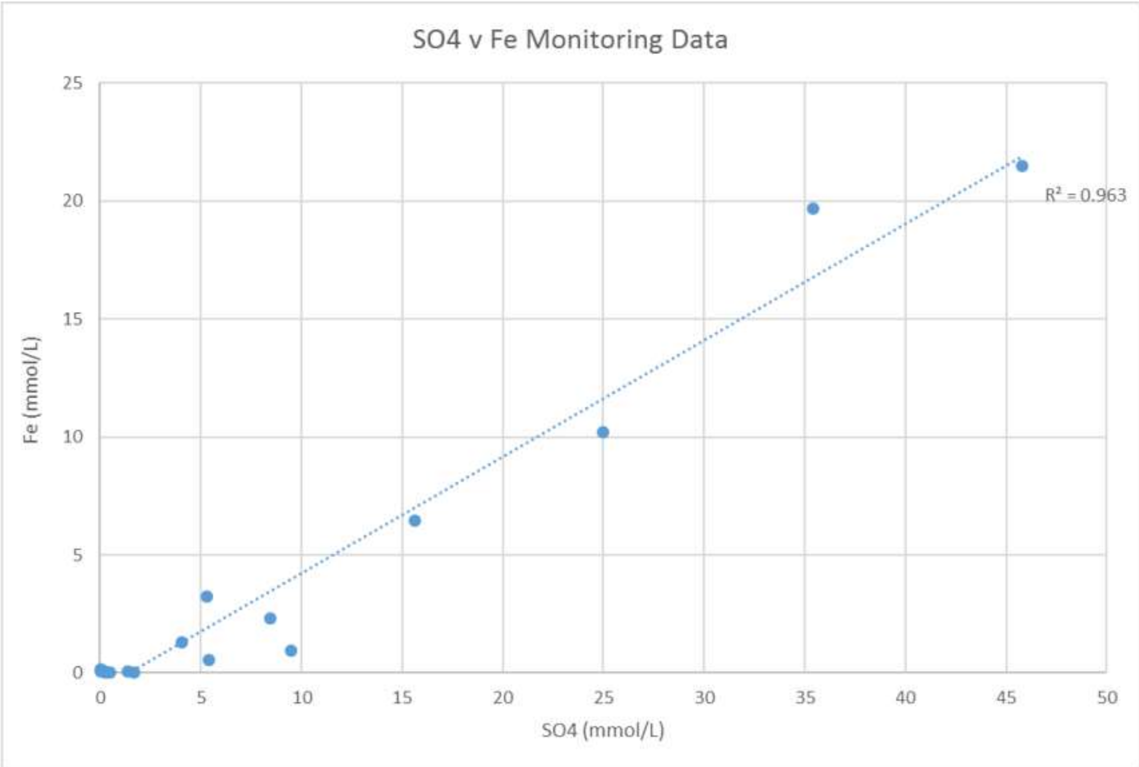


Figure 40: Fe to SO4 ratio of water in Big Swamp and Boundary Creek (GHD, 2019)

A full description of the model set up and assumptions are detailed in section 9 (GHD, 2019), however the key findings of the modelling are as follows:

- Based on the net acid mass that potentially remains in the unsaturated zone of Big Swamp and the potential mass flux rate into Reach 3, acid flux from the swamp could occur for more than 300 years in the absence of supplementary flows. This could be reduced to 50-100 years with the ongoing provision of supplementary flows.
- Upon direct treatment of acid sulfate soils with lime, pH increase in solution are largely off-set by precipitation of ferric iron minerals.
- The most significant effect of inundation would be to increase the water table in the swamp, limiting the oxidation of any potential acidity that remains in the sediments below the historic water table.
- Alkalinity generation via the precipitation of iron sulfide minerals is limited by the amount of dissolved sulfate in the swamp (this is consistent with the observations made by Cook (2019).

The addition of lime to Boundary Creek would result in an increase in pH that may lead to precipitation of some minerals. The potential precipitate minerals identified are $Fe(OH)_3$, $AlOHSO_4$ $Al(OH)_3$ and others.

Based on the above, the major hydro-geochemical and acid generating processes occurring within Big Swamp and Boundary Creek can be summarised by Figure 41 below. This shows that currently, the oxidation of sulfides and mobilisation of sulfuric acid from swamp sediments is the major process generating acid within the system.

It further shows that the infiltration and reduction of iron from Fe^{3+} to Fe^{2+} upon inundation or infiltration into the groundwater system may remove acidity from the system, however upon subsequent discharge in to the water column, this may re-oxidise and release acidity which had previously been removed further downstream of the swamp. The re-oxidation of Fe2+ may however be limited if residence times under reducing conditions are sufficient to result in adsorption within the sediment profile.

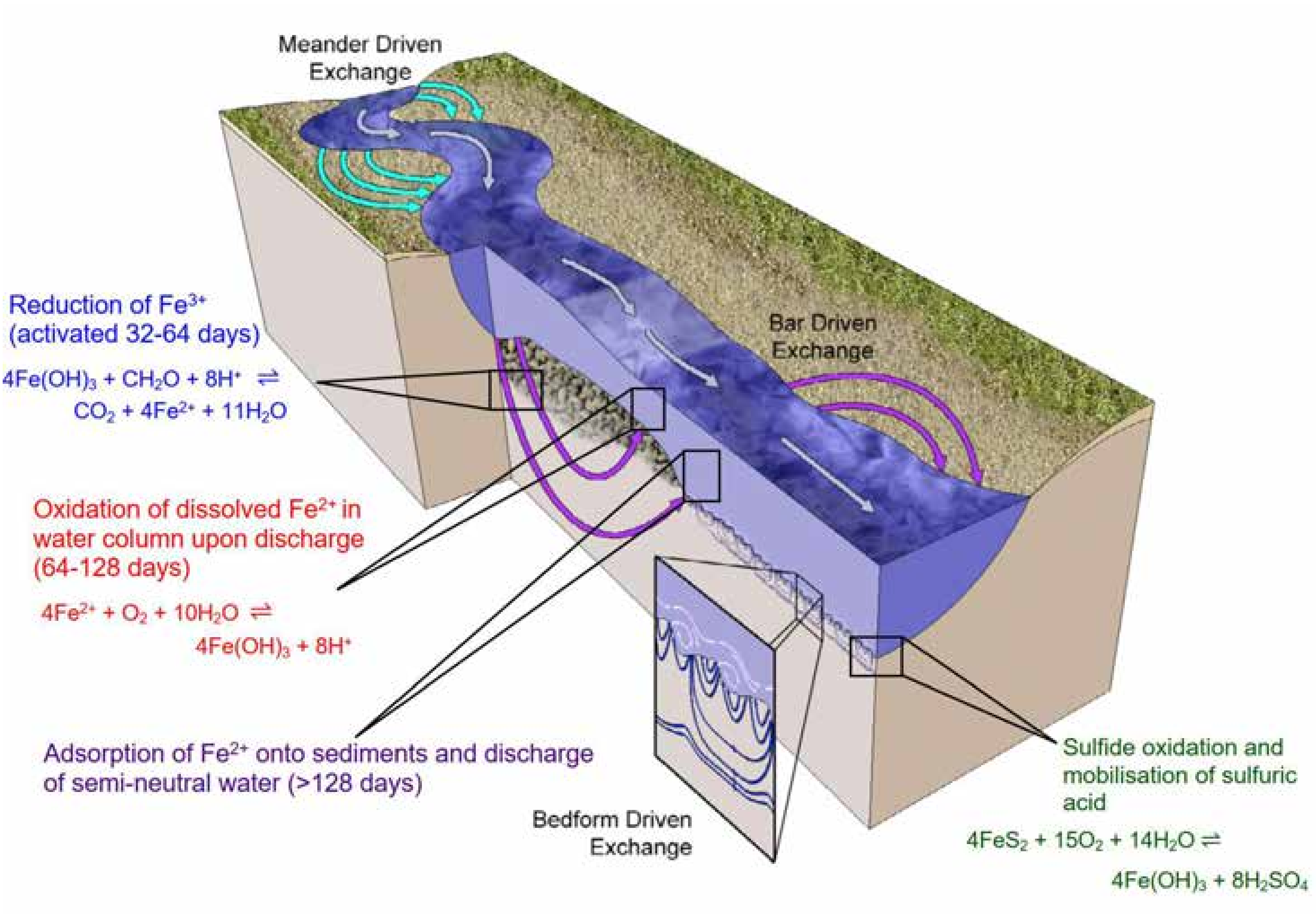


Figure 41: Major hydro-geochemical and acid generating processes occurring within Big Swamp (adapted from Stonedahl et al, 2010)Ecology

Eco Logical Australia (ELA) were engaged by Barwon Water to undertake a vegetation assessment of Big Swamp and provide commentary on how changing the wetting/drying regime in the swamp (from seasonal drying to permanently wet) would impact upon the existing vegetation class and health.

The assessment was to inform the preparation of the remediation plan and therefore the objectives of the study were to:

- establish the baseline ecological characteristics for Big Swamp.
- determine the hydrological requirements of past and current vegetation communities and advise likely responses to future surface and groundwater regimes.
- provide recommendations to improve ecological outcomes within the swamp, within the context of the broader objectives of the remediation plan.

Full details of the methods of assessment, results, interpretation and recommendations are provided in the Assessment of historical and current vegetation diversity and condition within Big Swamp (Eco Logical, 2019) in section 9.

The assessment undertaken by ELA (2019) confirmed that the ecology of Big Swamp is complex and intricately linked to the hydrology of the site. The hydrology is in turn influenced by a range of factors including soils, topography and climate, surface water use upstream and groundwater, particularly historical extraction from the underlying LTA).

ELA (2019) determined that historically the swamp is likely to have supported a diverse wetland ecosystem comprised of four distinct vegetation associations:

1. A low scrub community through the central and northern sections of the swamp plain which was likely to have been an association of the Riparian Fern Scrub vegetation community. It would have been tolerant of frequent or prolonged inundation and saturated soil conditions. As a result, sedges and rushes were likely to have been dominant in the understory.

2. A tall scrub at the western end of the swamp plain and fringing the swamp plain. This is likely to have been an association of the Riparian Fern Scrub vegetation community which is differentiated from the above community due to less frequent or less prolonged periods of inundation and moist rather than saturated soil conditions. It is likely that ferns were dominant throughout this association.

3. A highly variable, low riparian woodland along the main channels around the northern edge and eastern parts of the swamp. Swamp Gum is likely to have been the dominant canopy species, however the community would have included other Eucalypts tolerant of wet conditions as well as a high diversity of understory shrubs, ferns, sedges, rushes and herbs.

4. A damp woodland fringing the swamp plain and areas of riparian woodland, primarily along the southern edge and across much of the eastern third of the swamp outside the influence of existing channels. This varied woodland would have supported a range of tall Eucalypts as co-dominants in an open canopy, over a dense understory tree / shrub layer.

In addition to the dominant associations listed above, ELA (2019) report that there would have also been small pockets of unique vegetation communities throughout the swamp that persisted due to a combination of local conditions. An example of this is a small patch of Wet Verge Sedgeland which was identified at the western end of the swamp during their recent field surveys.

ELA (2019) also noted that from as early as the 1800s, the swamp has been affected by changing land and water use as vegetation clearance and agricultural practices expanded across the region. This activity has continued to the current day, with the extraction of groundwater from the LTA, reductions in surface water flows into the swamp and fires within the swamp serving as additional pressures on the system.

These cumulative effects have resulted in significant changes to vegetation over the past 20 years, including almost complete loss of vegetation cover across the swamp due to fire, substantially altering the structure of the vegetation communities throughout. Subsequent declines in soil structure appears to have also resulted in increased erosion of the swamp plain which may have been driven by large, seasonal surface flow events concentrating flows into a primary channel that now bisects the swamp plain.

Whilst there is likely to have been a gradual shift in community structure and composition since European settlement, and even prior due to decadal shifts in climate, ELA's assessment is that the last 30 years has seen significant changes to the vegetation of the Swamp.

The fires have had the greatest direct impact on vegetation, resulting in a reduction of both floristic and structural diversity across the swamp plain and damp woodlands, with the impact of fire driven by the drying of the swamp. Where a high cover of canopy species has regenerated in these areas, ELA (2019) noted that the understorey is often absent and where it has recovered it consists almost exclusively of Austral Bracken.

Therefore, during the assessment, Big Swamp was observed to currently support the following vegetation communities:

- **Riparian Fern Scrub (EVC A120)** was recorded throughout much of the swamp plain in the western and central sections of the Swamp. The majority of the EVC has been significantly modified by fire resulting in the loss of much of the original ground layer vegetation. The most heavily affected areas are now dominated by Prickly Tea-tree (*Leptospermum continentale*) or Scented Paperbark (*Melaleuca squarrosa*) with occasional patches of Austral Bracken (*Pteridium esculentum*) and/or Red-fruit Saw-sedge (*Gahnia sieberiana*). More intact patches occurr in the far west of the study area in areas apparently less affected by fire, supporting a diverse ground layer dominated by various sedges such as Tall Sedge (*Carex appressa*) and Tassel Sedge (*Carex fascicularis*). Areas closer to the main channel in the north of the site contained a braided system of channels and supported a higher cover of sedges and ferns, including additional species such as Spreading Rope-rush (*Empodisma minus*) and Scrambling Coral-fern (*Gleichenia microphylla*).
- **Swampy Riparian Woodland (EVC 83)** was recorded along the main channel and adjacent terraces of Boundary Creek and shared a broad ecotone with the adjacent Riparian Fern Scrub. This vegetation contained a scattered tree layer, dominated by Swamp Gum (*Eucalyptus ovata*), Brooker's Gum (*Eucalyptus brookeriana*) and Manna Gum (*Eucalyptus viminalis*), often over a secondary tree layer. In elevated sections with limited inundation a variety of ground, scrambling and tree ferns were common. The creek channel supported a range of aquatic and semi-aquatic forbs and sedges.

- **Wet Verge Sedgeland (EVC 932)** was recorded at the western end of the swamp in a small patch adjacent to the main channel. The patch shared floristic affinities with the adjacent Riparian Fern Scrub but woody species were mostly absent and the vegetation was dominated by relatively dense Tall Sedge and Tassel Sedge. Associated species included White Purselane (*Montia australasica*), Common Spike-sedge (*Eleocharis acuta*), Rushes (*Juncus* spp.) and Slender Knotweed (*Persicaria decipiens*).
- **Damp Sands Herb-rich Woodland (EVC 3)** was recorded on the lower slopes to the south and east of the swamp plain. This community was dominated by young Swamp Gum with a very species-poor understorey containing Austral Bracken and Red-fruit Saw-sedge. Whilst this community has been described as Damp Sands Herb-rich Woodland due to its current structural and floristic characteristics (which is likely a result of recent fires and changes in hydrology), this vegetation is considered to represent a derived state of the Swamp Gum (*Eucalyptus ovata*) Forest described by Carr and Muir (1994).
- **Lowland Forest (EVC 16)** was recorded on the slopes surrounding Big Swamp, upslope from areas historically effected by water-logging or inundation. This floristically diverse community was dominated by Messmate Stringybark (*Eucalyptus obliqua*) and Manna Gum with a high cover of Austral Bracken. Prominent shrubs included Silver Banksia (*Banksia marginata*), Prickly Moses (*Acacia verticillata*) and Sweet Bursaria (*Bursaria spinosa*).

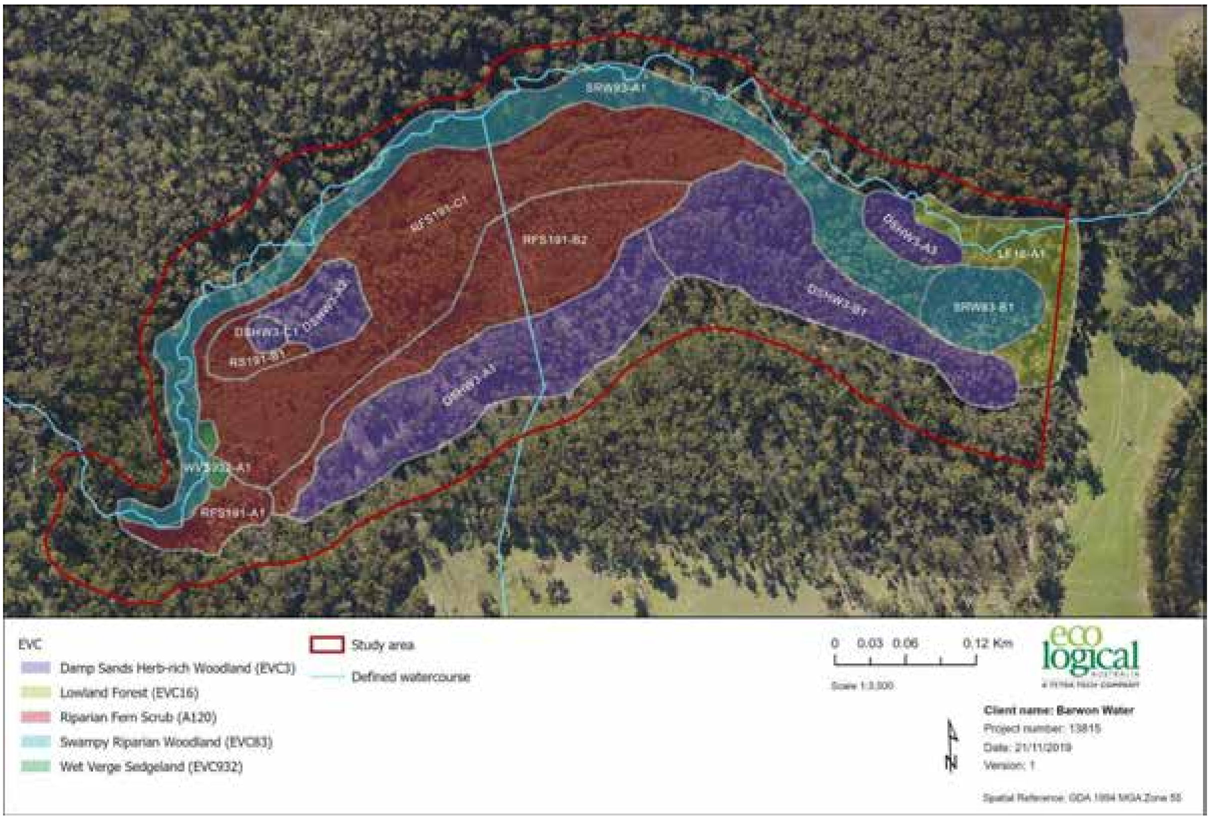


Figure 42: current vegetation communities observed in Big Swamp (ELA 2019)

ELA (2019) also noted that two major trends can currently be observed in the swamp and will likely continue and result in a substantial shift in the composition of vegetation and associated habitat across the swamp. These include:

- Restriction of flows through the swamp plain to a narrow, central channel that in the worst-case scenario may only flow intermittingly during seasonal high rainfall events. Combined with a continuing failure to restore a near-surface water table across much of the plain, the current Riparian Fern Scrub community is likely to reduce in extent to a narrow band limited by proximity to the remaining channels (i.e. one or two through the plain and the main channel along the northern edge). Vegetation outside of this band will in time be replaced by damp woodlands, with Swamp Gum progressively colonising the plain and eventually forming a mature canopy. The resulting consequence will be a significant depletion of the extent of the Riparian Fern Scrub and simplification of the floristic and structural diversity likely to have been present prior to extraction. In a worst-case scenario, the encroachment of woodlands may have a feedback effect, leading to further drying of the swamp plain as species with higher evaporation rates establish and mature. This could theoretically lead to the permanent loss of the Riparian Fern Scrub community from the swamp in the long term. Given climatic trends towards lower average annual rainfall, this scenario cannot be discounted.
- Similar to the Riparian Fern Scrub, a failure to restore ground water levels across the swamp may also see the encroachment of the surrounding Lowland Forest into areas historically dominated by damp woodlands, potentially reducing the extent of the swamp and wetland ecosystem as a whole.

An eco-hydrological analysis also undertaken by ELA (2019) compared the historic relationship between water and vegetation with the current conditions measured and modelled within the swamp across three zones:

- **Swamp Plain** – The Riparian Fern Scrub community that would have occupied the swamp plain requires near-continuous waterlogging of the soil with shallow, often prolonged, periods of inundation. Where conditions result in frequent or prolonged inundation, sedges and rushes are likely to become dominant in the understorey. Alternatively, drier conditions would have seen a shift to a fern dominated understorey with emergent trees common.

  In recent years, this part of the swamp has seen significant drying of the substrate, peat fires and the loss of vegetation cover. Dominant species such as Prickly Tea-tree and Scented Paperbark have recolonised the swamp plain, however understorey species are now virtually absent. A diverse and structurally complex understorey remains only at the west and northern edges of the swamp plain where strong interaction with the main channel is likely to have protected fern and sedge species from the impacts of drying and fires.

  The reduced water-table currently present throughout much of the swamp plain is unlikely to support a Riparian Fern Scrub community in the long-term, leading to a gradual shift to a terrestrial damp woodland community over time. Evidence of Swamp Gum encroachment in the form of distinct recruitment cohorts progressively expanding into the swamp plain were observed along the eastern edges and to the east of the small hillock during the field survey.

- **Main channel** – The Swampy Riparian Woodland community is likely to be reliant on surface flows along the main channel and associated infiltration into the surrounding ground layer. The depth of the channel and variation in elevation along the banks means inundation may have been limited to seasonal floods and localised depressions. Tall forest species less tolerant of inundation, such as Brooker's Gum and Manna Gum, were also present further up the bank as the community shifted into Lowland Forest.

Surface flow modelling indicates that even under relatively low flows (e.g. 2ML / day) water persists in the channel and as a result, this community is likely to be more tolerant of long-term reductions in surface flows and the associated reduction in water tables within the swamp. However, should cease-to-flow events continue for extended periods, as has occurred in recent years, this community is likely to be affected through a reduction in species diversity and encroachment by Lowland Forest species.

- **Damp woodlands** - Based on high flow modelling (20ML/day), these Damp Sands Herb-rich Woodlands are unlikely to have experienced inundation in normal years. They would still have been heavily dependent on ground water with near-constant access to water within the root zone of mature trees and shrubs (Jacobs 2016). These conditions are likely to have been a strong driver of this community and differentiated it from the Lowland Forest EVC on the slopes above.

  Currently, this community is in a state of transition, with species tolerant of wet conditions (e.g. Swamp Gum) expanding into the scrub dominated areas of the swamp. Without the restoration of the water table, opportunities may be created for Lowland Forest species to colonise this area as the canopy matures and thins. In time this would have the effect of reducing the overall extent of the wetland as the surrounding forests encroach.

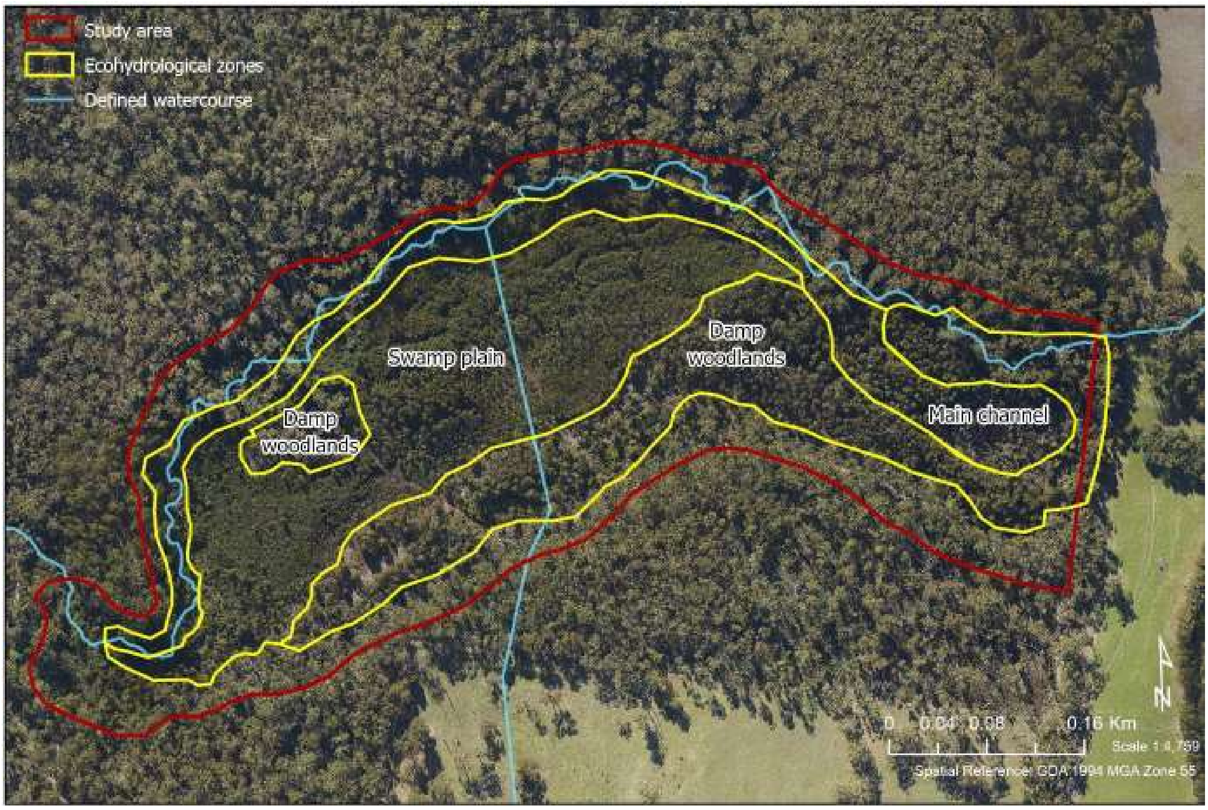


Figure 43: Current hydrologic-vegetation zones within Big Swamp (ELA 2019)

6.1.8 Barwon River

Water quality monitoring

Water quality monitoring in the Barwon River was undertaken as part of a sediment and macroinvertebrate assessment in the Barwon River (Austral, 2019). The location of sampling sites is illustrated in Figure 44 below. The water quality results from the sampling program have been summarised in Table 13.

The results describe the discharge of low pH water (3.9) from Big Swamp driving a reduction in pH in the Barwon River from 7.4 to 7.3.

Of the metals analysed, Aluminium and Zinc were found to exceed ANZECC (2000) guideline concentrations (Austral, 2019). Zinc concentrations were in exceedance upstream of the Boundary Creek confluence, however Aluminium concentrations were not. These remained above ANZECC concentrations between Boundary Creek and Colac-Lorne Road (~3.6 km downstream).

These results are consistent with the mobilisation of Aluminium under acidic conditions in Boundary Creek and subsequent dilution and precipitation during mixing with the higher pH water in the Barwon River. While this provides a first pass indication of potential impacts on the Barwon River, it represents only one flow state (5.7 ML/day Boundary Creek @ Yeodene, ~40 ML/day Barwon River @ Ricketts Marsh) and ongoing monitoring to characterise impacts over time is required to establish a robust baseline condition.

Figure 44: Water quality monitoring locations October 2019 (Austral, 2019)

Table 13: In situ and dissolved metal concentration in surface water in the Barwon River Catchment (Austral, 2019)

Site	Waterway	Sample date	Temp. (°C)	pH	Conductivity (µS/cm)	Specific Conductivity (µS/cm@25°C)	Dissolved oxygen (mg/L)	DO %	Alkalinity	Turbidity
Site 1	East Barwon Rv	04/10/19	13.2	6.2	186.7	240	13.07	123	5	9.09
Site 2	East Barwon Rv	04/10/19	15.5	6.3	544	664	6.8	66.8	10	9.97
Site 3	West Barwon Rv	03/10/19	14.7	5.26	473.4	590.6	7.3	73.5	10	16.3
Site 4	Barwon Rv	03/10/19	17.9	7.4	575	664	9.15	96.4	10	8.01
Site 5	Boundary Ck	03/10/19	12.1	3.94	777	1030	7.43	67.6	0	2.92
Site 5.5	Boundary Ck	03/10/19	14.2	5.55	1165	1285	7.05	68.2	-	-
Site 6	Barwon Rv	03/10/19	14.4	7.34	608	756	7.3	71.3	10	9.43
Site 7	Barwon Rv	03/10/19	13.4	7.9	599	770	7.2	71.7	5	10
Site 8	Barwon Rv	02/10/19	16.2	7.8	660	795	8.8	87.9	10	13.5
Site 9	Barwon Rv	02/10/19	15.4	7.8	1049	1288	9.7	98	15	16.6
Site 10	Barwon Rv	02/10/19	14.6	7.9	1252	1561	8.1	86.1	15	18
Site 11	Barwon Rv	02/10/19	13	7.9	1707	2227	9.23	87	15	26.1
Site 12	Barwon Rv	02/10/19	12.4	8	1788	2364	8.4	82.1	15	19.9

mg/L	Aluminium	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Mercury	Selenium	Silver	Zinc
Site 1	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.33	< 0.001	0.04	< 0.0001	< 0.001	< 0.005	0.032
Site 2	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.4	< 0.001	0.15	< 0.0001	< 0.001	< 0.005	0.008
Site 3	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.31	< 0.001	0.31	< 0.0001	< 0.001	< 0.005	0.051
Site 4	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.33	< 0.001	0.15	< 0.0001	< 0.001	< 0.005	0.017
Site 5	10*	< 0.005	< 0.001	0.0002	< 0.001	< 0.001	5.4	< 0.001	0.06	< 0.0001	< 0.001	< 0.005	0.34
Site 6	0.09	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.13	< 0.001	0.17	< 0.0001	< 0.001	< 0.005	0.057
Site 7	0.07	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.15	< 0.001	0.08	< 0.0001	< 0.001	< 0.005	0.013
Site 8	0.1	< 0.005	< 0.001	< 0.0002	< 0.001	0.001	0.23	< 0.001	0.066	< 0.0001	< 0.001	< 0.005	0.015
Site 9	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.22	< 0.001	0.098	< 0.0001	< 0.001	< 0.005	0.01
Site 10	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.22	< 0.001	0.09	< 0.0001	< 0.001	< 0.005	< 0.005
Site 11	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.42	< 0.001	0.1	< 0.0001	< 0.001	< 0.005	< 0.005
Site 12	0.07	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.56	< 0.001	0.1	< 0.0001	< 0.001	< 0.005	< 0.005
ANZECC	0.05 (>6.5pH) *ID (<6.5pH,)	ID	0.013	0.0002	0.001	0.0014	ID	0.0034	1.2	0.00006	0.005	0.00005	0.008

ID= insufficient data
Shaded exceeds trigger values
**aluminium results where pH is <6.5*

Sediment sampling & macro-invertebrate surveys

An assessment of macroinvertebrate community structures and sediment survey was undertaken to determine a baseline for ongoing monitoring of the Barwon River for potential impacts of acidic discharge from Big Swamp and Boundary Creek (Austral 2019).

In undertaking the assessment, a total of twelve sites were surveyed along East Barwon, West Barwon, and Barwon Rivers in addition to Boundary Creek (Figure 44). Full details on the assessment methodology, results, interpretation and recommendations are provided in the Investigation of Sediments and Macroinvertebrates in the Upper Barwon River Report (Austral 2019).

At the time of sampling, Austral (2019) noted the condition of the sampling sites in accordance with EPA habitat parameters. Summaries of the site conditions are provided below to illustrate the wide range of in stream and riparian habitat conditions observed along the upper reaches of the Barwon River.

Boundary Creek at Colac-Forrest Road was observed to have a mix of large deep pools, a large shallow pool at the bridge and shallow runs. It was bankfull at the time of sampling with an average stream width of four meters, narrow at the top of the surveyed reach and widening into a large pool upstream of the bridge. The substrate was a mix of cobble, pebble, gravel, sand, clay and silt. There were no macrophytes observed but there were filamentous algae and trailing bank vegetation present. The riparian zone is wide with a mix of native and exotic vegetation except for ground cover which is dominated by Convolvulus sp. and pasture grasses. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 81 out of 140 for this site.

Figure 45: Site 5 Boundary Creek at Colac-Forrest Road

The East Barwon River at Kents Road was observed to have diverse habitat with large deep pools and some riffle/run areas. Willows dominate the riparian zone and are growing within the stream channel. The substrate is a mix of clay and silt with a number of aquatic macrophytes growing in the margins and shallow pool areas. The average stream width at this site was eight meters and was bank full at the time of sampling. The majority of the riparian zone is exotic vegetation, dominated by blackberries, willows and pasture grass. One larval fish was collected as bycatch during macroinvertebrate sampling. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 74 out of 140 for this site.

Further downstream the East Barwon River at Dewings Bridge Road site consists of a slow flowing channel with extensive backwaters. There is very little riparian zone present but a number of submerged and emergent macrophytes provide good habitat. The substrate is a mix of clay and silt with some sand. The average stream width at this site was seven meters and was bank full at the time of sampling. The majority of the riparian zone is pasture grass with stock access on both sides. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 59 out of 140 for this site.

Figure 46: Sites 1 and 2 Barwon River East Branch at Kents Road and Dewings Bridge Road

The West Barwon River at Seven Bridges Road site has large deep pools with a number of large deep backwaters. The average stream width at this site is seven meters, narrow at the top of the surveyed reach and widening into a large pool near the bridge. The substrate is clay and silt mixed with 20% sand. There were some macrophytes present, along with trailing bank vegetation, roots and instream large woody debris (primarily willow branches).

Willows dominate the riparian zone with a mix of shrubs and native and pasture grasses in the understory. Four larval fish were collected as bycatch during macroinvertebrate sampling. A concurrent snapshot study by EnviroDNA (2019) found evidence of platypus at this site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 85 out of 140 for this site.

Figure 47: Site 3 - West Barwon River

The Barwon River immediately upstream of the Boundary Creek confluence is a large slow flowing channel with shallow side sections that support a number of macrophyte beds. The average stream width at this site is nine meters. The substrate is clay and black silt with some large woody debris and filamentous algae present in addition to macrophytes. Riparian vegetation is limited to some isolated trees, a narrow native plantation and pasture grass with stock access. The introduced Gambusia (mosquito fish) were collected as bycatch during macroinvertebrate sampling. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 79 out of 140 for this site.

The Barwon River immediately downstream of the Boundary Creek confluence is a narrow deep channel with wide shallow edges dominated by grasses and aquatic macrophytes. The average stream width at this site is five meters and is bank full. It is wide but still with a narrow channel at the top of the surveyed reach and narrowing to a confined channel downstream. The substrate consists of clay and silt with filamentous algae tangled through the macrophyte beds. Macrophyte species are varied with Triglochin, Polygonum, Phragmites, and Juncus all present in addition to trailing grasses. The riparian zone is limited to grasses and scattered native trees and shrubs with stock access to the site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 70 out of 140 for this site.

Figure 48: Site 4 and 6 Barwon River upstream of confluence with Boundary Creek & Barwon River immediately downstream of the confluence with Boundary Creek

The Barwon River upstream of WaterWatch sampling site CO_BAR16 is adjacent to the northern boundary of a pine plantation and has a large deep channel with any shallow areas dominated by beds of Phragmites. The average stream width at this site is seven meters with a substrate of clay and silt. In addition to the Phragmites beds there are beds of Triglochin, and scattered Polygonum, Juncus and other grasses. The riparian zone has a good mix of trees, shrubs and understory with a majority of native trees and shrubs. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 90 out of 140 for this site.

The Barwon River at Colac-Lorne Road has large deep pools with shallow areas at the sides and willow trees growing in the channel and some substrate exposed. The average stream width at this site is eight meters with a predominantly clay and silt substrate mixed with some sand. There are beds of Triglochin and Phragmites in addition to trailing grasses and large willows. The riparian zone consists of willow trees, pasture grasses and blackberries and allows stock access. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 69 out of 140 for this site.

Figure 49: Sites 7 and 8 Barwon River upstream of WaterWatch site CO_BAR16 and Barwon River at Colac-Lorne Road

The Barwon River at Birregurra site consists of a large deep slow flowing pool. The average stream width at this site is five meters with steep clay banks. The substrate is clay and silt with willow roots, some snags and Triglochin beds scattered along the edges of the channel. There have been recent willow removal works and replanting of the riparian zone in amongst the pasture grass and blackberry groundcover. Rakali footprints were evident in the soft sediment edge. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 67 out of 140 for this site.

The Barwon River at Conns Lane site has large deep pools with some small deep backwaters and a narrow deep run at the top of the reach. The average stream width at this site is six meters. The substrate is clay and silt mixed with some sand and gravel. Phragmites beds line the channel and there are isolated patches of Triglochin in addition to Polygonum and trailing grasses along the water's edge. The riparian zone consists of relatively new an older native revegetation with pasture grass understory. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 98 out of 140 for this site.

Figure 50: Sites 9 and 10 – Barwon River at Birregurra and Barwon River at Conns Lane

The Barwon River at Winchelsea - Deans Marsh Road site has large deep pools with a shallow run at the top of the reach. The average stream width at this site is five meters and the substrate is clay and silt mixed with some sand and gravel. Triglochin is growing in the shallow areas of the channel and there are roots, large woody debris and trailing grasses. The riparian zone is predominately native trees and understory with a mix of grasses as groundcover. Rakali footprints were spotted at the water's edge. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 90 out of 140 for this site.

The Barwon River at Winchelsea site has large deep pools with a large shallow pool at the top of the reach. The average stream width at this site is twelve meters. The substrate is clay and silt mixed with sand and some gravel. In addition to the Phragmites beds at the top of the reach and along some edges there are also patches of Triglochin. Large woody debris, trailing grasses and emergent vegetation such as Polygonum are also present. Riparian vegetation is predominantly native with many established eucalypts and groundcover is pasture grass. A concurrent snapshot study by EnviroDNA (2019) found evidence of platypus at this site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams resulted in a score of 88 out of 140 for this site.

Figure 51: Sites 11 and 12 – Barwon River at Winchelsea-Deans Marsh Road and Barwon River at Winchelsea

Macroinvertebrate assessment

Macroinvertebrate sampling was undertaken at each of the locations listed above to gain an understanding of the potential impact of acidic discharge from Big Swamp on the macroinvertebrate community structure in Boundary Creek and the Barwon River (Austral 2019). It is important to acknowledge that these results represent sampling at a single point in time during spring and further sampling is required in autumn to provide a more complete picture of macroinvertebrate communities following summer low flow periods.

This sampling also forms the start of establishing a baseline against which future monitoring results can be assessed.

The results of this round of macroinvertebrate sampling indicates that poor water quality from Boundary Creek is not currently impacting on macroinvertebrate communities within the Barwon River, except immediately downstream of the confluence with Boundary Creek.

Four of the five 'healthiest' sites as determined by SIGNAL2 and 'Number of Families' analysis were located downstream of the confluence with Boundary Creek and five of the seven sites below the confluence had higher AusRivAS scores than those sites located upstream of the confluence with Boundary Creek (Austral 2019). These results suggest that overall, the Barwon River was not being adversely impacted by inflows from Boundary Creek at the time of sampling (Austral 2019).

Analysis of the results from this sampling event also indicates that sites above and below the Boundary Creek confluence have similar macroinvertebrate families present, with site 1 on the East Barwon River at Kents Road, site 5 on Boundary Creek, and site 6 on the Barwon River immediately downstream of Boundary Creek exhibiting different macroinvertebrate community compositions (Austral 2019).

Site 9 on the Barwon River at Birregurra and Site 12 on the Barwon River at Winchelsea were identified as meeting the most objectives for ecosystem protection (EPA, 2004) and produced the highest AusRivAS score, suggesting that they were the healthiest sites sampled within the upper Barwon River (Austral 2019).

Austral (2019) reported that site 1 on the East Barwon River at Kents Road and site 5 on Boundary Creek were classified as being 'Outside the experience of the AusRivAS model', while site 10 on the Barwon River at Conns Lane was classified as 'Nearly outside the experience of the model'. This means that based on the environmental data entered, no reference sites could be found to compare to the test site for sites 1 and 5 while limited reference sites were found for site 10. This is often the case with single season samples compared to use of combined results from autumn and spring sampling. Therefore, as noted previously, these results currently only represent part of the picture and require further analysis following a round of autumn sampling (Austral 2019).

Unusual readings such as the alkalinity at site 5 on Boundary Creek can also make it difficult to match with reference sites within the AusRivAS model. Site 1 on the East Barwon River at Kents Road and site 5 on Boundary Creek were also identified to be outliers in that they have SIGNAL2 scores that indicate they are subject to moderate pollution, whereas all other sites sampled were classified as in the mild pollution category (Austral 2019).

While SIGNAL2 scores alone can be used to provide an indication of water quality in the river from which the macroinvertebrate sample was collected, combining the SIGNAL2 with the families richness score (how many different macroinvertebrate families are present) can also provide an indication of the types of pollution and other physical and chemical factors that may be affecting the macroinvertebrate community (Austral 2019).

Site 3 on the West Barwon River, site 6 on the Barwon River immediately downstream of Boundary Creek, site 8 on the Barwon River at Colac-Lorne Road, site 9 on the Barwon River at Birregurra and site 12 on the Barwon River at Winchelsea all have high scores for SIGNAL2 and number of macroinvertebrate families, suggesting the habitat and water quality at these locations are favorable and stress factors are low.

Site 2 on the East Barwon River at Dewings Bridge Road and site 7 on the Barwon River upstream of water watch site CO_BAR16 both have lower SIGNAL2 scores, possibly due to water quality influences but the high number of families present suggest that any toxicants are not present in large amounts.

Site 11 on the Barwon River at Winchelsea-Deans Marsh Road has a high SIGNAL2 score but fewer number of families. This suggest this site may be affected by pollution other than on which SIGNAL2 scores are based (i.e. organic, nutrient enrichment or salinity).

Site 1 on the East Barwon River at Kents Road, site 4 on the Barwon River upstream of Boundary Creek, site 5 on Boundary Creek and site 10 on the Barwon River at Conns Lane all have lower SIGNAL2 scores and low numbers of families suggesting that they are subject to a number of impacts.

Whilst these results indicate that macroinvertebrate communities are at reference condition at all sites except Site 1 on the east Barwon River at Kents Road which was outside the experience of the AusRivAS model for an unknown reason, and Site 5 on Boundary Creek which is severely impacted by the low pH, a second season of sampling in Autumn would give a more complete picture and enable comparisons with biological objectives.

6.2 Clause 2.5b: An outline and risk assessment of the processes/activities on the Property which may impact on Boundary Creek, Big Swamp and the surrounding environment (including, but not limited to hydrogeology, hydrology and soil chemistry)

6.2.1 Risk assessment for activities on the property

This section considers the processes/activities on the property (the Barwon Downs Borefield) which may impact upon Boundary Creek, Big Swamp and the Surrounding Environment. Within the context of this document, this section considered potential activities over a 10-year timeframe.

To assess the risk of any proposed activities which may impact upon Boundary Creek, Big Swamp and the Surrounding Environment, the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) were drawn on as a starting point.

The likelihood of rivers being impacted by activities has been assessed according to their level of connection to the Lower Tertiary Aquifer (from which the production bores on the property extract from) and the consequence assessed according to the groundwater pumping caused reduction in low flows.

The likelihood of vegetation and acid sulfate soils being impacted by activities has been assessed based on the likelihood of connection and drawdown. A description of the receptors and potential risks, likelihood, consequence and risk framework is provided in the tables below.

As Barwon Water's groundwater extraction licence expired in June 2019, the only activities on the property which may impact upon Boundary Creek, Big Swamp and the Surrounding Environment are considered to be:

- Groundwater extraction for the maintenance of borefield assets – capped at 30 ML/year as set out in the current Gerangamete Permissive Consumptive Volume, and
- Groundwater extraction for the delivery of emergency water supplies.

Monitoring of the Boundary Creek and Big Swamp environments indicates that the system is currently hydraulically disconnected from the regional LTA and will remain so for the next 10 years (see section 6.1.5). Given this, the likelihood of connection is classified as low.

Additionally, Boundary Creek ceases to flow annually (see section 6.1.4). As such, no impact on the low flow can manifest from additional groundwater extraction, and any impact to Boundary Creek and Big Swamp is considered minor. This corresponds with a **low risk**.

Due to the small volumes associated with the extraction of groundwater for maintenance purposes, numerical groundwater model simulations were not undertaken for this assessment and instead, a simple Theis drawdown analysis was undertaken using the modelling software package AQTESOLVE. The use of the borefield for maintenance purposes is capped at 30 ML/year and the timeframe for drawdown impacts set to 10 years (5 ML per bore per year).

The maximum drawdown in the aquifer will occur when transmissivity (K) and storativity (S) of the aquifer are low and so, for this assessment, a lower range of LTA thickness, K and S have been adopted here for a relatively conservative assessment of risk.

For this purpose, the lower range of values at the borefield given by Hancock (1970), Blake (1978) and Layton Groundwater Consultants (1982) were adopted, as reported in Witebsky (1995). Accordingly, the LTA thickness was set at 100 m, the T at 366 m/day and the S at 3.0×10^{-4}. The results of the analysis are illustrated in Figure 52 below.

Given the small volume proposed for maintenance extraction, this approach and the assumptions used are considered reasonable.

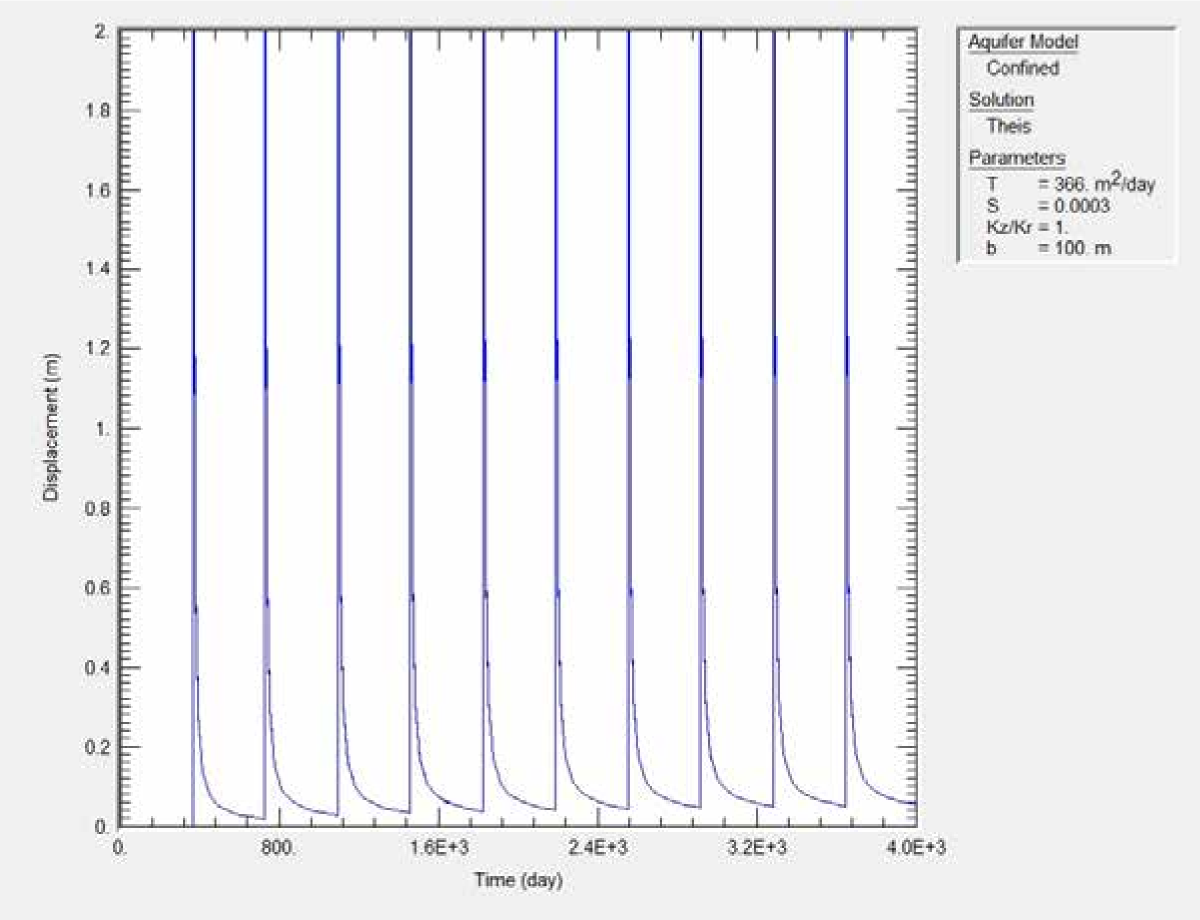


Figure 52: AQTESOLVE analysis of drawdown over time at the Barwon Downs borefield in response to extraction of 5 ML/day from each bore annually over 10 years (This analysis ignores any contribution from regional recharge to recovering water levels, which would increase the rate of recovery).

At the centre of the wellfield, over 350 m of aquitard (combined Gellibrand and Narrawaturk Marl) overly the LTA. As such, the likelihood of connection between the LTA and any groundwater dependent ecosystems at the surface within the drawdown cone is low.

Given this, and according to the risk matrix outlined in
Table 16, risks to groundwater receptors at the borefield will only increase from low to moderate when drawdown in the LTA is classed as significant (>2 m).

To illustrate this point, the 2 m drawdown contour surrounding the borefield has been illustrated at time steps of 1 day, 2 days and 3 days after the 10th maintenance pumping period described in Figure 52 (when residual drawdown will be greatest). This shows that a moderate risk to groundwater receptors would be present for a very short period of time (<4 days). Given this, consequences such as reductions to streamflow or drawdown at groundwater dependent vegetation are not expected to manifest.

Given the above, the use of the borefield for maintenance pumping is considered to be a **low risk**.

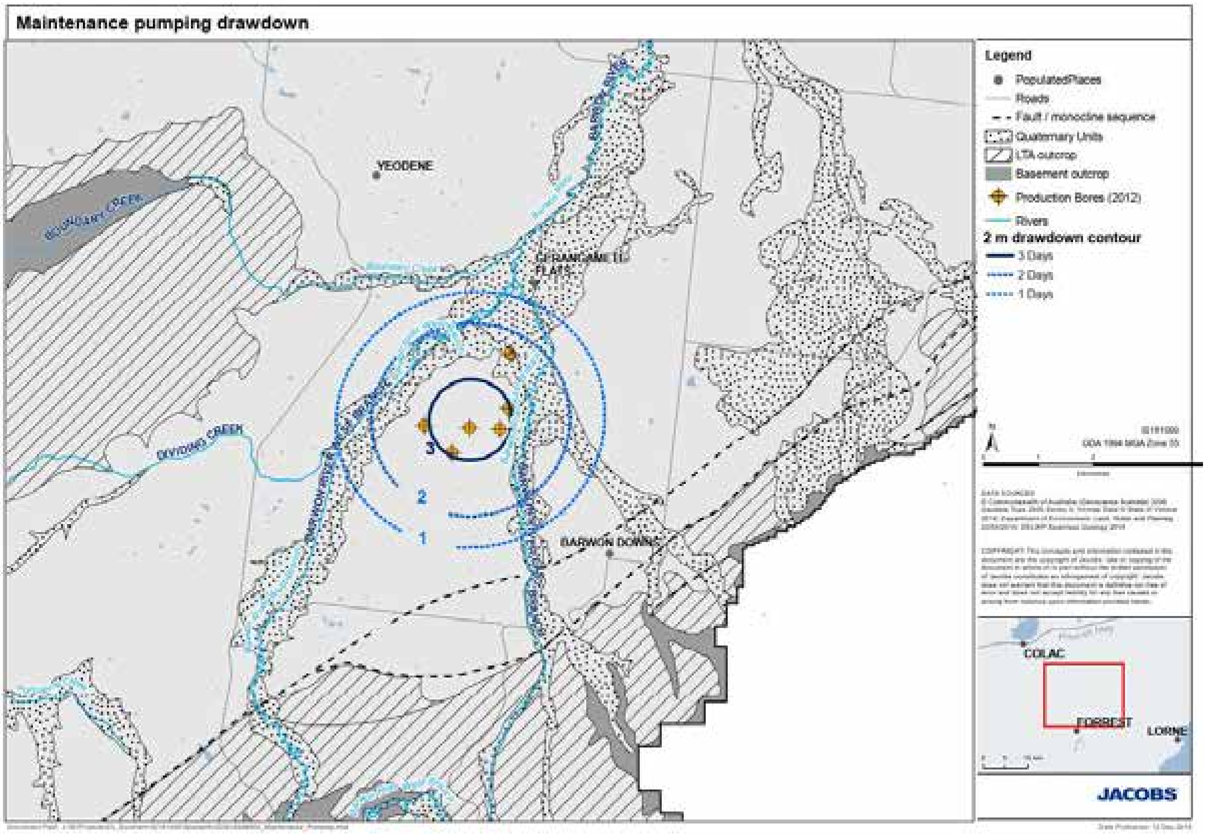


Figure 53: Drawdown contours 1 day, 2 days and 3 days after 10th maintenance pumping period described in Figure 52

The use of the Barwon Downs Borefield for the delivery of emergency water supplies may yield a range of risks to groundwater dependent environmental receptors across the Barwon Downs Graben. These will vary spatially and temporally according to the likelihood of each receptor's connection to groundwater, the degree of drawdown and/or proportion of baseflow reduction realised at each receptor.

Further to this, the amount of groundwater recovery (from historical extraction) leading up to emergency supply, the climatic conditions and the volume of extraction during emergency supply remain unknown (although it is a very low probability that the volume associated with emergency supplies will exceed those previously experienced during the Millennium Drought).

Given this, it is likely that the risks associated with historical groundwater extraction represent an upper estimate of the risks that may be realised during emergency water supply (Jacobs, 2017). These risks have been summarised in Table 14 and range from **Low to High**. According to the Ministerial Guidelines (DELWP, 2015), these risks may be acceptable in the event of special need provided the risks are fully documented.

In the highly unlikely event that an emergency water shortage occurs and emergency extraction is required from the Barwon Downs borefield could only be considered if, Barwon Water obtains a qualification of rights process as per Section s33AAA of the Water Act, 1989. This is a rigorous process overseen by DELWP with final decision to be made by the Minister for Water. The Act clearly sets out the notification procedures applying to qualifications, including what scenarios a qualification of rights will be considered and if granted, conditions that may be imposed on the holder of an entitlement that is qualified.

It should be noted that the risks from historical management of groundwater extraction as documented in Jacobs (2019) are currently being further refined and as it progresses, a review and update of this risk assessment will be undertaken as part of the adaptive management approach.

Table 14: Summary of potential risks to receptors during emergency borefield operation

Receptor	Risk (unmitigated)
Reach 1 Boundary Creek	Low
Reach 2 Boundary Creek	High
Reach 3 Boundary Creek	Medium
Barwon River East (overlying the LTA)	High
Barwon River East (overlying the MTD)	High
Barwon River West (overlying the LTA)	Low
Barwon River West (overlying the MTD)	Medium
The Barwon River (downstream confluence)	High
Dividing Creek	Medium
Gellibrand River	High
Porcupine Creek	Low
Ten Mile Creek	Medium to low
Yahoo Creek	Medium to High
Loves Creek	Medium
Barongarook Creek	Medium
Vegetation	Low to High
Acid sulfate soils	Low to High

Table 15: Summary of risks from activities on the property

Activity Within the next 10 years)	Receptor	Likelihood	Consequence	Risk
Maintenance	Boundary Creek and Big Swamp	Low	Minor	Low
Emergency supply	Boundary Creek and Big Swamp	Low	Minor	Low
Maintenance	Surrounding Environment	Low	Minor	Low
Emergency supply	Surrounding Environment	Low to High	Minor to significant	Low to High

6.2.2 Risk assessment framework

Table 16: Likelihood criteria for rivers and GDE's based on depth to watertable and measure of surface flow (note, GDE's such as ASS and vegetation have been assessed according to depth to watertable)

Likelihood	Description	Ministerial Guidelines		Application for this project
		Measure depth to watertable	Measure surface flow	
Unlikely	A disconnected ecosystem	Depth to watertable > 6 m from surface	>12 months' time lag until 60% of extraction comes from river	River known to be disconnected
Possible	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface	Between 3 – 12 months' time lag until 60% of extraction comes from river.	River flows over regional aquitard
Certain	A well-connected ecosystem	Depth to watertable < 2 m from surface	<3 months' time lag until 60% of extraction comes from river	River flows over regional aquifer

Table 17: Consequence criteria for rivers and GDE's based on measured drawdown and impact on low (note, ASS and vegetation are assessed according to depth to drawdown)

Consequence	Description	Measure Drawdown (m)	Measure % Low (low) flow
Minor	Proposed extraction impacts on natural or current streamflow are small	Watertable decline of <0.1 m	Less than 1% reduction in the low flow rate
Moderate	Proposed extraction impacts measurably on natural or current streamflow	Watertable decline of 0.1 - 2 m	Between 1% and 10% reduction in the low flow rate
Significant	Proposed extraction impacts significantly on natural or current streamflow	Watertable decline of > 2 m	More than 10% reduction in the low flow rate.

Table 18: Consequence criteria for rivers and GDE's based on measured drawdown and impact on low (note, ASS and vegetation are assessed according to depth to drawdown

Connection between receptor class and groundwater		Minor	Moderate	Significant
	Unlikely	Low	Low	Medium
	Possible	Low	Medium	High
	Certain	Medium	High	High

Groundwater Drawdown

6.3 Clause 2.5c: A range of controls and actions that could be practicably carried out to protect and improve the condition of Boundary Creek and Big Swamp and the surrounding environment, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan

This section details the results of a Remediation Options Assessment (ROA) undertaken to identify a preferred remediation option to address impacts caused by the historic management of groundwater extraction for Boundary Creek and Big Swamp.

Figure 54 outlines the process undertaken to develop the remediation options assessment framework. The ROA was built on key findings and outcomes of technical work found in section 9 and incorporated input and feedback from the Remediation Working Group and their nominated technical experts as well as a range of specialists.

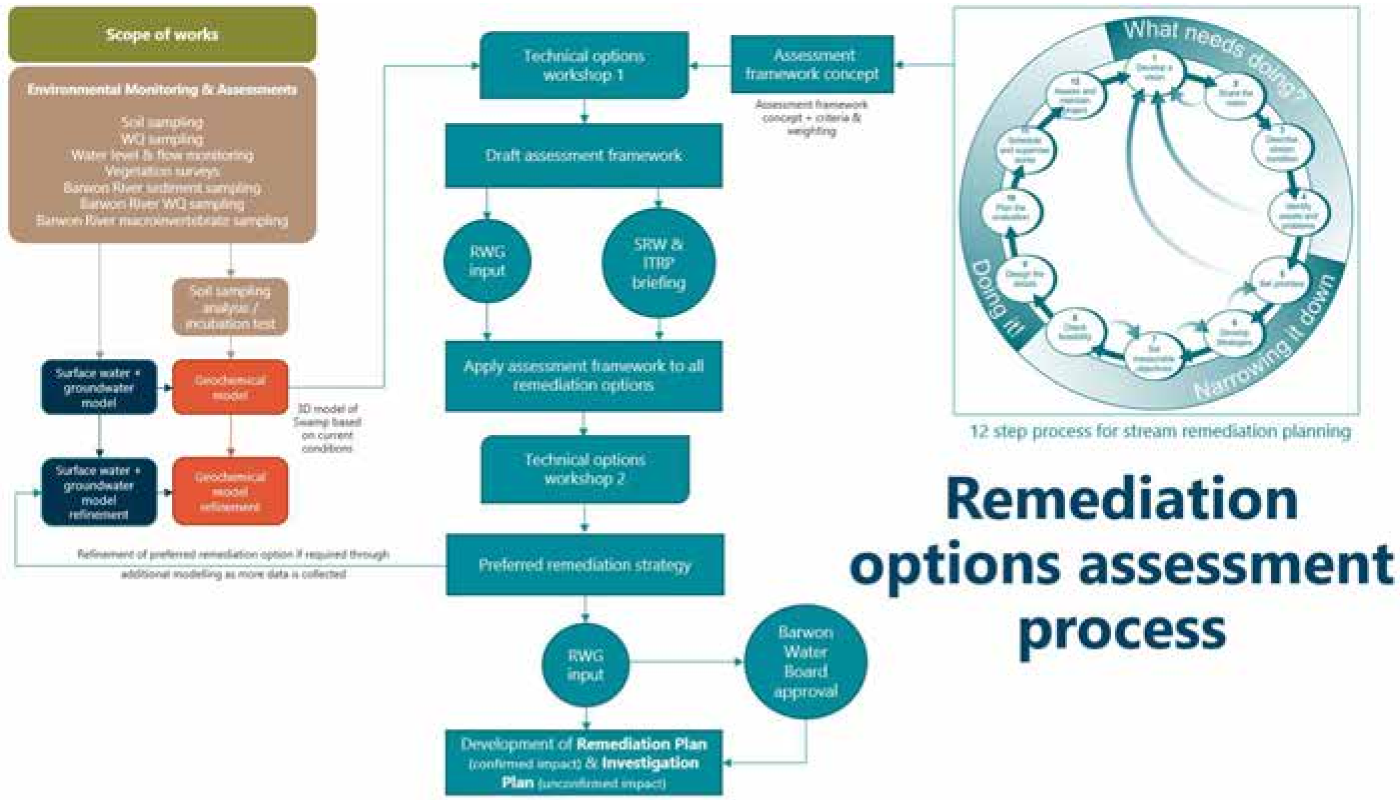


Figure 54: Remediation options assessment process and inputs to select a preferred option

The framework developed to identify the preferred remediation option is summarised in Figure 55 and the steps outlined below. Further detail of each step in the assessment is available in the following sub-sections.

- **Technology identification**
  A comprehensive literature review for initial identification of a broad spectrum of available options for remediation of impacts. The outcome of this task was identification of 17 remediation options.
- **Preliminary screening**
  A screening process to restrict more detailed and site-specific assessment to only those options considered to be potentially feasible for the site. Following preliminary screening, seven remediation options were retained for detailed assessment.
- **Detailed assessment**
  The retained remediation option (developed at a conceptual level) were assessed against a range of weighted criteria and indicators.

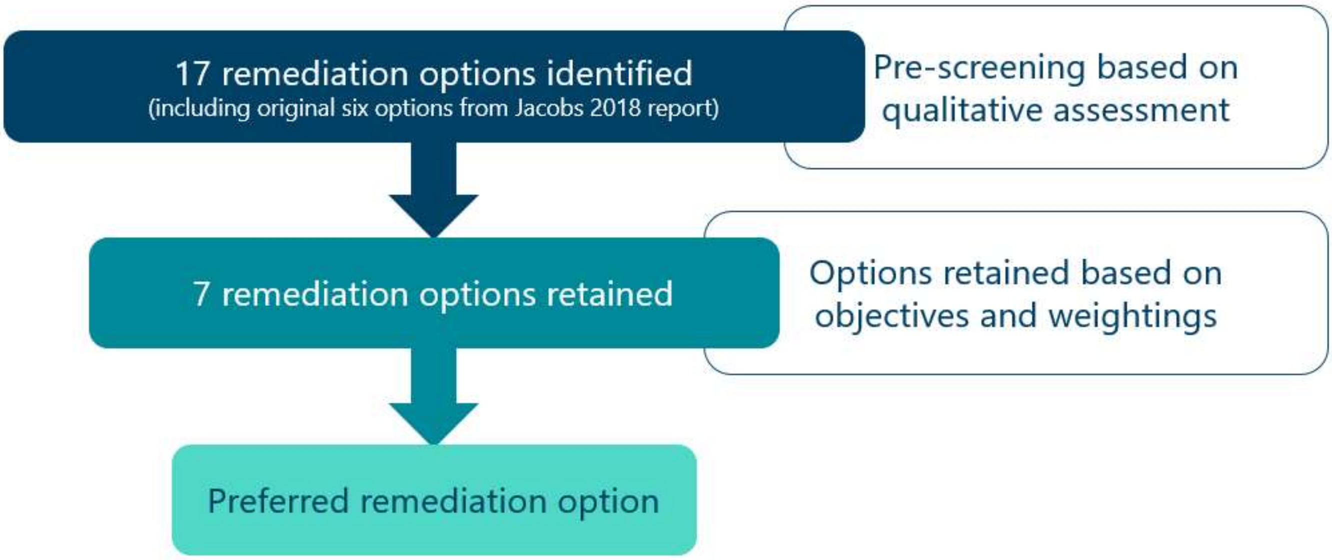


Figure 55: Screening process to select preferred remediation strategy

6.3.1 Identification of potentially applicable remediation options

Table 19 presents a summary of the 17 remediation options identified for preliminary screening and provides the following information:

- The underlying principle of the remediation option.
- A high-level description of possible implementation at the site.
- Advantages and disadvantages of the remediation option.
- A discussion on key issues related to implementation including technical, logistical and regulatory/community considerations.

Table 19: Remediation Options Identified for Preliminary Screening (Options from Yeodene Swamp Study (Jacobs, 2018b) listed first)

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O1	**True 'do nothing'**	Limited further intervention	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018). During the first technical workshop, it was agreed that a true 'do nothing' approach should reflect historical conditions and management practises at the site, which include the following: • Supplementary flow not passed entirely at McDonalds Dam • Continued presence of existing drainage channels across Big Swamp • Water users along Reach 3 of Boundary Creek unable to access water allocation during periods of 'no flow' • Unlikely recovery of groundwater levels in the LTA aquifer to pre-pumping conditions in the short term (i.e. 5 years)	• Lowest financial cost	• High socio-environmental cost • Does not satisfy notice requirements.	• It is unlikely that a 'do nothing' approach will meet any of the project objectives.
O2	**Implementation of contingency measures**	Limited further intervention	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018). During the first technical workshop, it was recognised that a range of contingency measures have been identified to ameliorate some of the issues associated with historical conditions at the site. These contingency measures include: • Minimum supplementary flow of 2 ML/d passed entirely at McDonalds Dam (already implemented) • Infilling of existing drainage channels across Big Swamp (potentially applicable) • Construction of a water pipeline to provide water to users along Reach 3 of Boundary Creek (to be implemented) • No interim pumping from the LTA until a new licence from SRW is obtained.	• Low financial cost • Provides short term relief to water users downstream of Big Swamp.	• High socio-environmental cost • Does not satisfy notice requirements.	• It is unlikely implementation of the planned contingency measures will meet all of the project objectives. • The aim of considering this option is to provide a baseline assessment of future trajectory end environmental outcomes for Big Swamp, Boundary Creek and Barwon River in consideration of a range of existing/potential contingency measures implemented or to be potentially implemented at the site (i.e. in addition to the remediation options).
O3	**Direct treatment of soils with neutralising agents (wetland liming)**	Treatment to neutralise acidity (soil and water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018) and envisages spreading of agricultural lime (or other suitable neutralising agent) over all or a part of Big Swamp to neutralise acidity of the upper soil profile as well as increasing pH and alkalinity of the water leaving Big Swamp and discharging into Boundary Creek. Once the areas requiring treatment and the treatment rate (expressed as mass of neutralising agent per unit area) have been evaluated, a variety of implementation methods are possible, including terrestrial applications and aerial methods.	• Effective duration longer compared to in-stream liming methods; in some cases, effects last 10 to 20 years • Lower amount of aluminium is exported to streams. May have less aluminium precipitate on stream bottom compared to other stream liming methods.	• Clearing of vegetation for construction of access tracks in case of terrestrial application over the entire swamp area • Impacts of the neutralising agent on the terrestrial and aquatic ecosystems affected by the treatment • Grain diameter of the neutralising agent must be evaluated to minimise potential for downstream transport during high rainfall events, which may cause uneven coverage of the treatment area • Metal precipitation in Boundary Creek associated with increased surface water pH.	• Terrestrial applications (i.e. using truck mounted equipment, pressure hose for slurry applications or manual spreading) are likely to be challenging because of access constraints and soft consistency of the soil across Big Swamp. • Aerial application by helicopter is likely to overcome some of the logistical constraints related to terrestrial applications, however, will incur increased costs. • This technology is generally more effective when application of the neutralising agent is targeted at water discharge areas (i.e. areas of high groundwater levels during periods of high rainfall) compared to uniform application over the entire swamp area. • Compared to surface water liming, this technology generally provides more sustained treatment timeframes, requiring less frequent applications. • Because dissolution and penetration of the neutralising agent is associated with rainfall (amongst other factors), this method is generally less suitable

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
						for dry and severely acidified environments.
O4	**Oxic (aerobic) limestone drain (OLD)**	Treatment to neutralise acidity (water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018) and envisages construction of an open drain channel filled with limestone (or other suitable material) downstream of Big Swamp to improve quality of Boundary Creek water (i.e. increase pH/alkalinity and decrease dissolved metals concentration). Key design parameters of OLDs are mass and size of the limestone aggregate, slope of the drain and water residence time (in the range of several hours). The slope of the drain is inversely proportional to residence time, however higher slopes increase OLDs' efficiencies by limiting the potential for metal precipitation on the surface of the aggregate (armouring). Armouring reduces limestone pore space and surface area, decreasing the limestone dissolution rate and acid neutralising capacity.	• Low cost • Simple implementation	• Armouring of the alkaline materials caused by metal precipitation has the potential to be detrimental to efficiency and longevity of the limestone drain. • Ongoing maintenance is required to ensure treatment efficiency is maintained over time. • Depending on quality (i.e. pH, metal and anion/cation concentrations) of the water leaving the OLD, a settling pond may be required for collection of precipitates prior to discharge in Boundary Creek.	• Construction of an OLD (and potentially settling pond) with adequate slope and residence time to treat Boundary Creek water is likely to impact on the following: – Hydrological and hydrogeological regime of Boundary Creek (Reach 2/Reach 3) and Big Swamp. – Amenity and natural environment of Big Swamp and Reach 3 of Boundary Creek.
O5	**Dilution of acidic discharge**	Treatment to neutralise acidity (water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018) and envisages provision of additional water volumes (i.e. in addition to the supplementary flow of 2 ML/d released upstream of McDonalds Dam as part of the contingency measures) to improve water quality in Boundary Creek. Implementation of this option will require construction of a dedicated water infrastructure and identification of a sustainable source to supply water in the long term (this option does not address generation of acidity in Big Swamp, which will continue). The Yeodene Swamp Study (Jacobs, 2018) assumes that the additional water volumes will be delivered through McDonalds Dam. However, to increase effectiveness and minimise potential side effects to natural environments downstream of the release point, the additional water volumes could also be delivered downstream of Big Swamp (i.e. in the upper reaches of Reach 3 of Boundary Creek). While not mentioned in the Yeodene Swamp Study (Jacobs, 2018), the additional water may also be amended with neutralising agent to increase pH/alkalinity and therefore volumetric requirements.	• Relatively simple implementation	• Geochemical modelling conducted as part of the Yeodene Swamp Study (Jacobs, 2018) indicates that, using low alkalinity additional water, significant volumes are required to improve the quality (i.e. reduction of metal concentration and increase of pH) of Boundary Creek water. • The water volumes required to achieve dilution of acidic discharge are not available in the region and could potentially trigger water management issues in other parts of Victoria. • Delivering of significant volumes of additional water is likely to have significant impacts on the hydrology, hydrogeology and natural environments downstream of the delivery point, which will require detailed assessment to support detailed design and implementation of this option.	• Addition of neutralising agents to the additional water (by construction of an automated dosing station) is likely to reduce the volumes of water required to improve water quality at Boundary Creek. • A settling pond will be needed downstream of the water delivery point to capture metal precipitates.
O6	**Water flow diversion and Big Swamp isolation**	Reduce export of existing acidity	This option was included in the Yeodene Swamp Study (Jacobs, 2018) and envisages isolation of Big Swamp (source of acidity) and diversion of Boundary Creek flow so that the swamp is by-passed and transport of acid drainage to Reach 3 of Boundary Creek is minimised. Implementation of this option would require building a channel so that water flowing into Boundary Creek does not disperse into Big Swamp, as well as construction of a series of impermeable structures to prevent groundwater within the alluvial swamp sediment to discharge into Reach 3 of Boundary Creek. Additional water retention structures may be also required to minimise risks of acid flushes from Big Swamp into Reach 3 of Boundary Creek.	• This option could be effective in improving water quality in Boundary Creek by breaking the pathway between source (Big Swamp) and downstream environments	• This option is likely to have significant impacts on the hydrology, hydrogeology and natural environments of Boundary Creek (Reach /Reach 3) and Big Swamp, which will require detailed assessment to support detailed design and implementation of this option. • Implementation of this option, in the absence of contingency measures, has the potential to worsen intensity of 'acid flushes' associated with drying and wetting cycles. In addition, dryer conditions across Big Swamp will increase fire risks.	• This option is likely to severely impact on the natural environment of Big Swamp, which is likely to dry out further and continue to generate acidity. It is therefore considered that this option is unlikely to gain stakeholder's approval unless: – A water retention system and artificial water recharge are implemented so that surface water and groundwater levels can be maintained at acceptable conditions across Big Swamp; – It is demonstrated to be the only alternative to manage acid discharges to Boundary Creek and Barwon River; – The community agrees that Boundary Creek and Barwon

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
						River are of higher value compared to Big Swamp.
O7	**Flooding of Big Swamp (natural anaerobic wetland) and managed groundwater levels**	Treatment to neutralise acidity (water) and prevent (further) oxidation	This option was included in the Yeodene Swamp Study (Jacobs, 2018) and envisages flooding of Big Swamp to create permanently waterlogged areas where microbially mediated iron reducing and sulfate reducing reactions have the potential to increase alkalinity, raise pH and remove dissolved metals by precipitation. For sulfate reduction reactions to occur, the following conditions must be realised in the re-flooded portions of Big Swamp: • A permanent water coverage having enough depth to maintain generally anaerobic conditions within the water column • Presence of a bioavailable organic carbon source (electron donor) • pH between 5 and 8 • Presence of sulfate and low concentration of competing electron acceptors such as nitrate (NO_3^-), manganese (Mn^{4+}) and ferric iron (Fe^{3+}). Implementation of this option envisages the following steps: • construction of water retention structures (likely to be located at the downstream side of Big Swamp) to realise a permanent water coverage across a significant portion of Big Swamp • infilling of existing drainage channels across Big Swamp to assist with water retention • supply of additional water volumes to achieve the required permanent water coverage • supply of additional organic carbon source (and potentially sulfate) in case of deficiencies of these elements in the natural environment. In addition to promoting favourable geochemical conditions to neutralise acidity, this option would aim to maintain or increase groundwater levels in the Big Swamp alluvium aquifer to prevent or minimise further oxidation of ASS sediments.	• Reversal of iron sulfides oxidation processes • Minimise further oxidation • Relatively low cost • Barrier installation is a proven technology and can be supported by adequate modelling	• The delivery of supplementary flow to maintain waterlogged conditions and higher groundwater levels will result in increased surface water flow in Big Swamp, which has the potential to enhance mobilisation and downstream transport of acidification by-products accumulated in near-surface sediments. • Preliminary results from laboratory incubation work from Monash University and GHD geochemical modelling suggest that there is a risk that the soluble ferrous iron generated under reducing conditions will not precipitate in Big Swamp and will be transported downstream in Boundary Creek. • Visual amenity will be impacted because vegetation not tolerant to higher groundwater levels or permanently waterlogged conditions is likely to retreat or die following inundation of Big Swamp.	• Groundwater and surface water modelling are required to assist in assessment of the following technical aspects associated with this option: – additional water volumes to be delivered to Big Swamp to achieve the required minimum groundwater levels – extent and location of the water retention structures required to maintain groundwater at the desired levels – potential impacts to hydrological and hydrogeological regime of Boundary Creek upstream and downstream of Big Swamp • Geochemical modelling is required to assist with assessment of nature and rate of reactions that may be triggered by inundation of Big Swamp and the potential for mobilisation of acidity (both existing and as a consequence of iron reduction).
O8	**Soil excavation/ treatment and rehabilitation**	Treatment to neutralise acidity (soil)	This option involves excavation and removal of the oxidised ASS sediments within Big Swamp, which are treated (or disposed) according to EPA Victoria ASS management guidelines. Construction of access tracks and significant removal of vegetation will be required to implement this option. The excavation is likely to be progressed as separate cells to minimise potential exposure of non-oxidised sediments to oxygen. Following removal of the oxidised sediments, lime would be added at the base of the excavations to neutralise potential future acidity generation and then the excavation would be backfilled with suitable imported fill material. After remediation and backfilling, the site would be landscaped and revegetated to resemble the original character of Big Swamp.	• Could effectively remove the source of acidic discharges into Boundary Creek and Barwon River • The extent of excavation areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.	• The soft consistency of the soil across Big Swamp is likely to pose significant logistical constraints to implementation of this option. • Irrespective of the extent of excavations, implementation of this option will severely impact on the natural environment of Big Swamp and the hydrological/ hydrogeological regime of Boundary Creek. • This option is the less likely to achieve any rehabilitation of the site to its original values. However, removal of acid generating sediments within Big Swamp is likely to be an effective solution to reduce acid impacts to the waters of Boundary Creek and Barwon River. • Based on a comparison of aerial images captured since 2010 (when the majority of Big Swamp vegetation was severely affected by a fire), it appears that low lying vegetation would re-establish within 3 to 5 years after re-planting.	• This option is the least preferred approach based on EPA Victoria ASS management hierarchy. • It is considered that this option is unlikely to gain stakeholders approval, **unless**: – It is demonstrated that removal of oxidised sediments is the only alternative to manage acid discharges to Boundary Creek and Barwon River; – The community agrees that Boundary Creek and Barwon River are of higher value compared to Big Swamp; – Remediation of Big Swamp to a satisfactory 'engineered end-point' as opposed to rehabilitation to some of its original values is an acceptable outcome for the project.
O9	**Soil mixing**	Treatment to neutralise acidity (soil)	This option involves the use of a large diameter (one to three metres) hollow-flight auger fitted with special mixing 'paddles' (or other suitable	• Compared to surface liming, this option has the potential to achieve	• The soft consistency of the soil across Big Swamp is likely to pose	• If applied on a large scale, this option will severely impact on the

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
			device) to achieve mixing of a neutralising agent with the oxidised sediments in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require to be rehabilitated through landscaping and planting of vegetation.	effective neutralisation of oxidised ASS sediments at depth. • The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.	significant logistical constraints to implementation of this options.	natural environment of Big Swamp (refer to Option 8).
O10	**Alkaline slurry injection**	Prevent (further) oxidation and treatment to neutralise acidity (soil)	This option involves injection of a slurry composed of alkaline and impermeable materials to minimise oxygen infiltration and neutralise acidity. Depth of application would be typically to the top of the unoxidized ASS in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require rehabilitation through landscaping and planting of vegetation.	• Compared to surface liming, this option has the potential to achieve effective neutralisation of oxidised ASS sediments at depth. • The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.	• Same considerations as Option 9 'Deep soil mixing' • Additionally, soil heterogeneity could limit the ability to achieve uniform distribution of the injected amendments.	• If applied on a large scale, this option will severely impact on the natural environment of Big Swamp (refer to Option 8).
O11	**In-stream limestone sand**	Treatment to neutralise acidity (water)	This option involves placement of limestone sand (or other suitable neutralising agent) directly in the streambed of Boundary Creek. The sand is carried into the stream during high flow periods where it dissolves releasing alkalinity and increasing pH.	• No maintenance, simple, and relatively inexpensive.	• Water quality improvement may be inconsistent. • Effectiveness diminishes with time. Limestone sand must be applied repeatedly, usually at least once per year. • Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH.	• Unlikely to be effective, considering the limited flow and gentle slopes of Boundary Creek, limiting the potential for downstream transport of the neutralising sand.
O12	**In-stream treatment system**	Treatment to neutralise acidity (water)	This option involves installation of an active or semi-active treatment system to treat water quality in Reach 3 of Boundary Creek. The system would be installed at the downstream end of Big Swamp and will comprise a range of equipment (i.e. tanks, mixers, pumps) to dose dry or liquid chemicals in the Boundary Creek water to increase alkalinity/pH and remove metals (by precipitation and settling). Depending on system configuration and design parameters, precipitation of metals could be achieved in a settling pond or above ground clarifiers.	• Compared to passive systems, active systems are better suited to manage high acid loads, high flows and variability in acid loads. They also require a smaller footprint compared to passive systems.	• Disadvantages of active systems include – higher capital and ongoing costs; – infrastructure requirements (power, water, access roads, etc.); – potential generation of large volumes of low-density sludges requiring management; – potential acquisition of land to operate system; – effects on amenity (noise, visual impacts, etc.)	• Semi-active systems could be used to treat Boundary Creek water in-stream, and off-set some of the disadvantages associated with fixed plant systems.
O13	**Limestone diversion wells**	Treatment to neutralise acidity (water)	This option envisages that a portion of the flow in Boundary Creek downstream of Big Swamp is diverted into a series of limestone-filled wells to increase alkalinity/pH and precipitate metals. Following treatment, the flow is diverted back into Boundary Creek.	• Typical pH increases are about ½ to 2 units during average flows. • Multiple diversion wells can be installed to increase effectiveness.	• Typically, this option is suitable for treating small flows and likely to fail in cases when a stream has a variety of flow regimes during the year. • High maintenance (weekly to biweekly) is required. • Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH.	• Unlikely to be suited for site conditions.
O14	**Anoxic limestone drains (ALD) and settling pond**	Treatment to neutralise acidity (water)	This option envisages construction of a buried drain lined with impermeable material, filled with limestone (or other suitable neutralising agent) and covered by impermeable materials.	• Increases efficiency of other treatment types. For example, anoxic limestone drains can be used to pre-treat water prior to entering a wetland system.	• Water pre-treatment may be required prior to the ALD to remove dissolved oxygen and generate reducing conditions to promote conversion of	• High concentration of Al (i.e. >25 mg/L) in the water requiring treatment will form floc in the ALD, progressively reducing its permeability and efficiency.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
			The water seeping downstream of Big Swamp is diverted into the limestone (to maintain saturated conditions and anoxic conditions) where dissolution of the limestone increases alkalinity and pH. Low oxygen conditions in the ALD would prevent precipitation of metals and armouring issues. The water leaving the ALD is then directed into an aerobic settling stage where metals are precipitated and removed from the water. Removal of metal precipitates (sludges) is required at periodic intervals.	• ALDs can also be used as a post-treatment system to add additional alkalinity.	ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}). • The infrastructure required for precipitation and settling of metals (i.e. settling tank, engineered section of Boundary Creek or settling pond) is likely to impact on the natural environment of Big Swamp and Reach 3. • Anoxic condition in the drain are likely to reduce issues associated with iron armouring of alkaline materials. • Variable alkalinity output. • Effluent pH difficult to maintain over time. • Treatable effluent limited to low oxidised metal concentrations (aluminium and ferrous iron) and low dissolved oxygen.	
O15	**Constructed aerobic wetland**	Treatment to neutralise acidity (water)	Construction of an aerobic wetland to remove metals by oxidation and hydrolysis.	• Relatively inexpensive • Lower maintenance than active treatment systems. • Can improve amenity.	• Metal removal efficiencies vary because pH is seldom constant. • pH decreases as metals are removed. • Land area required must be large. • Limited useful life. Substrate becomes saturated with metals and must be replenished or replaced. Most are constructed within a 15-to 25-year lifetime.	• This option is generally suited for water streams that are slightly alkaline, with a pH greater than 5.5 and contain low to moderate concentrations of metals. • These conditions are unlikely to be realised by the Boundary Creek waters downstream of Big Swamp.
O16	**RAPS (reducing and alkalinity producing systems)**	Treatment to neutralise acidity (water)	Construction of a vertical flow anaerobic wetland to increase alkalinity, raise pH and remove metals by precipitation of insoluble hydroxides, carbonates and sulfides. The anaerobic wetland comprises an organic-rich substrate at the top, a layer of limestone at the bottom and a drainage system. The wetland is constructed within a watertight basin and water flowing from the top across the organic layer and the limestone layer is collected by the drainage system and released into an aerobic settling pond. Alkalinity is generated by microbial process in the organic layer (if sulfate is available) and through dissolution of the limestone. An aeration and settling stage may be required prior to discharge to increase oxygen and promote precipitation of residual dissolved metals.	• Area required for RAPS is relatively small compared to other passive systems • Treat poorer quality water compared to passive systems.	• Drainage system limited by high concentrations of aluminium and ferric iron. • Noxious odour (hydrogen sulfide) produced in vicinity of the system. • Risk of people or animal drowning.	• The construction of an anaerobic wetland is likely to impact on the natural environment of Big Swamp and Reach 3.
O17	**Permeable reactive barrier**	Treatment to neutralise acidity (groundwater)	Construction of permeable reactive barriers in Big Swamp (perpendicular to groundwater flow direction) to intercept and treat acidic groundwater.	• Relatively low maintenance and installation costs. • Ability to treat a range of contaminants.	• Construction of a permeable reactive barrier is likely to impact on the natural environment of Big Swamp. • Clogging and periodic removal of barrier material.	• The ability of permeable reactive barriers to ameliorate water quality in Boundary Creek depends on the acid load associated with groundwater.

6.3.2 Technology screening

Based on the information presented in Table 19, the following remediation options have **not been carried forward** for detailed assessment:

- **O1 - Do nothing**
  The main reasons for removing this remediation option is the likely inability of meeting any of the project objectives based on magnitude and inferred persistence of acid generating processes within Big Swamp. This option would also fail to meet the requirements of the Section 78 Notice.

- **O2 - Contingency measures**
  This option comprises implementation of various contingency measures including efficient delivery of a supplementary flow of 2 ML/d to Boundary Creek downstream of 'McDonalds Dam', infilling of key drainage lines across Big Swamp and construction of a water pipeline to water users along Reach 3 of Boundary Creek. Because the contingency measure of most relevance to the ROA (i.e. provision of 2 ML/d supplementary flow) has already been implemented, this option is removed from detailed assessment and used as a baseline to compare the other options.

- **O4 - Oxic limestone drain**
  This option was removed because the concentrations of iron and aluminium in the water requiring treatment are outside of the recommended range for this technology to be suitable. Armouring of the limestone aggregate caused by metal precipitates is likely to impact on the long-term effectiveness of the OLD. The relatively gentle slopes of the site do not provide favourable conditions for installing the OLD with the recommended 20% gradient that is indicated as one of the main design factors to limit the severity of armouring issues.
  In addition, an OLD constructed in accordance to the recommended design water retention time of 3 hours, will require approximately 310 m^3 of limestone aggregate (assuming a porosity of 40%) for each ML/d of water requiring treatment, equivalent to an open channel 5 m wide, 1 m deep and 60 m long. It is considered that such a structure will impact on the visual amenity of the area downstream of Big Swamp.

- **O5 - Dilution of acidic discharges**
  This option is removed because of the large water volumes (estimated by Jacobs in the range of 60-250 ML/d depending on flow conditions) required to achieve effective dilution of acidity and acidity impacts in Boundary Creek. It is considered that sourcing and delivery of such volumes of dilution water would be impracticable, unlikely to be accepted by the authority (dilution for management of contamination is usually considered an unacceptable management practice by EPA Victoria) and a risk of impacting on water availability in other parts of Victoria.

- **O6 - Water flow diversion and Big Swamp isolation**
  This option is removed because of the technical challenges associated with providing an effective hydraulic barrier to prevent acidic discharges from Big Swamp to the surrounding receiving environments and the additional impacts to Big Swamp caused by further declines of surface water and groundwater water levels that are likely to eventuate as a result of decreased inflows into the swamp. The progressive acidification of Big Swamp and the drier environment caused by hydraulic isolation will also increase fire risk and potential for episodic and high intensity 'acid

flushes' in case the integrity of the barrier is compromised during high rainfall events. It is also unlikely that this option would gain regulatory approval and/or community support.

- **O10 – Alkaline slurry injection**
  This option is removed because a generally equivalent option (soil mixing) has been retained for detailed assessment. Soil mixing was retained over slurry injection because it is considered to be easier to implement in consideration of the high liming rates required to neutralise ASS in Big Swamp, the low hydraulic conductivity of the majority of the alluvium sediments in Big Swamp and the potential for preferential pathways to affect homogeneity of treatment.

- **O11 - In-stream limestone sand**
  This option has been removed because during periods of low flow the limestone sand is unlikely to be transported downstream in Boundary Creek, resulting in low consistency of this technology in managing water quality impacts. In addition, a generally equivalent option (active treatment) has been retained for detailed assessment which has the advantage of providing more consistent outcomes in terms of treatment efficient and water quality results.

- **O13 - Limestone diversion wells**
  This option has been removed because the high concentrations of iron and aluminum in the water requiring treatment are outside of the recommended range for this technology to be suitable. In addition, limestone diversion wells require a very high O&M intensity (i.e. weekly) to maintain system efficiency and replacement of the limestone aggregate.

- **O14 - Anoxic limestone drain**
  This option has been removed because the concentrations of iron and aluminum in the water requiring treatment are outside of the recommended range for this technology to be suitable. In addition, the high retention times required for effective limestone dissolution (in the range of 13 hours) generally require construction of large structures.
  For example, an ALD designed to treat 4 ML/d of impacted water would typically be 1.5 m deep (1 m of limestone and 0.5 m of impermeable cover), 5 m wide and 1,000 m long (assuming limestone porosity of 40%). It is considered that construction and ongoing maintenance of such a structure downstream of Big Swamp would be impracticable.

- **O17 - Permeable reactive barrier**
  This option has been removed because the surface water and groundwater modelling results provided by Jacobs appear to indicate that groundwater discharges into Reach 3 of Boundary Creek account only for a small proportion of the total flow (i.e. less than 0.3 ML/d), and therefore groundwater transport does not significantly contribute to acidic impact to Boundary Creek.

The following remediation options were retained for detailed assessment:

- O3 - Wetland liming
- O7 - Flooding of Big Swamp and managed groundwater levels
- O8 - Soil excavation, disposal and rehabilitation
- O9 - Soil mixing
- O12 – Active treatment system
- O15 - Constructed aerobic wetland. This technology would not treat impacted water from Big Swamp, however is has been retained because it could be uses as a final step of a treatment train including other remediation options
- O16 – RAPS

6.3.3 Concept designs of retained remediation options

Additional detail on concept designs for the seven retained remediation options included the following considerations:

- Review of the principle of operation of the selected remediation option.
- Envisaged approach for implementation approach.
- Assessment of expected technology performance.
- Inputs from groundwater/surface water and geochemical modelling works by Monash University, Jacobs and GHD (where relevant).
- Estimate of relative costs for technology implementation.
- Assessment of the technology ability to meet the project objectives.

A summary of the above considerations for each remediation option can be found in Table 20 with further detail in section 9.

6.3.4 Remediation Plan for Boundary Creek and Big Swamp

The Boundary Creek and Big Swamp Remediation Plan outlines an adaptive approach to improve flows and water quality, as well as vegetation and ecology in Boundary Creek and Big Swamp so that downstream impacts to the Barwon River are minimised.

Actions to be implemented for ‘managed groundwater levels and flooding’ include the combination of:

- **continued delivery of a supplementary flow** to meet the objective of maintaining minimum flows in Reach 3 of Boundary Creek all year round (recording a flow of at least 0.5 ML/day at the Yeodene stream gauge).
- **construction of a series of hydraulic barriers** to effectively distribute flows across the swamp to allow for a greater area to be inundated and increasing surface water flow connectivity across Big Swamp and preventing progressive water table decline in the perched alluvial aquifer.
- **infilling the existing fire trenches** and agricultural drain at the eastern end of the swamp to allow the swamp to retain more water over the winter months.

- **preventing the encroachment of dry vegetation classes** (e.g. Swamp Gum) in Big Swamp to provide suitable conditions for wetland species to recolonise disturbed areas.
- **ongoing data collection** to inform the adaptive monitoring approach.
- **Additional data collection and testing to inform feasibility of the contingency options** ('aerial liming', 'in-stream treatment' and 'limestone sand'). This is particularly important for the 'in-stream treatment' option in consideration of its higher complexity and financial implications. Subsequent refinement of the geochemical model will inform the feasibility, risks and trade-offs associated with the need for additional treatment as a contingency to manage low pH events while the re-wetting strategy takes effect.

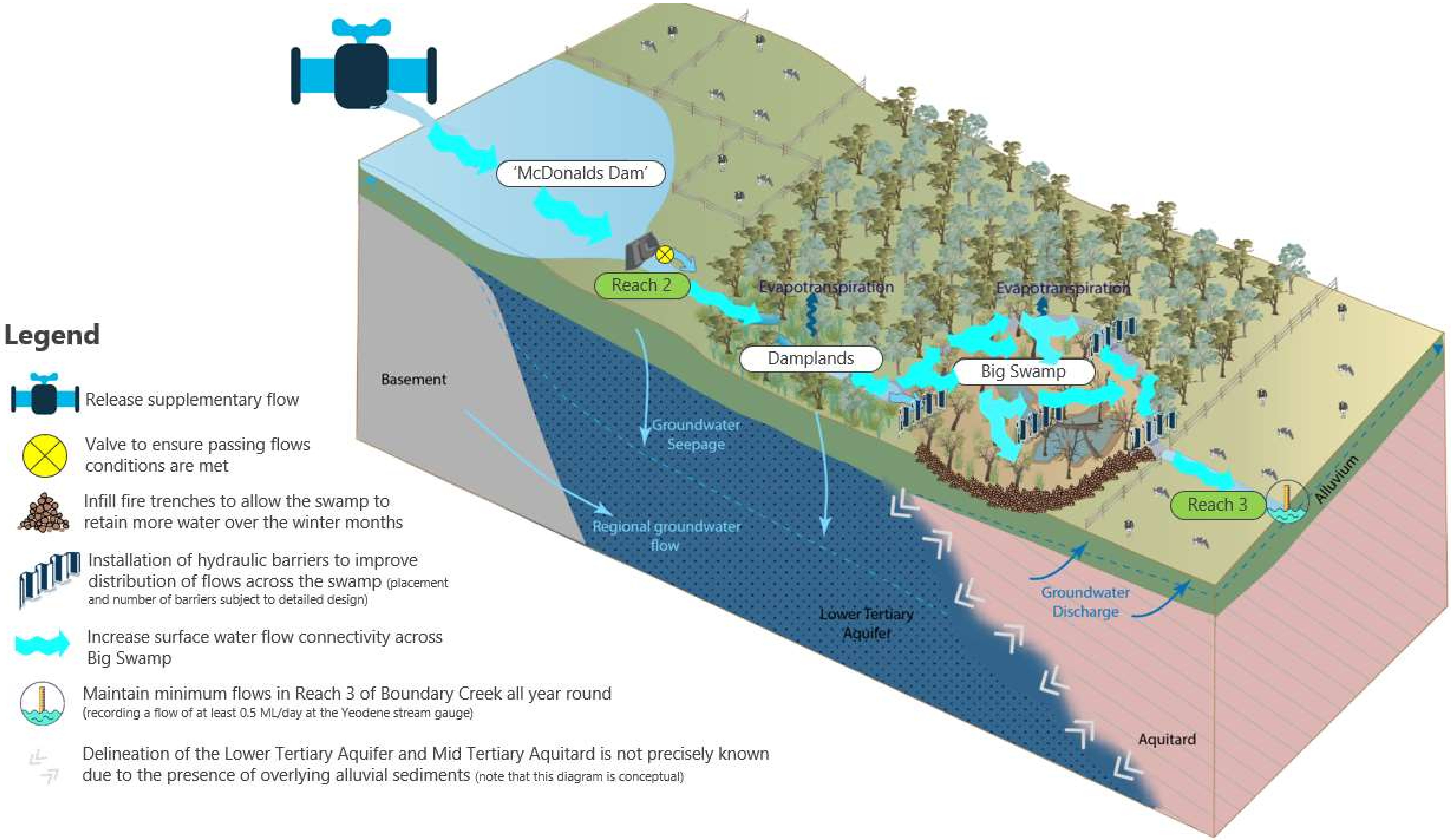


Figure 56: Remediation plan to rewet the swamp (concept level)

6.3.5 Technology scoring, ranking and weighting

Ranking of each indicator for the shortlisted remediation options, based on information provided in the previous sections, is presented in Table 21.

The score for each category has been totaled and normalised before a total score is calculated. The total score for each category has been set at 50, with a potential total score of 300 (six categories). This provides an unweighted score, where each category has equal weighting. The total category scores, total unweighted score and ranking of technologies is presented in Table 22.

The seven remaining options were assessed against weighted criteria under the categories of; Technical, Logistical, Financial, Stakeholders, Timing and Sustainability. The weighted score and ranking are also shown in Table 22 ‘Managed groundwater levels and wetland flooding’ ranked highest in both the weighted and unweighted assessments. The ‘aerobic wetland’ option and ‘in-stream dosing’ rank equal third in the unweighted assessment, but when technical aspects are prioritised in the weighting, the ‘aerobic wetland’ option drops to fourth, with ‘in-stream dosing’ scoring much higher and ranking third.

Table 20: Summary of concept design considerations for the seven retained remediation options

Option	Maintain minimum groundwater levels in Big Swamp	Control acid release	Manage secondary precipitates	Maintain Boundary Creek minimum flow	Improve vegetation	Reduce fire risk
O3 - Wetland liming	No effect on groundwater levels is expected from implementation of this technology	The ability of the technology to reduce acid releases into Boundary Creek will depend on several factors, including the rate of lime dissolution compared to the rate of acid production, the potential for armoring of lime surfaces, rainfall patterns and the parameters (i.e. total mass, distribution, etc.) of each lime application. When mobilisation of existing and retained acidity in the soil profile occurs at a higher rate than lime dissolution rate, pH increase in Boundary Creek surface waters is likely to be limited. However, as the existing and retained acidity are flushed from the system pH is likely to start to increase because the lime dissolution rate is likely to be higher than ASS oxidation rate (GHD, 2019)	Formation of iron/ aluminum precipitates following pH increase is likely. These precipitates, if not captured within Big Swamp, have the potential to be carried downstream and settle in Boundary Creek and/or Barwon River.	No effect on surface water flows is expected from implementation of this technology.	The effect on vegetation is unknown, although it is possible that aerial application of lime could cause harm to vegetation that has adapted to acidic conditions.	No effect on fire risk is expected from implementation of this technology
O7 - Flooding of Big Swamp and managed groundwater levels	Based on modelling results, when a 2 ML/d supplementary flow is delivered, it does not appear that groundwater levels can be significantly increased (eastern end of the swamp) or maintained (central and western parts of the swamp) with or without the presence of a hydraulic barrier at the eastern end of the swamp. Conversely, when a 20 ML/d supplementary flow is delivered, groundwater levels appear to remain steady or increase across most of the swamp. Under this higher supplementary flow scenario, the influence of a hydraulic barrier at the eastern end of the swamp appears localised. By extrapolating these results, it is considered that a combination of practically achievable supplementary flows (i.e. in the range of 5ML/d) and strategically placed hydraulic barriers is likely to be effective in maintaining minimum groundwater levels across targeted areas of Big Swamp. Additional surface water and groundwater modelling work will be required to progress design of this option and to support cost-benefit analysis.	This will depend on the volume of supplementary flow delivered, the proportion of Big Swamp that will be permanently inundated and the ability of the natural system to establish iron reducing and sulfate reducing conditions. GHD (2019) indicates that initially the delivery of supplementary low is likely to increase release of actual and retained acidity, which will then progressively abate over time as the establishment of higher groundwater levels will minimise further aerobic oxidation of ASS sediments. The Monash University incubation testing also indicate that, even if the system is unlikely to progress to sulfate reducing conditions, iron reducing conditions have also the ability to neutralise acidity, within a timeframe estimated in the range of 1-2 years.	The increase soluble ferrous iron generated by reducing conditions in the permanently flooded portions of Big Swamp has the potential to be exported to downstream receiving environments (i.e. Boundary Creek and Barwon River) generating acidity and iron precipitates. The magnitude of this secondary effect depends on several factors and ongoing monitoring will be required to evaluate severity of potential impacts. However, the mass associated with this is unlikely to be significant in comparison to the actual and retained acidity within the swamp. Recent results from the Monash University testing indicate a reduction of soluble iron after 128 days of incubation, indicating the potential for the iron to be retained in Big Swamp rather than exported downstream. Contingency measures (such as construction of an intermediate settling pond between Big Swamp and Boundary Creek) should be included as part of the remediation action plan to manage the risk of formation of acidity and secondary precipitates in Boundary Creek.	Based on surface water modelling results, release of supplementary flow upstream of McDonalds Dam in the range of 2 ML/d appears to be adequate to sustain a flow in the range of 1 ML/d in Boundary Creek at the Yeodene gauge.	The Big Swamp ecological assessment (Eco Logical, 2019) indicates creation of permanently inundates areas across Big Swamp will cause complete loss of vegetation. This negative side effect will be partially offset by improved vegetation in areas of increased surface flow and higher groundwater levels. To mitigate loss of vegetation, Eco Logical suggests that hydraulic barriers are realised so that a dynamic regime of inundation and drying is established over the year. It is noted that, while a seasonal regime would be beneficial for vegetation, it may not be practical to implement and also have the adverse consequences of increasing acid release downstream of Big Swamp and limit the ability to promote reducing conditions required for neutralisation of acidity.	Increasing groundwater levels and maintaining a more permanent surface water coverage across Big Swamp is likely to reduce fire risks, depending on the portion of the Big Swamp that will be permanently inundated.
O8 - Soil excavation, disposal and rehabilitation	No effect on groundwater levels is expected from implementation of this technology.	Because of the limited extent of ASS volumes that can be excavated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.	No effect on secondary precipitates is expected from implementation of this technology.	No effect on surface water flows is expected from implementation of this technology.	Vegetation across 'hot spots' targeted for excavation will require clearing prior to the works. Replanting will be required after remediation with reestablishment of vegetation	No effect on fire risk is expected from implementation of this technology.

Option	Maintain minimum groundwater levels in Big Swamp	Control acid release	Manage secondary precipitates	Maintain Boundary Creek minimum flow	Improve vegetation	Reduce fire risk
					expected within a few years from completion of the site works.	
O9 - Soil mixing	No effect on groundwater levels is expected from implementation of this technology.	Because of the limited extent of ASS volumes that can be practicably treated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.	No effect on secondary precipitates is expected from implementation of this technology	No effect on surface water flows is expected from implementation of this technology	Vegetation across 'hot spots' targeted for treatment will require to be cleared prior to the works. Replanting will be required after remediation with reestablishment of vegetation expected within a few years from completion of the site works.	No effect on fire risk is expected from implementation of this technology
O12 – Active treatment system	No effect on groundwater levels is expected from implementation of this technology	This technology has a high potential to control the acid discharge from the swamp, assuming that adequate design parameters are selected using additional data from Boundary Creek monitoring (flow rates and water quality), geochemical modelling, treatability studies and pilot trials.	Secondary precipitates will be captured in the settling pond.	No effect on surface water flows is expected from implementation of this technology.	Implementation of this technology will have no effect on vegetation in Big Swamp.	No effect on fire risk is expected from implementation of this technology.
O15 - Constructed aerobic wetland	No effect on groundwater levels is expected from implementation of this technology.	Unlikely to be able to treat the acid load in Boundary Creek water unless coupled with other treatment technologies.	As a polishing step, an aerobic wetland will provide additional retention time to assist with oxidation and precipitation of residual metals prior to final release of water into Boundary Creek.	No effect on surface water flows is expected from implementation of this technology.	Construction of a vegetated wetland is expected to sustain a range of vegetation and ecosystems. However, this will have no impact on the vegetation across Big Swamp.	No effect on fire risk is expected from implementation of this technology.
O16 - RAPS	No effect on groundwater levels is expected from implementation of this technology.	Subject to proper design and maintenance, a RAPS would have the ability to treat the acid load in Boundary Creek water. However, Boundary Creek flow rates above the design capacity of the system will not be treated by the RAPS.	Secondary precipitates will be captured in the settling pond.	No effect on surface water flows is expected from implementation of this technology.	Construction of a vegetated RAPS is expected to sustain a range of vegetation and ecosystems, as well as improving downstream ecological values. However, it will have no effect on the vegetation across Big Swamp.	No effect on fire risk is expected from implementation of this technology.

Table 21: Technology scoring of the seven retained remediation options

Indicators	Aerial liming	Soil Mixing	Excavation & disposal	Aerobic Wetland	RAPS	In-stream dosing	Flooding & GW levels
A1 - Ability to meet project objectives	2	2	2	1	3	4	4
A2 - Technology development status	3	4	5	4	4	4	4
A3 - Track record of success in similar conditions	3	4	4	1	2	4	3
A4 - Amount of additional data required for detailed design	5	4	4	3	2	2	3
A5 - Potential side effects of remediation	3	2	1	4	4	3	3
A6 - Potential for residual risks following remediation	2	2	2	1	3	4	3
B1 - Footprint and infrastructure requirements	5	2	2	2	2	4	4
B2 – O&M intensity	4	4	4	3	2	1	4
B3 - Availability of equipment and supplies	4	3	4	4	4	3	5
B4 - Health and safety	3	3	3	4	2	3	5
C1 – Estimated capital costs	5	4	2	5	1	3	5
C2 – Estimated O&M costs	5	4	4	4	3	2	5
C3 - Potential for cost overruns	5	2	2	3	2	3	3
D1 - Regulatory acceptance	4	3	3	4	4	4	5
D2 - Community acceptance	4	2	1	4	3	4	4
D3 – Licensing and permits	4	3	3	3	3	4	4
D4 - Impacts on surrounding users and environment	3	2	2	3	2	3	4
D5 - Potential for legacy impacts following remediation	2	3	3	4	3	4	3
E1 - Timeframe for design and construction	5	3	3	3	3	4	3
E2 - Timeframe to meet remediation objectives	2	3	3	2	4	4	3
E3 – Longevity of treatment	2	5	5	3	3	3	4
F1 – Natural resource use	5	2	1	4	3	3	3
F2 – Chemical resource use	4	2	5	4	3	2	5
F3 - Waste generation and recycling potential	5	4	1	3	2	2	5
F4 – Emissions	4	3	3	4	2	3	4

Table 22: Category scores, total scores and ranking, weighted and unweighted

Option	A - Technical	B - Logistical	C- Financial	D - Stakeholders	E - Timing	F - Sustainability	Total unweighted score	Unweighted Rank	Total weighted score	Weighted Rank
Aerial liming	30	40	50	34	30	45	229	2	210	2
Soil Mixing	30	30	33	26	37	28	184	5	176	5
Excavation and disposal	30	33	27	24	37	25	175	6	169	7
Aerobic Wetland	23	33	40	36	27	38	196	3	184	4
RAPS	30	25	20	30	33	25	163	7	171	6
In-Stream dosing	35	28	27	38	37	25	189	4	203	3
Managed Groundwater Levels and Wetland Flooding	33	45	43	40	33	43	238	1	228	1

6.4 Clause 2.5d: a comprehensive risk assessment of proposed controls and actions documented in c);

This section outlines a risk assessment of proposed controls and actions for the proposed controls and actions (i.e. the 17 feasible remediation options).

The results of the risk assessment are presented in Table 23 noting it only displays medium residual risks (which was the highest ranked residual risk). For more information see section 9.

The remediation options were assessed in accordance with AS/NZS ISO 31000:2009 Risk Management – Principles and guidelines and included the following tasks:

- Identification of a set of risk groups considered applicable categories for project risk considerations.
- Based on the current understanding of the project context and the characteristic of the proposed practical remediation options, identification of the potential risks events associated with each option.
- Qualitative evaluation of the potential significance of project risks (risk analysis), based on assessment of likelihood of occurrence and adverse impacts of occurrence.
- Identification of mitigation measures that could be implemented to address project risks and evaluation of residual risks.

The following risk groups were considered relevant for the risk assessment:

- **Health and safety**
  Potential for the remediation option to impact on human health of worker, operators, visitors and members of the public during construction and operation.
- **Environment**
  Potential for the remediation option to cause detrimental effects on the environment, including generation dust, vibration, noise, air emission and impacts on soil, groundwater or surface water quality.
- **Financial**
  Potential for the remediation option to incur additional capital or ongoing costs, as well as additional potential costs associated with remediation of detrimental side effects or financial impacts to third parties.
- **Community**
  Potential for the remediation option to cause negative feedback or concerns from the community.
- **Regulatory**
  Potential for the remediation technology to cause concern, delays or litigation by the relevant Regulatory Authorities or fail to meet Section 78 Notice requirements.
- **Technical Performance**

Potential for the remediation technology to not perform as expected because of insufficient site characterisation, site complexity, inadequate technology selection, design or construction, lack of maintenance or inappropriate remediation objectives.

- **Logistical, infrastructure and planning**
  Potential for the remediation technology to be constrained by difficult access, lack or resources, damage to infrastructure, local zoning or long-term land use plan.

Table 23: Risk register for high and medium residual risk

Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
			Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
Environment	Provide supplementary flow	Change in vegetation communities in eastern part of the swamp due to increased extent of permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Certain	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with increased surface flow. Establish supplementary flow so that the extent of the permanently inundated areas is kept to a minimum. Allow seasonal variability of supplementary flow to minimise potential loss of vegetation. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	3 - Moderate	E - Almost Certain	2E	**Medium**
Environment	Install hydraulic barriers	Change in vegetation communities across the swamp due to the creation of additional permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Certain	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with installation and operation of hydraulic barriers. Design hydraulic barriers so that the extent of the permanently inundated areas is kept to a minimum. Design hydraulic barriers so that inundation levels cab be seasonally adjusted. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	3 - Moderate	E - Almost Certain	3E	**Medium**
Environment	Settling pond and sludge management	Loss of vegetation for construction of settling pond	3 - Major	Environment suffers harm for 5 to 10 years	E – Almost certain	Event could all the time	3C	High	Locate settling pond in an area of low ecological value. Consider construction of an aerobic wetland as part of the settling pond to offset loss of vegetation.	2 - Moderate	E – Almost certain	2E	**Medium**
Environment	Aerobic wetland	Change in vegetation type associated with permanently inundated conditions	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Locate aerobic wetland in an area of low ecological value. Design aerobic wetland to incorporate areas of different water depth so that diverse vegetation and ecosystem will establish.	3 - Major	C - Possible	3C	**Medium**
Community	Install hydraulic barriers	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	**Medium**

Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
			Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
Community	In stream treatment – Boundary Creek	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	**Medium**
Community	Settling pond and sludge management	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	**Medium**
Community	Aerobic wetland	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	**Medium**
Regulatory	Settling pond and sludge management	Approval for waste disposal or onsite storage of generated sludge required	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Include planning for waste disposal early in the design process and engage with potential receivers. Test any sludge developed during pilot trials to inform planning of waste disposal and waste categorisation.	3 - Major	C - Possible	3C	**Medium**
Technical	Install hydraulic barriers	Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions)	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	5C	Critical	Continue to monitor during installation of barriers and inundation to improve understanding of geochemical reactions in the swamp. Consider implementation as a staged approach (one barrier at a time) so that the effects can be assessed on a small scale before wider implementation. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment.	4 - Severe	B - Unlikely	4B	**Medium**

6.5 Clause 2.5e: the controls and actions to be implemented, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan

This section outlines remedial actions that Barwon Water is proposing to implement for the Boundary Creek and Big Swamp Remediation Plan. Best available data and technical analysis underpinned the setting of targets and success measures using SMART (specific, measurable, achievable, relevant and time-limited) principles as the basis.

Through the remediation options assessment process three options were assessed as being able to be practically implemented Boundary Creek and/or Big Swamp. They include 'managed groundwater levels and flooding', 'in-stream dosing' and 'aerial liming'.

Based on the vision and the objectives, and outcomes of the remediation options assessment, Barwon Water will progress with the option of '**managed groundwater levels and flooding**' – i.e. rewetting the swamp – and intend to keep the remaining two retained options of 'in-stream dosing' and 'aerial liming' as potential contingency measures dependent on feasibility.

The '**managed groundwater levels and wetland flooding**' remediation option is the only option with the ability to achieve the following objectives:

- Maintain groundwater levels above the top of the most severe sulfides in Big Swamp (to prevent oxidation of deeper sediments within the swamp).
- Maintain flows in Reach 3 of Boundary Creek all year round.
- Preserve/improve the ecological values of Big Swamp and Boundary Creek.
  This objective is focused around addressing the changes to the vegetation assemblages within the swamp post acidification, fire, and drying in the swamp which has created a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities.
- Reduce the peat fire risk in Big Swamp.

This option also has the potential to improve water quality within Big Swamp and Boundary Creek over the long-term (i.e. 10 years) by limiting sulfide oxidation, flushing the existing acidity in the soils and generation of alkalinity via iron reduction. Therefore, subject to confirmation through collection of further data and subsequent modelling results, may also address the following objectives:

- Control of the acid discharge (i.e. pH, sulfate and metals) from Big Swamp into the lower reach of Boundary Creek.

The other options were considered unlikely because of technical, logistical and financial considerations and overall assessment of their ability to meet project objectives.

6.5.1 Development of targets and success measures

The development of remediation targets and success measures for Boundary Creek, Big Swamp and the Surrounding Environment needs to take into account the existing condition of the system, the processes leading to its current condition, what is desirable and what is practicably achievable.

A significant number of technical investigations have been undertaken to help answer these questions and have been documented in section 6.1.

Vegetation

Given the significant and fundamental changes that have occurred to the substrate across much of the swamp as a result of fires and subsequent erosion, physical works in the form of additional hydraulic barriers are likely to also be required to distribute the flow of water evenly across the swamp plain to mitigate the effects of drying and subsequent colonisation by woodland communities (ELA, 2019).

It is also indicated that the remediation of the swamp will be more reliant on surface flows than restoration of groundwater levels. The wetting of the swamp from the 'top down' using surface flows, in association with physical works to distribute flows across the swamp, will help to ameliorate immediate issues associated with ASS whilst preventing the current south-to-north drying of the swamp and transition of the wetland to a woodland community.

Flows however should not result in inundation of the swamp plain for a continuous period of more than 6 months, and ideally should be designed to result in continuous seasonal inundation (maximum 30 cm depth) of the plain for up to three months.

Installation of hydraulic barriers are recommended through sections of the swamp plain to block the deeper channels that have formed in the swamp plain and distribute flows across broader areas. While it may be unavoidable in places, it is important to limit the creation of permanently inundated areas of open water. Gradually vegetation and sediment will fill the existing channels and any small areas of open water created by the bunds and over time start to return the profile of the swamp plain to a fine series of braided channels as believed to have originally occurred. Given the modification of the substrate, small diversion barriers may be required to direct flows into and through the swamp plain.

Areas of open water at the eastern end of the swamp (either the existing small pool or the larger pool likely to be created with installation of a hydraulic barrier) may facilitate the colonisation of specific wetland species (e.g. Phragmites australis) as bio-accumulators to treat water quality issues associated with acid-sulfate and heavy metals.

Restoration of a functional hydrological regime across the swamp will allow for the recolonization of modified areas with a range of species currently persisting in small pockets throughout the swamp, thus restoring a degree of diversity and function to the majority of the wetland overtime.

The current vegetative community within Big Swamp represents the encroachment of terrestrial woodland into the swamp plain as a result of fire related die back followed by reduced surface water flows through the swamp (related to dry climate conditions and groundwater extraction). As such, it is recognised that the original, pre-extraction condition cannot be practicably attained, either via an interventionist or passive approach (ELA, 2019). Given this, remediation should focus on the long-term persistence of a diverse, functional wetland community across the pre-extraction swamp's full extent.

To achieve the above goal, the following objectives are proposed to address the negative trends identified within the swamp. These objectives, which can also be considered 'health indicators' and include:

- No further encroachment of terrestrial woodland into the swamp plain. This can be assessed through regular monitoring using established transects.
- No encroachment of Lowland Forest dominant species into areas of Damp Forest. This can be assessed through regular monitoring using established transects.
- No loss of structural or floristic diversity along the main channel and western end of the swamp. Monitoring quadrats be established within these communities to assess changes in species diversity over time.
- Increase diversity of understorey species within swamp plain, with a focus on ferns and sedges. Monitoring quadrats be established within these communities to assess changes in species diversity over time.

Water quality

The development of remediation targets and success measures related to water quality is a difficult process, as it is related to the current and historical hydrology, hydrogeology and geochemistry of the Boundary Creek and Big Swamp system, as well as what's practicably achievable.

Firstly, to inform remediation related to groundwater extraction, the target should take into account the likely condition of the Big Swamp and Boundary Creek system in the absence of groundwater extraction. The regional groundwater model suggests that in the absence of extraction, the drying of Big Swamp would have been buffered by baseflow contributions to Boundary Creek until the late 1990's (Figure 31). However, these contributions are likely to have diminished in the early 2000's due to climate related reductions in groundwater levels. As such, groundwater contributions to Boundary Creek from the year 2000 are estimated to have ranged between 0 (neutral) and approximately -5 L/sec (slightly losing).

The groundwater model indicates that relatively similar hydrogeological conditions would have existed between 1993 and 1997, with groundwater contributions to Boundary Creek again ranging between 0 (neutral) and approximately -5 L/sec (slightly losing). Under these conditions, a summer low flow ≥0.5 ML/day and a median pH of 5.4 was recorded at the Yeodene stream gauge. The pH of water in Boundary Creek during this period is highlighted in blue in Figure 57.

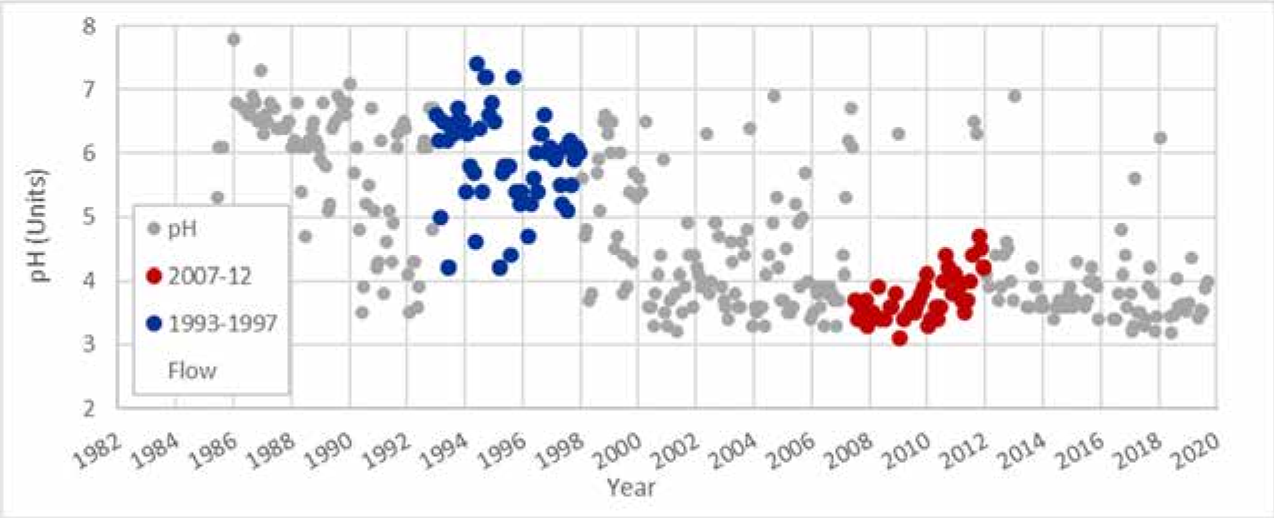


Figure 57 pH in Boundary Creek at Yeodene (1993-19987 and 2007-2012 periods highlighted)

It is recognised that such pH values would still present a risk to the environmental values within Boundary Creek and the Barwon River and are not consistent with recommended pH values the State Environment Protection Policy (Victorian Waters). However, they may be reflective of the natural pH within Boundary Creek given the current climate conditions. Such conditions are consistent with the oxidation of sulfidic material throughout Western Victoria, the Corangamite Catchment and the Barwon Downs Graben during the Millennium Drought (1997–2010). These have been discussed in Fitzpatrick et al. (2008), Glover (2014) and Jacobs (2017b), in which the oxidation of sulfidic soils due to climatic shifts and seasonal drying has been highlighted.

Figure 57 also indicates highlights pH in Boundary Creek between 2007 to 2012. This represents a period over which flow cessation in Boundary Creek gradually reduced from 207 days to 11 days. Over the same period, pH in the creek recovered from a median of 3.6 in 2007 to a median of 4.1 in 2012 with a minimum low flow of ≥0.5 ML/day (Figure 58). This suggests that even in the absence of regionally low groundwater levels, and losing conditions in Reach 2, the delivery of sufficient surface water through the swamp can increase the median pH values by (1) maintaining a locally high water table in the alluvial aquifer and (2) flushing the existing acidity from the upper soil profile in the swamp.

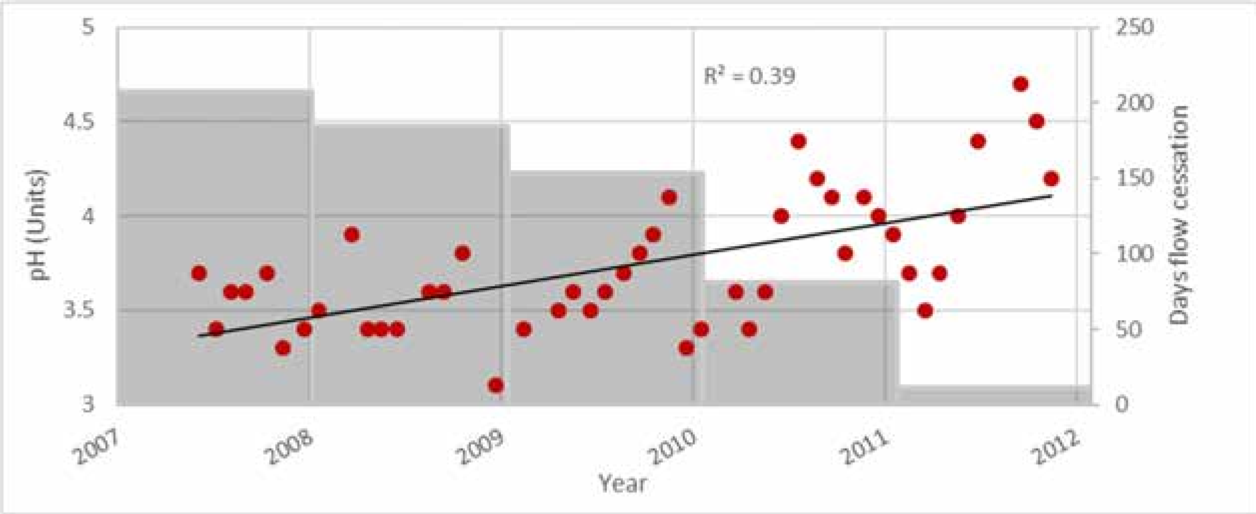


Figure 58: pH and flow cessation in Boundary Creek at Yeodene 2007-2012 (outliers under high flow conditions excluded)

Soil sampling and analysis indicates that while highly variable, sulfide concentrations exceeding 1% S generally occur below 1.0 metre depth at many locations throughout the swamp, however it does vary from location to location.

The sulfide horizon varies significantly in the bores located at the western end of Big Swamp. The horizon was not apparent in BH16 or BH17 but was apparent in close proximity to the surface at BH14 (less than 0.7 m depth) and BH15 (less than 0.5 m depth). The depth of the horizon in BH14 and BH15 sits well above the groundwater levels measured under a winter high flow period of greater than 50 ML/day.

It is therefore considered unlikely that a groundwater level target of less than 0.5 m is achievable at these locations. Further, the extent of permanent inundation associated with the flows necessary to achieve such levels would result in significant vegetation die back through the swamp. As such, a target of 1.0 m below ground level (bgl) has been set at BH15 to keep the higher concentrations of potential acid deeper in the profile saturated to prevent activation.

Given this, remediation should target the maintenance of a water table above the 1% S horizon where this is achievable to limit ongoing oxidation and any associated release of acid. Where this is not considered achievable, water levels should be maintained to prevent oxidation and release of potential acid below these levels as is proposed for the western end of Big Swamp. In these areas, other contingency measures may need to be considered to specifically target existing acid hotpots. This will be informed by the further data collection, groundwater-surface water modelling, geochemical modelling and detailed design

Table 24 below summarises the sulfide horizon depths to be targeted for a representative selection of bores. At least one bore has been chosen from each transect to account for the variation in ground surface elevation from west-east across Big Swamp. These levels will subsequently form the basis for groundwater level targets.

Table 24: Depth of sulfidic horizon (>1 %S)

Bore	Target WL (m bgl)
BH01	1
BH06	1.5
BH09	1.8
BH12	1.2
BH15[1]	1.0

[1]Target water level based on sulfide horizon >10 %S

The groundwater-surface water modelling indicates that where surface water flows and inundation persists, localised recharge and hydraulic loading result in an increase in the water table elevation and a reduction in the depth to water table.

The results suggest that when the surface water flow path through the center of the swamp is activated and a single hydraulic barrier is in place, a depth to water table of less than 1.0 m can be achieved through the majority of the swamp, particularly in those areas proximal to surface water flow/inundation. However, it is noted that the modelling also indicates that the effect of the implementation of a single barrier on groundwater levels is largely limited to the area of inundation immediately upstream of the barrier.

This suggests that multiple barriers will be required to effectively distribute flows across the swamp to maintain a greater area of saturation, increase surface water flow connectivity across Big Swamp and help maintain the perched alluvial aquifer water table across the swamp. Given this, the groundwater levels outlined above appear practicable via the installation of multiple hydraulic barriers with the exact number and location to be confirmed through detailed design.

The incubation of different soil types under reducing conditions has also indicated that soils from below the water table did not exhibit any clear trend in pH over time (Cook, 2019). This is intuitive as the generation of alkalinity via reductive mechanisms would not be expected given their pre-existing reduced condition. It also indicates that under persisting reducing conditions, acid generation via oxidation will be limited.

Conversely, soils containing shallow, oxidised material exhibited a pH increase of between 0.5 and 1.5 units over the 128 days. As outlined in section 6.1.6, this suggests that some buffering related to iron reduction may be realized in the soil profile in Big Swamp through the provision of supplementary flows and installation of hydraulic barriers.

It is noted that soils previously burned during peat fires did not respond differently to other oxidised soils, and exhibited a pH increase in response to treatment. As such, the effect of fires on soil mineralogy does not appear to affect remediation strategies or targets.

Geochemical modelling highlights that the primary acidification process in Big Swamp is the oxidation of iron sulfide minerals, with pyrite being the main acid source mineral (GHD, 2019). Given this, the most significant effect of increasing inundation would be to increase the water table in the swamp, limiting the oxidation of any potential acidity that remains in the sediments above the historic water table. Modelling also indicates that alkalinity generation via the precipitation of iron sulfide minerals is limited by the amount of dissolved sulfate in the swamp, as is consistent with the observations made by Cook (2019).

Feedback from the Southern Rural Water's Independent Technical Review Panel regarding the scope of works also highlighted that the data collected for the technical investigations outlined above would be seasonally variable and vary between years depending on climatic conditions; therefore, the setting of indicators and measures of success would be dependent on the periods and seasonality of monitoring. To ensure this seasonality has been adequately factored into the setting of success targets, it is proposed to review and potentially refine some targets subject to completion of monitoring over a full seasonal cycle and outcomes from further geochemical modelling.

Macro-invertebrate communities

Continued macroinvertebrate sampling of Boundary Creek will also give an excellent indication as to its recovery during remediation works and introducing macroinvertebrate sampling at sites currently monitored by WaterWatch will add to the information already collected from the Barwon River.

Therefore, it is recommended that a further round of sampling be undertaken in autumn and based on the outcomes an ongoing monitoring regime developed.

Summary

Therefore, given the above historical observations, groundwater and surface water monitoring, incubation tests, geochemical modelling and feedback received from Southern Rural Water, the following targets have been set:

- No further encroachment of terrestrial woodland into the swamp plain.
- No encroachment of Lowland Forest dominant species into areas of Damp Forest.
- No loss of structural or floristic diversity along the main channel and western end of the swamp.
- Increased diversity of understorey species within swamp plain, with a focus on ferns and sedges.
- Groundwater level targets ranging between 0.2 and 1.8 m bgl have been set across the swamp to limit sulfide oxidation as per Table 25.
- A minimum flow target of 0.5 ML/day at Yeodene has been set to continue to flush existing acidity from Big Swamp and maintain shallow pools and shallow riffles in Reach 3 of Boundary Creek.
- A pH target of 6.5 at Yeodene has been set in accordance with State Environmental Protection Policy (Victorian Waters) (SEPP) Guidelines, however the timing for which this may be achieved will be informed by additional hydro-geochemical modelling subsequent to 12 months of data collection, and recovery rates similar to those observed in Figure 58 may be expected.

6.5.2 Reasonable targets and/or success measures

Table 25 outlines proposed success targets based on the rationale provided in the previous section.

Table 25: Proposed success targets for the Boundary Creek and Big Swamp Remediation Plan

Success Target	Measurement	Timeframe
Recovery trend for groundwater levels in the LTA (subject to median climate and no additional groundwater extraction above the current PCV limit)	Monitoring of groundwater levels in observation bores 64229, 64236, 82844 and 109131 to develop hydrographs to confirm a recovery trend line in LTA groundwater levels.	The term of the s78 notice
No further encroachment of terrestrial woodland into the swamp plain	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping to form the baseline for assessment of change along with condition scores.	Within 10 years of Implementation of hydraulic barriers
No encroachment of Lowland Forest dominant species into areas of Damp Forest	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping to form the baseline for assessment of change along with condition scores.	
No loss of structural or floristic diversity along the main channel and western end of the swamp.	Independent regular monitoring of quadrats to assess changes in species diversity over time, with a baseline assessment undertaken to form the basis for measuring changes in structural or floristic diversity along with condition scores.	
Increase diversity of understorey species within the swamp plain, with a focus on ferns and sedges	Independent monitoring of established transects to map changes in distribution and area, with current vegetation mapping to form the baseline for assessment of change along with condition scores.	
Big Swamp BH01 water table level less than 1.0 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH06 water table level less than 1.5 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH09 water table level less than 1.8 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
Big Swamp BH12 water table level less than 1.9 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers

Success Target	Measurement	Timeframe
Big Swamp BH15 water table level less than 1.0 m below ground level* maintained for a period of 2 years	Water table levels	Within 10 years of implementation of hydraulic barriers
At least 0.5 ML/day flow maintained at site 233228 Boundary Creek @ Yeodene stream gauge maintained for a period of 2 years (Subject to passing flow conditions being enforced at 'McDonald's Dam' in accordance with its licence conditions - dam licence no. WLE043336)	Flow ML/day	Within 10 years of implementation of hydraulic barriers
Annual median pH equal to or greater than 6.5* at site 233228 Boundary Creek @ Yeodene stream gauge maintained for a period of 2 years To be refined pending completion of geochemical modelling (Dec 2020).	pH equal to or greater than 6.5* (annual median)	Within 10 years of implementation of hydraulic barriers*

**Additional data is required to be collected to enable the modelling of the hydrological and geochemical processes through the swamp and for this to be used to refine the forecast of the achievable target for this measure. The interim target of median pH of 6.5 has been selected based on the SEPP Guidelines. The interim target for water table levels for each bore have been set based on a very short period of data and depending on the final locations of hydraulic barriers the location of the water table level targets may be revised to ensure protection of key areas and vegetation.*

6.6 Clause 2.5f: A monitoring program to check the controls and actions documented in e);

Barwon Water has adopted the following definition for adaptive management of the REPP:

> 'a continuous cycle of improvement based on setting goals and priorities, developing strategies, taking action and measuring results, and then feeding the results of monitoring back into new goals, priorities, strategies and actions'
>
> (Mackay, 2016)

An adaptive approach to remediation is considered best practice, whereby the remediation plan can be adapted to observed changes. This approach positions Barwon Water to 'watch' through a monitoring and assessment program to evaluate if systems are responding to interventions 'and act' if further action like contingency measures are required.

Barwon Water proposes that the following monitoring and assessment program be implemented to continuously review the effectiveness of the controls and actions for remediation of Boundary Creek and Big Swamp.

Table 26: Monitoring program for Boundary Creek and Big Swamp Remediation Plan

Monitoring Asset	What is being monitored?	Why	Frequency
Regional PASS bores			
PASS 1	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
PASS 2	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
PASS 3	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
PASS 4	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp piezometers			
Big Swamp BH1	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH2	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH3	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)

Monitoring Asset	What is being monitored?	Why	Frequency
Big Swamp BH4	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH5	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH6	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH7	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH8	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH9	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH10	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH11	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH12	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH14	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH15	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH16	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)

Monitoring Asset	What is being monitored?	Why	Frequency
Big Swamp BH17	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Big Swamp BH18	Level Spot WQ	Monitor changes in groundwater levels and quality in Big Swamp	Instantaneous level Monthly WQ (subject to revision as required)
Boundary Creek stream gauges			
Gauge 233273 (Boundary Creek @ Barongarook)	Level Flow EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Gauge 233231 (Boundary Creek @ upstream of McDonalds Dam)	Level Flow EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Gauge 233229 (Boundary Creek @ downstream of McDonalds Dam)	Level Flow pH EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Gauge 233275 (Boundary Creek @ upstream of Big Swamp)	Level Flow pH EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Gauge 233276 (Boundary Creek @ downstream of Big Swamp)	Level Flow pH EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Gauge 233228 (Boundary Creek @ Yeodene)	Level Flow pH EC Temp	Monitor requirements for supplementary flow and WQ conditions in Boundary Creek	Instantaneous
Vegetation monitoring in Big Swamp			
Transect 1 (West - Main channel to swamp plain)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 2 (North-west - Main channel to swamp plain)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 3 (South – Damp forest to swamp plain)	Vegetation communities	To track changes in the extent, structure and	Every 2 years or as recommended pending outcomes of monitoring

Monitoring Asset	What is being monitored?	Why	Frequency
		diversity of vegetation communities	
Transect 4 (Central - Damp forest to swamp plain)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 5 (East – Damp forest to open pool)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 6 (North - Main channel to swamp plain)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 7 (South-east - Damp Forest to Swampy Riparian Forest)	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Transect 8 (South – Lowland forest to Damp Forest	Vegetation communities	To track changes in the extent, structure and diversity of vegetation communities	Every 2 years or as recommended pending outcomes of monitoring
Barwon River water quality sampling			
Site 1- East Barwon River@ Kents Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 2- East Barwon River@ Dewings Bridge Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 3- West Barwon River@ Seven Bridges Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 4- Barwon River upstream of Boundary Creek confluence	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 5- Boundary Creek @ Colac-Forrest Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling Additional WQ monitoring also undertaken at this site to align with WaterWatch	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring

Monitoring Asset	What is being monitored?	Why	Frequency
		monitoring of pH in Barwon River	Monthly to fortnightly
Site 6- Barwon River downstream of Boundary Creek confluence	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 7- Barwon River upstream of CO_BAR16	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring
Site 8- Barwon River @ Colac-Lorne Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling Additional WQ monitoring also undertaken at this site to align with WaterWatch monitoring of pH in Barwon River	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring Monthly to fortnightly
Site 9- Barwon River @ Birregurra	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling Additional WQ monitoring also undertaken at this site to align with WaterWatch monitoring of pH in Barwon River	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring Monthly to fortnightly
Site 10- Barwon River @ Conns Lane	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling Additional WQ monitoring also undertaken at this site to align with WaterWatch monitoring of pH in Barwon River	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring Monthly to fortnightly
Site 11- Barwon River@ Winchelsea-Deans Marsh Road	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling Additional WQ monitoring also undertaken at this site to align with WaterWatch monitoring of pH in Barwon River	Spring & Autumn every 2nd year to align with macroinvertebrate sampling Or as recommended pending outcomes of monitoring Monthly to fortnightly
Site 12- Barwon River @ Winchelsea	Water quality	To understand water quality conditions at the time of macroinvertebrate sampling	Spring & Autumn every 2nd year to align with macroinvertebrate sampling

Monitoring Asset	What is being monitored?	Why	Frequency
		Additional WQ monitoring also undertaken at this site to align with WaterWatch monitoring of pH in Barwon River	Or as recommended pending outcomes of monitoring Monthly to fortnightly
Barwon River sediment sampling			
Site 1- East Barwon River@ Kents Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 2- East Barwon River@ Dewings Bridge Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 3- West Barwon River@ Seven Bridges Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 4- Barwon River upstream of Boundary Creek confluence	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 5- Boundary Creek @ Colac-Forrest Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 6- Barwon River downstream of Boundary Creek confluence	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 7- Barwon River upstream of CO_BAR16	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 8- Barwon River @ Colac-Lorne Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 9- Barwon River @ Birregurra	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 10- Barwon River @ Conns Lane	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Site 11- Barwon River@ Winchelsea-Deans Marsh Road	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring

Monitoring Asset	What is being monitored?	Why	Frequency
Site 12- Barwon River @ Winchelsea	Metals	Monitor changes in metal levels in sediment	Every 2 years initially, Or as recommended pending outcomes of monitoring
Macro-invertebrates survey			
Site 1- East Barwon River@ Kents Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 2- East Barwon River@ Dewings Bridge Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 3- West Barwon River@ Seven Bridges Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 4- Barwon River upstream of Boundary Creek confluence	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 5- Boundary Creek @ Colac-Forrest Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 6- Barwon River downstream of Boundary Creek confluence	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 7- Barwon River upstream of CO_BAR16	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 8- Barwon River @ Colac-Lorne Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 9- Barwon River @ Birregurra	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring

Monitoring Asset	What is being monitored?	Why	Frequency
Site 10- Barwon River @ Conns Lane	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 11- Barwon River@ Winchelsea- Deans Marsh Road	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring
Site 12- Barwon River @ Winchelsea	Macroinvertebrates	To monitor changes in composition	Spring & Autumn every 2nd year, Or as recommended pending outcomes of monitoring

6.7 Clause 2.5g: contingency measures designed to address any issues identified from monitoring results

Contingency measures (noting that they are at a conceptual design level) for remediation through '**managed groundwater levels and flooding**' are listed below. These contingency measures are predominantly specific to mitigating the potential occurrence of acid generation processes at Boundary Creek and Big Swamp, and include:

- Increasing or reducing supplementary flow.
- Use of agents to supplement sulfate deficit in Big Swamp.
- Use of neutralising agents (either via aerial liming or placement of limestone sand) along established surface water flow paths to mitigate potential spikes in acidity promoted by increases in surface water and groundwater levels.
- Installation of a settling pond to protect Boundary Creek and the Barwon River from metal oxidation and precipitation.
- Installation of silt traps/barriers to protect Boundary Creek and the Barwon River from metal oxidation and precipitation.
- Instream treatment to control acid release and manage potential secondary precipitates being released into Boundary Creek and the Barwon River.
- Active management of vegetation to reduced vegetative fuel loads should it become problematic during transition of vegetation distribution across the swamp.

In addition, during the implementation of remedial works, contingencies may need to be considered for ongoing environmental risks that have been highlighted in section 6.4. These risks include:

- The discharge of acidic water from Boundary Creek affecting water quality in the Barwon River;
- Acidification related to soil disturbance during barrier installation, and
- Acidification related to the discharge of ferrous groundwater to Big Swamp and Boundary Creek.

The first of the above risks will be informed by ongoing monitoring of flow and quality in Boundary Creek and the Barwon River to determine the flow conditions under which acidic discharge to the Barwon River may pose significant risks. This can be controlled in the first instance by managing flow diversions from the Barwon River to reduce the risk of these flow conditions from being realised.

The risk of soil disturbance during barrier installation can be controlled by the application of lime during barrier installation. This will be informed by soil sampling during the detailed design stage.

The discharge of ferrous groundwater to Big Swamp and Boundary Creek will be informed by groundwater, surface water and geochemical modelling and can be controlled by groundwater level management, lime application at key discharge sites, and as a last resort, instream treatment.

It should be noted that these contingency measures will require further development to determine how and when each contingency may be triggered for implementation and at what scale.

This will be completed in parallel with detailed design of the hydraulic barriers, which will require completion of the soil incubation tests, collection of further geochemical data and updating of the groundwater, surface water and geochemical models.

6.8 Clause 2.5h: a schedule of timeframes by which the controls and actions documented in e) will be carried out

Barwon Water is proposing the schedule outlined in Figure 59 for the Boundary Creek and Big Swamp Remediation Plan.

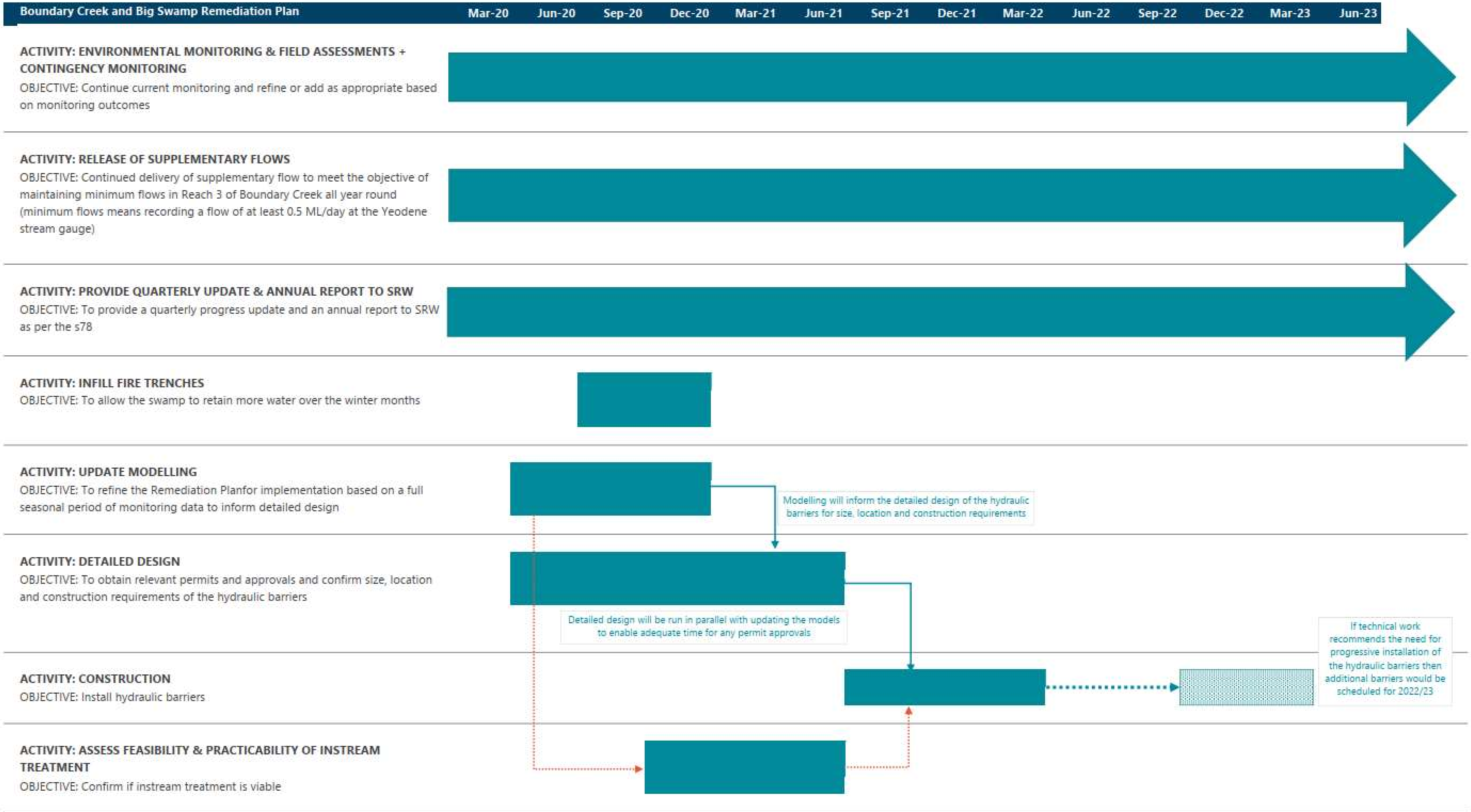


Figure 59: High level schedule of Remediation

6.9 Clause 2.5i: a reporting schedule, whereby Barwon Water will provide a minimum of quarterly updates to SRW which report on the progress of the Plan, as well as an Annual Report. The Annual Report must be submitted to SRW and made publicly available by 30 September each year.

The schedule outlined in Table 27 proposes that Barwon Water provide a quarterly update and an annual report to Southern Rural Water to meet the requirements of the s78 notice.

The reporting schedule will be reviewed and if necessary, readjusted, at the conclusion of the implementation of the REPP, anticipated for 2023.

Table 27: Reporting schedule for the REPP

Date	Reporting requirement
30 June 2020	Quarterly update 1
30 September 2020	Quarterly update 2 + Annual Report
31 December 2020	Quarterly update 3
31 March 2021	Quarterly update 4
30 June 2021	Quarterly update 1
30 September 2021	Quarterly update 2 + Annual Report
31 December 2021	Quarterly update 3
31 March 2022	Quarterly update 4
30 June 2022	Quarterly update 1
30 September 2022	Quarterly update 2 + Annual Report
31 December 2022	Quarterly update 3
31 March 2023	Quarterly update 4
30 June 2023 +	Quarterly update 1

7 Surrounding Environment Investigation

The Barwon Downs Graben covers an area of approximately 500 km^2 which extends from the township of Gellibrand in the south west to the Birregurra Monocline in the north east (Blake, 1974). However, the Gellibrand Saddle to the east of Kawarren has been reported to act as a hydraulic barrier (Petrides and Cartwright, 2006), which may limit the connectivity of the far south west of the graben from other areas.

The Surrounding Environment Investigation considers the whole extent of the Lower Tertiary Aquifer and will focus on eight '**high**' risk areas identified through a risk assessment process adapted from the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015). This process was detailed in the revised scope of works submitted to and approved by Southern Rural Water.

While the eight sites identified for further investigation are spread across the whole extent of the LTA, the information gaps common to them all relate to answering the following questions:

- Has historic groundwater pumping caused a reduction in baseflow to rivers from the LTA (either directly or indirectly) in areas identified as high risk? If so, how much and is it significant?
- Has historic groundwater pumping caused a decline in water table in areas where there a high value GDEs? And if so, how much and is it significant?

The regional groundwater model was used as a basis to inform a local scale conceptualisation of each of the eight high risk areas. Each conceptualisation seeks to represent current thinking (although in most cases, based on limited data-sets) in terms of hydrogeological setting (i.e. groundwater characteristics like recharge, discharge and flow) and processes like groundwater-surface water interactions.

The regional groundwater model is understood to over-state potential drawdown in regional aquitards and in areas where Quaternary aquifers have been confirmed to be present but have not been included in the model. These layers are known to act as physical constraints, such as clay layers within the formations that restrict groundwater flow from the regional aquifer and therefore may limit groundwater drawdown. As these physical constraints have not been included in the regional groundwater model, the model does not account for the restriction of groundwater flow and subsequent decrease in drawdown observed at these locations.

The Technical Works Monitoring Program (SKM, 2013) undertaken by Barwon Water to inform the Barwon Downs licence application confirmed the presence of many Quaternary alluvial aquifers which are not influenced by pumping (Jacobs 2017). In these areas, monitoring indicates that the model over predicts drawdown caused by pumping and thus also over-predicts the subsequent risk to environmental receptors at the surface.

The predicted drawdown in these areas and associated risk will need to be confirmed with further technical site-specific investigations to confirm or amend predicted drawdown and subsequent risk to environmental receptors at the surface. This data can then also be used to help confirm the presence and level of impact at the surface to inform decisions regarding any further actions required.

Impacts predicted by the regional groundwater model are based on the consequences defined in the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015) and relate to reductions in groundwater levels and subsequent reductions in low flows in rivers. These are detailed in Table 28 and Table 29 below.

Table 28: Consequence classifications for streams (drawdown and reduction in baseflow to river)

Consequence	Description	Measure Drawdown (m)	Measure % Low (low) flow
Minor	Proposed extraction impacts on natural or current streamflow are small	Watertable decline of <0.1 m	Less than 1% reduction in the low flow rate
Moderate	Proposed extraction impacts measurably on natural or current streamflow	Watertable decline of 0.1 - 2 m	Between 1% and 10% reduction in the low flow rate
Significant	Proposed extraction impacts significantly on natural or current streamflow	Watertable decline of > 2 m	More than 10% reduction in the low flow rate.

Table 29: Consequence (drawdown in water table level)

Consequence	Description	Measure
Minor	Proposed extraction is small with respect to the aquifer's ability to supply	Watertable decline of <0.1 m
Moderate	Proposed extraction impacts measurably with respect to the aquifer's ability to supply	Watertable decline of 0.1 - 2 m
Significant	Proposed extraction impact is large with respect to the aquifer's ability to supply	Watertable decline of > 2 m

Through addressing the information gaps, the Surrounding Environment Investigation will be better placed to identify if environmentally significant impacts occurred in the surrounding environment caused by historic management of groundwater pumping and subsequently, the lowering of groundwater levels in these areas.

To resolve these gaps, more data is required to validate the regional groundwater model predicted change in groundwater levels and therefore verify that the current risk ranking of '**high**' allocated to the eight high risk areas, is accurate.

Data-sets for these eight '**high**' risk areas are currently limited, as they either they don't exist, or the data is insufficient. Therefore, the first step in the investigation will be to install the following monitoring assets:

- 22 groundwater monitoring bores;
- 5 surface water stream gauges, and
- 6 new vegetation monitoring sites.

The additional monitoring required for each '**high**' risk area is outlined in more detail in Table 30.

Barwon Water will also continue to monitor the regional network of groundwater monitoring bores and stream flow gauges within the Gerangamete and Gellibrand Management Areas to refine and update the regional groundwater model.

After a minimum 12-month data collection period from each of the new monitoring sites, the additional data will be analysed and used to update the hydrological conceptual model to confirm:

- Presence and thickness of an alluvial aquifer.
- Surface water flows and levels in the river.
- Groundwater levels in the alluvial aquifer, LTA or MTD.
- Vertical gradients between aquifers and rivers.
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).
- Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS).

The review of the additional data and hydrological conceptual model could result in 1 of the following 3 scenarios for each area:

Scenario 1
Site specific monitoring data confirms that the regional groundwater model has overstated the risk to surface features such as rivers and GDE's because:

- The regional groundwater model over-predicts impact on groundwater levels as a result of drawdown.
- The presence of an alluvial aquifer is confirmed which acts as a buffer between the surface environment and drawdown in the LTA.
- Observed groundwater levels in the water table aquifer are higher than the modelled water levels.
- The new monitoring confirms that an upward gradient exists from the LTA to the alluvial aquifer.
- Comparison of observed flow data with the groundwater flux or water table decline predicted by the regional model indicates that the risk from historical groundwater pumping from Barwon Downs is low.

If scenario 1 eventuates then monitoring has confirmed that the surface environment is buffered from drawdown in the LTA and therefore, the regional groundwater model has over-predicted drawdown caused by historical pumping at Barwon Downs and overstated the subsequent risk to environmental receptors at the surface.

Scenario 2

The site specific monitoring confirms the regional groundwater model predictions because:

- The new monitoring confirms the absence of an alluvial aquifer and therefore the surface is not buffered from drawdown in the LTA.
- The new monitoring confirms that groundwater levels in the water table aquifer are consistent with those predicted by the regional groundwater model.
- The measured flow data confirms the groundwater flux predicted by regional model.

If scenario 2 occurs, then the regional groundwater model will be used to estimate the magnitude of reduction in groundwater levels as a result of historical groundwater pumping at Barwon Downs and subsequently estimate the magnitude of reduction in river baseflow. The estimation of groundwater level reduction coupled with the outcomes of vegetation monitoring will also inform the assessment of potential impact on groundwater dependent vegetation.

Scenario 3

The site specific monitoring data confirms a '**high'** risk because:

- The new monitoring confirms the presence of an alluvial aquifer.
- The new monitoring confirms that observed groundwater levels in the water table aquifer are higher than the water levels predicted by the regional groundwater model.
- The new monitoring confirms the existence of a downward gradient between the LTA and alluvial aquifer.
- The measured flow data confirms the groundwater flux predicted by regional model.

If scenario 3 occurs, then a localised groundwater model may need to be developed to estimate the magnitude of reduction in groundwater levels as a result of historical groundwater pumping at Barwon Downs and subsequently estimate the magnitude of reduction in river baseflow. The estimation of groundwater level reduction coupled with the outcomes of vegetation monitoring will also inform the assessment of potential impact on groundwater dependent vegetation.

Further data collected through the investigation and subsequent updating of modelling has the potential to result in identifying additional areas that may need to be investigated further, or conversely the removal of areas where environmental indicators are not shown to have been impacted by historic management of groundwater pumping.

In carrying out the Surrounding Environment Investigation, Barwon Water will engage with community and stakeholders to consider insights and other available technical or scientific information so that there is a robust process (for example, that the investigation is well resourced, that data is quality controlled and appropriate project management protocols are followed) for implementing the Surrounding Environment Investigation.

The outcomes from the investigation of each site will be progressively provided to Southern Rural Water as they are finalised, with expected conclusion by July, 2023. Remediation actions which may be required to be carried out by Barwon Water as a result of the Surrounding Environment Investigation must directly relate to confirmed environmentally significant adverse impacts caused by the historical management of groundwater extraction at Barwon Downs by Barwon Water in order meet the requirement of the s78 notice.

Costs for the Surrounding Environment Investigation are estimated to be in the order of $1.6M.

Table 30: Additional monitoring data recommended to address data gaps for high risk areas (Jacobs, 2019b)

Area	Why	What is the information gap	Recommended additional monitoring assets
BARWON RIVER CATCHMENT			
Barwon River east branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River east branch and regional groundwater system / outcropping LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing), if there is baseflow contribution from the LTA and if borefield impacts on baseflow are buffered by the presence of alluvial aquifers.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores PASS 2 and 48249 **Additional Surface water monitoring** Install one stream gauge on the East Branch near Seven Bridges Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. **Survey data** Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction. Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.
Barwon River west branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and	Currently there is limited data to confirm surface water groundwater connection between Barwon River west branch and regional groundwater system / outcropping LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

Area	Why	What is the information gap	Recommended additional monitoring assets
	modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 64237 and 108915. **Additional Surface water monitoring** Install one stream gauge on the West Branch near Boundary Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Barwon River downstream of confluence	Rated as high risk as there are particular sections considered to have a possible likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River downstream of the confluence and the regional groundwater system / MTD. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the MTD.	**Additional Groundwater Monitoring** Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 82838. **Additional Surface water monitoring** Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Area	Why	What is the information gap	Recommended additional monitoring assets
GELLIBRAND CATCHMENT			
Gellibrand River	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between the Gellibrand River and the regional groundwater system / LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Ten Mile Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. Survey the stream bed elevation in the vicinity of the gauge and the bores.

Area	Why	What is the information gap	Recommended additional monitoring assets
Yahoo Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Yahoo Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. **Survey data** Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.
Vegetation and PASS investigations			
Yeodene	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA).	**Additional Groundwater Monitoring** Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Area	Why	What is the information gap	Recommended additional monitoring assets
	validate the predicted impact and inform further actions		**Additional Surface water monitoring** Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. Survey the elevation of the creek bed close to the bores and at any gauge locations. **Additional Vegetation monitoring** Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.
Deans Marsh	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA). Vegetation assessments are required to confirm vegetation types and their reliance groundwater.	**Additional Groundwater Monitoring** Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Vegetation monitoring** Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition.

Area	Why	What is the information gap	Recommended additional monitoring assets
			Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.
Gellibrand	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the LTA. This data is required to understand the nature of groundwater dependence from the LTA.	**Additional Groundwater Monitoring** See recommendations for Gellibrand River **Additional Vegetation monitoring** Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

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9 Appendices

Supporting documentation:

- Remediation working group meeting summary
- 12-step stream rehabilitation planning process
- Technical reports:
    - Eco Logical (2019) Assessment of historical and current vegetation diversity and condition within Big Swamp, report prepared for Barwon Water.
    - Austral Research and Consulting (2019) Investigation of Sediments and Macroinvertebrates in the Upper Barwon River, report prepared for Barwon Water.
    - Jacobs (2019c) Boundary Creek and Big Swamp Remediation and Environmental Protection Plan, Soil sampling and well completion report, report prepared for Barwon Water.
    - Jacobs (2019a) Groundwater and surface water modelling for Big Swamp, report prepared for Barwon Water.
    - Cook, P (2019) Big Swamp Acid Sulfate Soils Study; Spatial extent of acid sulfate soils and potential for neutralisation of acidity upon re-flooding. School of Chemistry, Monash University, report prepared for Barwon Water.
    - GHD (2019) Basic Conceptual Geochemical Modelling for Big Swamp, report prepared for Barwon Water.
    - CDMSmith (2019) Boundary Creek and Big Swamp remediation: Options Assessment, report prepared for Barwon Water.
    - Jacobs (2019b) Barwon Downs borefield investigation plan for areas of potential high risk, report prepared for Barwon Water.
- Barwon Water response to Southern Rural Water and its independent Technical Review Panel on the revised scope of works

Remediation Working Group summary of meetings

Meeting	Date	Description
Meeting 1	May 2018	Working group members met for the first time and were presented a remediation option for Boundary Creek and Big Swamp as part of the Yeodene Swamp Study report. The meeting saw the group identify actions to help address information gaps and stakeholder concerns regarding the remediation option. The group also nominated a selection of technical experts to support them in their discussions.
Meeting 2	July 2018	Nominated technical experts are announced and meet the group – Prof. Richard Bush, Dr Darren Baldwin and Dr Vanessa Wong. The experts presented to the group their response to the proposed remediation approach and the information gaps the working group had raised. The action falling out of the meeting was for the nominated experts and Barwon Water to develop short and long term objectives for the remediation plan.
Meeting 3	August 2018	The purpose of the meeting was to: • identify and prioritise success measures to inform the development of the remediation plan • reaffirm the information gaps to help support the scoping of the field program. The success measures outlined by the group and their experts included: • improved pH water leaving Big Swamp • maintain flows in the lower reaches of Boundary Creek • reducing impact to stock and domestic water • reducing peat fire risk / threat • increasing trust in Barwon Water and ongoing engagement • groundwater level recovery • adaptive approach to remediation and monitoring The meeting also discussed the next steps in developing and implementation of the field program.
Between Meeting 3 and 4, there were a number of online update to the working group to keep them informed on the developments regarding remediation. In September 2018, Barwon Water was issued the Section 78 notice ordering Barwon Water develop a remediation plan for Boundary Creek, Big Swamp and surrounding environments and that a scope of works outlining the area, environmental value and assessments and methodology to develop the plan be submitted to Southern Rural Water on 20 December 2018.		
Meeting 4	February 2019	Working group members were presented information on the scope of works that Barwon Water had submitted to Southern Rural Water as part of the section 78 process. Information presented to the working group included: • an overview of the scope of works and proposed activities (such as soil sampling, modelling, mapping and ecological assessments) • assessment and feedback from the group's nominated technical experts (Dr Darren Baldwin) on the scope of works

Meeting	Date	Description
		• assessment and feedback from Southern Rural Water's technical proposed adjustments for Barwon Water to make. Barwon Water advised that the environmental assessments as part of the field program would commence in April to ensure as much data could be collected ahead of the wet weather. It was anticipated the field program could take up to six months to complete. Barwon Water committed to monthly online updates to the group on any interim results on the program and circulate any new documentation. At the completion of the field program, the group agreed to come back together along with the independent experts to look at the results and using the expert's advice start to inform and design the remediation action plan.
Meeting 5	March 2019	Barwon Water withdrew its groundwater extraction licence application for the Barwon Downs borefield in early March. Barwon Water thought it would be a good idea to bring the working group together for a meeting to talk about this in more detail and what this means going forward. Barwon Water also understood there were concerns and follow up questions about what this means for the Section 78 remediation plan. The purpose of the meeting saw the working group posed a number of questions including specifics of the section 78 notice, ongoing working relationship with their nominated technical experts. At this meeting Barwon Water agreed to do further studies to understand if broader impacts have occurred with the group in principally agreeing to a three step approach to remediation: fixing what we know, investigating what we don't know and analysing the "learnings" to inform future actions (if required).
Meeting 6	May 2019	The purpose of meeting 6 was to provide a more in-depth update on the field program progress and interim results and discussion with the nominated experts to better understand results and steps to develop the remediation plan.
Meeting 7	July 2019	The purpose of the meeting was to share and discuss: • field program progress and interim data. • revised 'Scope of Works' based on feedback from Southern Rural Water technical review panel and the working group's nominated technical experts. • Remediation Plan process/pathway The working group requested a number of amendments be made to the Scope of Works document, Barwon Water agreed to do this, with a final review of the revised Scope of Works by the group's nominated experts prior to re-submitting to Southern Rural Water.
Meeting 8	October 2019	Working group members were provided with an update on: • the interim results from the field program (including soil sampling incubation, vegetation survey, Barwon River survey and groundwater and surface water modelling). • proposed criteria for selecting the preferred remediation option for Boundary Creek and Big Swamp Working group members had the opportunity to discuss the results in detail with their nominated technical experts to listen to their feedback and advice. The group provided feedback on the vision and goals for the remediation option criteria and assessment framework. Working group members were invited to provide further feedback (online) into the weightings of the framework.

Meeting	Date	Description
Meeting 9	November 2019	Working group members were presented with information on: • Existing remediation options and process to determing the preferred option for the Boundary Creek catchment • Nominated technical expert assessment and feedback on process and preferred option • High level outline of success measures and contingencies for the Boundary Creek remediation option and surrounding area investigation. The working group members participated in discussion with their nominated experts, supporting technical consultants and Barwon Water. Following the conclusion of the meeting the majority of the working group were comfortable with the approach to developing the plan and looked forward to reading and discussing the draft at Meeting 10.
Meeting 10	December 2019	Working group members were provided with the draft Remediation and Environmental Protection Plan to review prior to the face to face meeting. At the meeting, working group members heard the assessment and feedback from their nominated technical experts on the draft plan. The working group discussed the plan in closer detail focusing on the principles, success measures, contingency plans and surrounding area investigation. The working group requested consideration to the principles specifically the recovery of the Lower tertiary Aquifer and for this to be re-circulated to the group ahead of the plan submission. Barwon Water re-circulated the principles to the group with a close off for comments 18 December. Barwon Water indicated it would finalise the plan with all feedback in mind and submit the plan to Southern Rural Water on 20 December 2019 and provide updates to the while awaiting Southern Rural Water's feedback on the plan. Barwon Water advised a final meeting with the working group would be held in March 2020 following receipt of the feedback from Southern Rural Water and would outline future community engagement activities

Supporting the face-to-face meetings were regular email updates to the working group regarding the issuing of the section 78 notice, submission of the scope of works (part of the s78 process) and results from the field program.

A final meeting (number 11) will be held in early 2020 to inform the group of Southern Rural Water's feedback on the Remediation and Environmental Protection Plan.

During 2020, Barwon Water will commence further engagement with the community around implementation objectives and activities.

Assessment of historical and current vegetation diversity and condition within Big Swamp

Barwon Water

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Executive Summary

Introduction

Recent technical work and modelling confirmed that Barwon Water's pumping from the Barwon Downs borefield over the past 30 years is the main cause of a reduction in baseflow in the lower reach of Boundary Creek, increasing the frequency and duration of no flow periods. This has been a major factor causing Big Swamp to dry out, resulting in the oxidation of naturally occurring acid sulfate soils in the swamp, and release of acidic water downstream of the swamp.

In response to the environmental degradation, Barwon Water was issued with a section 78 Ministerial Notice in September 2018, to legally enforce the development and implementation of a remediation plan for Boundary Creek, Big Swamp and surrounding environments impacted by past groundwater extraction.

Eco Logical Australia (ELA) has been engaged by Barwon Water to undertake an ecological assessment of Big Swamp and provide commentary on how changing the wetting/drying regime in the swamp (from seasonal drying to permanently wet) will impact upon the existing vegetation diversity and condition.

The primary goal of the assessment is to inform the preparation of the remediation plan in accordance with the ministerial notice issued pursuant to Section 78 of the Water Act 1989. The objectives of this study are therefore:

1. establish the baseline ecological characteristics for Big Swamp.
2. determine the hydrological requirements of past and current vegetation communities and advise likely responses to future surface and groundwater regimes.
3. provide recommendations to improve ecological outcomes within the swamp, within the context of the broader objectives of the remediation plan.

The proposed study area covers the wetland and riparian extent of Big Swamp near Yeodene, Victoria within parcels 115A\PP3987 and 1\PS501652.

Methods

Literature and data review

A review of existing literature and data was undertaken to extract information relevant to the past and current ecological and physical conditions of the swamp, along with water requirements of communities and dominant species identified as currently, or previously, present. Information relating to the past ecological and physical conditions of the swamp has been presented in chronological order to align with three time periods:

- Pre-European settlement
- Post-European settlement up until commencement of extraction from the Barwon Downs borefield, and
- Post-extraction from the Barwon Downs borefield up until the current day (i.e. 1983 to 2019).

Field surveys

A vegetation survey was conducted on 21 and 22 August 2019. The aim of the field survey was to collect data on wetland vegetation extent and floristic composition, as well as condition and health. The entire study area was traversed on foot and the distribution of ecological vegetation classes (EVCs) and associations were mapped using a combination of ground-truthing and interpretation of high-resolution aerial imagery carried into the field. All flora and fauna species observed during the survey were recorded and assigned as either indigenous or introduced, whilst significant species observed were spatially referenced. Geo-referenced photographs were taken throughout the study area of the various vegetation communities and points of interest to allow for future comparison.

Vegetation condition was assessed using either the Index of Wetland Condition (IWC) or Vegetation Quality Assessment (VQA) methods, depending on the nature of the vegetation and availability of EVC benchmarks.

A comparison of floristic diversity and structure was undertaken using five 50 metre long transects. These were aligned from the perimeter of the swamp into the core, crossing various vegetation community boundaries in the process. The data provides an overall frequency of each plant species and ground attribute occurring across the transect as well as a snapshot of the distribution of functional plant groups and species across wetland gradients. Transect data has been used to inform the dominant species associated with the vegetation associations and used in the ecohydrological analysis. It will also provide a baseline for future monitoring of vegetation within Big Swamp.

Palynological analysis

A palynological analysis of two cores taken from the western and eastern ends of the swamp is currently being undertaken by the university of Melbourne. The results of this study will be incorporated into the assessment once completed in early 2020.

Ecohydrological analysis

An ecohydrological analysis was undertaken to determine the water requirements of key species and vegetation communities and their relationship with the past and present hydrological regimes. When combined with hydrological modelling, a prediction of the future extent and composition of wetland vegetation within Big Swamp has been made under differing remediation scenarios. The analysis involved:

1. Identifying vegetation communities and associated dominant species
2. Defining water requirements for communities and dominant species
3. Determining past, current and future hydrological regimes across the swamp
4. Establishing a link between dominant species/vegetation communities and past and present hydrological regimes
5. Extrapolating future changes to vegetation composition and structure based on proposed water management scenarios.

Results

Hydrological context

The physical conditions across the site were extrapolated from existing data and literature, and field observations. For the purpose of completing the ecohydrological analysis, the key surface and groundwater parameters for the swamp are presented below for both pre-extraction and post-extraction timeframes.

Prior to the installation of MacDonalds Dam in 1979 and subsequent extraction commencing in 1983, the hydrology of the swamp is assumed to be defined by:

- Seasonal rainfall patterns consisting of dry summers and wet winters. Annual average rainfall is assumed to be 600-700 mm.
- Below average rainfall between 1900 and 1950, switching to above average rainfall in the latter half of the century.
- Surface flows gaining water from the groundwater (baseflow) through Reach 2 prior to entering the swamp.
- Surface flows into the swamp ranging from 2ML/day in summer to 40ML/day in winter.
- Surface flows through the swamp are primarily focused in the main channel around the northern edge. Where flows exceeded the capacity of the channel, water moved through a series of fine, braided channels across the swamp plain in the eastern and central sections of the swamp. This broadly distributed flow converged with the main channel in the north of the site, before again flowing through a series of more confined channels in the eastern section of the swamp.
- Groundwater within the swamp was influenced by a clay aquitard which thins in the west of the site and is absent upstream of the swamp. As a result, surface water infiltration leads to development of localised perched aquifers, with the overlying alluvium and humous-rich substrates becoming saturated.
- Groundwater tables at or near the surface across much of the swamp, with seasonal variation of 1-2 metres in parts of the swamp.
- Complete drying of soils within the swamp very uncommon, with moisture ranging from saturated to damp throughout the year.

Following the installation of MacDonalds Dam in 1979, extraction from the borefield commencing in 1983 and major droughts through much of the 1990s and 2000s, changes to the hydrology of the swamp are assumed to include:

- Below average rainfall as a result of drought events in 1982 and between 1995 and 2010 (i.e. the Millennium drought).
- Surface flows losing water to groundwater through Reach 2 prior to entering the swamp (loss of baseflows).
- Yearly cease-to-flow events in summer and reduced winter flows (<20ML/day). Noting that 2ML/day releases have prevented cease-to-flow events in recent years.
- Surface flows through the swamp remain in the main channel around the northern edge. Where flows exceed the capacity of the channel, water moves through the flood plain along a limited

number of channels that have been scoured and deepened by increased rates of erosion and collapse of soil structure following recent fire events. Flows through the swamp still converge with the main channel in the north of the site, before flowing through a narrow band of interconnected channels at the eastern end of the swamp.

- Groundwater across much of the swamp has dropped below 1 metre, with near-surface water table levels only persisting at the eastern-most end. Throughout much of the central and western sections of the swamp, water levels are below 2 metres. This represents an overall drop in the water table across the swamp of between 1 and 2 metres.
- Drying within the swamp has exposed acid-sulphate soils (ASS) down to a depth of 2 metres, with low pH surface and ground water, along with heavy metals, being released. Heavy iron flocculation covering inundated surfaces is also present.

In addition, drying of the swamp has caused a loss of soil bulk density with slumping now present across much of the swamp plain. This has been exacerbated by the burning of organic deposits further reducing soil bulk density. This loss of structure has likely been a key contributor to erosion within the swamp leading to the formation of a sediment plug, and an open water pool, at the eastern most end.

Historic vegetation communities

Historically, the swamp is likely to have supported a diverse wetland ecosystem comprised of four distinct vegetation associations:

1. A low scrub community through the central and northern sections of the swamp plain. This is likely to be an association of the Riparian Fern Scrub vegetation community which is tolerant of frequent or prolonged inundation and saturated soil conditions. As a result, sedges and rushes are likely to be dominant in the understorey.
2. A tall scrub at the western end and fringing the swamp plain, considered to be an association of the Riparian Fern Scrub vegetation community which is differentiated from the above due to less frequent or prolonged periods of inundation and moist rather than saturated soil conditions. Likely that ferns were dominant throughout this association.
3. A highly variable, low riparian woodland along the main channels around the northern edge and eastern parts of the swamp. Swamp Gum is likely to have been the dominant canopy species, however the community would have included other Eucalypts tolerant of wet conditions as well as a high diversity of understorey shrubs, ferns, sedges, rushes and herbs.
4. A damp woodland fringing the swamp plain and areas of riparian woodland, primarily along the southern edge and across much of the eastern third of the swamp outside the influence of existing channels. This varied woodland would have supported a range of tall Eucalypts as co-dominants in an open canopy, over a dense understorey tree / shrub layer.

In addition to the dominant associations listed above, there would have also been small pockets of unique vegetation communities throughout the swamp that persisted due to a combination of local conditions. An example of this is the small patch of Wet Verge Sedgeland which was identified at the western end of the swamp during field surveys.

Current vegetation communities

Currently, the swamp supports the following vegetation communities:

- **Riparian Fern Scrub (EVC A120)** occurs across the swamp plain in the western and central sections of the Swamp. The majority of this EVC has been significantly modified by the previous fires resulting in the loss of much of the original understorey diversity. The most heavily affected areas are now dominated by Prickly Tea-tree (*Leptospermum continentale*) or Scented Paperbark (*Melaleuca squarrosa*) with occasional patches of Austral Bracken (*Pteridium esculentum*) and/or Red-fruit Saw-sedge (*Gahnia sieberiana*). More intact patches occur in the far west of the swamp in areas apparently less affected by fires, supporting a diverse ground layer dominated by various sedges such as Tall Sedge (*Carex appressa*) and Tassel Sedge (*Carex fascicularis*). Areas closer to the main channel in the north of the site contained a braided system of channels and supported a higher cover of sedges and ferns, including additional species such as Spreading Rope-rush (*Empodisma minus*) and Scrambling Coral-fern (*Gleichenia microphylla*).

- **Swampy Riparian Woodland (EVC 83)** occurs along the main channel and adjacent terraces of Boundary Creek, sharing a broad ecotone with the adjacent Riparian Fern Scrub. This vegetation contained a scattered tree layer, dominated by Swamp Gum (*Eucalyptus ovata*), Brooker's Gum (*Eucalyptus brookeriana*) and Manna Gum (*Eucalyptus viminalis*), often over a secondary tree layer. In elevated sections with limited inundation a variety of ground, scrambling and tree ferns were common. The creek channel supported a range of aquatic and semi-aquatic forbs and sedges.

- **Wet Verge Sedgeland (EVC 932)** occurs at the western end of the swamp in a small patch adjacent to the main channel. The patch shared floristic affinities with the adjacent Riparian Fern Scrub but woody species were mostly absent and the vegetation was dominated by relatively dense Tall Sedge and Tassel Sedge. Associated species included White Purselane (*Montia australasica*), Common Spike-sedge (*Eleocharis acuta*), Rushes (*Juncus* spp.) and Slender Knotweed (*Persicaria decipiens*).

- **Damp Sands Herb-rich Woodland (EVC 3)** occurs on the lower slopes to the south and east of the swamp plain. This community was dominated by young Swamp Gum with a very species-poor understorey containing Austral Bracken and Red-fruit Saw-sedge. Whilst this community has been described as Damp Sands Herb-rich Woodland due to its current structural and floristic characteristics (which is likely a result of recent fires and changes in hydrology), this vegetation is considered to represent a derived state of the Swamp Gum (*Eucalyptus ovata*) Forest described by Carr and Muir (1994).

- **Lowland Forest (EVC 16)** occurs on the slopes surrounding Big Swamp, upslope from areas historically effected by water-logging or inundation. This floristically diverse community was dominated by Messmate Stringybark (*Eucalyptus obliqua*) and Manna Gum with a high cover of Austral Bracken. Prominent shrubs included Silver Banksia (*Banksia marginata*), Prickly Moses (*Acacia verticillata*) and Sweet Bursaria (*Bursaria spinosa*).

Ecohydrological analysis

The ecohydrological analysis compares the historic relationship between water and vegetation with the current conditions measured and modelled within the swamp across three zones:

- **Swamp Plain** – The Riparian Fern Scrub community that would have occupied the swamp plain requires near-continuous waterlogging of the soil with shallow, often prolonged, periods of inundation. Where conditions result in frequent or prolonged inundation, sedges and rushes are likely to become dominant in the understorey. Alternatively, drier conditions would have seen a shift to a fern dominated understorey with emergent trees common.

  In recent years, this part of the swamp has seen significant drying of the substrate, resulting in fires and the loss of vegetation cover. Dominant species such as Prickly Tea-tree and Scented Paperbark have re-colonised the swamp plain however understorey species are absent in many areas. A diverse and structurally complex understorey remains only at the west and northern edges of the swamp plain where strong interaction with the main channel likely protected fern and sedge species from the impacts of drying and fires.

  The reduced water-table currently present throughout much of the swamp plain is unlikely to support a Riparian Fern Scrub community in the long-term, leading to a gradual shift to a terrestrial damp woodland community over time. Evidence of Swamp Gum encroachment in the form of recruitment cohorts progressively expanding into the swamp plain were observed along the eastern edges and to the east of the small hillock during the field survey.

- **Main channel** – The Swampy Riparian Woodland community is likely to be reliant on surface flows along the main channel and associated infiltration into the surrounding ground layer. The depth of the channel and variation in elevation along the banks means inundation may have been limited to seasonal floods and localised depressions. Tall forest species less tolerant of inundation, such as Brooker's Gum and Manna Gum, where also present further up the bank as the community shifted into Lowland Forest.

  Surface flow modelling indicates that even under relatively low flows (e.g. 2ML / day) water persists in the channel. As a result, this community is likely to be more tolerant of long-term reductions in surface flows and the associated reduction in water tables within the swamp. However, should cease-to-flow events continue for extended periods, as has occurred in recent years, this community is to likely to be affected through a reduction in species diversity and encroachment by Lowland Forest species.

- **Damp woodlands** - Based on current high flow modelling (20ML/day), these Damp Sands Herb-rich Woodlands are unlikely to have experienced inundation in normal years. They would still have been heavily dependent on ground water with near-constant access to water within the root zone of mature trees and shrubs (Jacobs 2016). These conditions are likely to have been a strong driver of this community and differentiated it from the Lowland Forest EVC on the slopes above.

  Currently, this community is in a state of transition, with species tolerant of wet conditions (e.g. Swamp Gum) expanding into the scrub dominated areas of the swamp. Without the restoration of ground water levels, opportunities may be created for Lowland Forest species to colonise this area as the canopy matures and thins. In time this would have the effect of reducing the overall extent of the wetland as the surrounding forests move in.

Discussion

The ecology of Big Swamp is complex and intricately linked to the hydrology of the site. The hydrology is in turn informed by a range of factors including soils, topography and climate, as well as surface water use upstream and ground water extraction from the underlying deep aquifer leading to greater rates of surface water infiltration throughout the catchment.

From as early as the 1800s, the swamp has been affected by changing land and water use as vegetation clearance and agricultural practices expanded across the region. This activity has continued to the current day, with the extraction of ground water from the deep Tertiary aquifer, and subsequent reduction in surface flows into the swamp, the most recent pressure on the system. Unfortunately, the cumulative effects have come to a head over the past 20 years with drought conditions triggering intensive ground water extractions and severely limiting surface flows into the swamp. The result was the drying of the swamp through the 1990s and 2000s. While difficult to ascertain, the this drying may have commenced prior to groundwater extraction as the installation of MacDonalds Dam would have changed the flow regime along Boundary Creek from the late 1970s. As the water table dropped and drying occurred, both the vegetation and underlying soil layers rich in organic carbon became susceptible to fire, with two major events occurring in 1998 and 2011. The latter fire resulted in an almost complete loss of vegetation cover across the swamp, substantially altering the structure of the communities throughout. Subsequently, it appears erosion of the swamp plain, likely driven by large rainfall events combined with exposed post-fire soils, has concentrated surface flows into a primary channel that now bisects the plain. The resulting eroded sediment appears to have in part accumulated at the eastern end of the swamp in the form of a plug, leading to the formation of a small pool of standing water which now persists year-round.

Whilst there is likely to have been a gradual shift in community structure and composition since European settlement, and even prior due to decadal shifts in climate, the last 30 years has seen significant and potentially irreversible changes to the ecology of the Swamp. The fires have had the greatest direct impact on vegetation, resulting in a reduction of both floristic and structural diversity across the swamp plain and damp woodlands. While a high cover of canopy species has regenerated in both these areas, the understorey is absent in many places and where it has recovered consists almost exclusively of a few common species. Fires are a natural phenomenon in the Australian landscape, even in swamps, and are therefore not necessarily considered a degrading event that would have long term consequences for the Swamp's ecosystem. However, when combined with a distinct shift in the hydrological regime, widespread modification of the under lying substrate due to drying and sub-surface fires and the development of acid sulfate conditions, the consequences are potentially severe in the long term. Two major trends, which can currently be observed in the swamp, will likely continue and result in a shift in the composition of vegetation and associated habitat across the swamp. These include:

- Restriction of flows through the swamp plain to a narrow, central channel, that in the worst-case scenario may only flow intermittingly during seasonal, high rainfall events. Combined with a continuing failure to restore a near-surface water table across much of the plain, the current Riparian Fern Scrub community is likely to reduce in extent to a narrow band limited by proximity to the remaining channels (i.e. one or two through the plain and the main channel along the northern edge). Vegetation outside of this band will in time be replaced by damp woodlands, with Swamp Gum progressively colonising the plain and eventually forming a mature canopy. The resulting consequence will be a significant depletion of the extent of the Riparian Fern Scrub and simplification of the floristic and structural diversity likely to have been present prior to extraction. In a worst-case scenario, the encroachment of woodlands may have a feedback effect, leading to further drying of the swamp plain as species with higher evaporation rates establish and mature. This could theoretically lead to the permanent loss of the Riparian Fern Scrub community from the swamp in the long term. Given climatic trends towards lower average annual rainfall, this scenario cannot be discounted.

- Similar to the Riparian Fern Scrub, a failure to restore ground water levels across the swamp may also see the encroachment of the surrounding Lowland Forest into areas historically dominated by damp woodlands. Whether the overall extent of the damp woodlands will change is difficult to say, however it will have the effect of reducing the extent of the swamp and ecosystem as a whole.

Remediation

Remediation of the swamp recognises that the original, pre-extraction condition cannot be practicably attained, either via an interventionalist or hands-off approach. The aim is therefore to improve ecological values to a satisfactory end-point. In order to provide a definition of this state, the following is proposed as the remediation goal for Big Swamp:

> *"Ensure the long-term persistence of a diverse, functional wetland community across the pre-extraction swamp's full extent"*

While the swamp does not currently meet this goal, it can reasonably be assumed that should suitable hydraulic regimes be returned, communities will re-establish a degree of structural and floristic diversity over time. Supporting this hypothesis is the persistence of floristic elements in the western end of the swamp and along the main channel which currently contain a high diversity of lifeforms and species in sufficient numbers to allow for re-colonisation of the swamp as conditions improve. Complimenting this is the distinct lack of introduced species within the swamp, despite the substantial disturbance that has occurred over the past 20 years. It is also widely recognised that wetland communities are particularly resilient to modification provided suitable conditions are re-established within an acceptable timeframe. Whether this remains the case for Big Swamp, given the multiple issues confronting it, is difficult to say.

To achieve the above goal, the following objectives are proposed to address the negative trends identified within the swamp. These objectives, which can also be considered 'health indicators' or 'success measures', include:

- No further encroachment of terrestrial woodland into the swamp plain over the next 15 years.
- No encroachment of Lowland Forest dominant species into areas of Damp Forest over the next 15 years.

- No loss of structural or floristic diversity along the main channel and western end of the swamp over the next 15 years.
- Increase diversity of understorey species within the swamp plain, with a focus on ferns and sedges, over the next 25 years.

Monitoring of these objectives can be achieved through repeat transect surveys of those established during the field survey. To cover all relevant ecological gradients identified in the study and ensure sufficient data is available to assess the objectives listed above, an additional three transects are recommended to complement the existing five. Monitoring is recommended every two years.

Given the significant and fundamental changes that have occurred to the substrate across much of the swamp as a result of fires and subsequent erosion, a focus on flow intervention is unlikely to be sufficient to restore ecological function to the site (with the long-term aim of allowing pre-extraction wetland communities to return). Physical works may therefore be required to distribute the flow of water evenly across the swamp plain to mitigate the effects of drying and subsequent colonisation by woodland communities.

Whilst specific quantities are still to be determined, this assessment indicates rehabilitation of the swamp will be more reliant on surface flows than restoration of groundwater levels. Raising groundwater levels also has the unwanted potential to liberate additional acidity from ASS from depth to the surface, further exacerbating the current issue. The wetting of the swamp from the ‘top down’ using surface flows, in association with physical works to distribute flows across the swamp, will help to contain immediate issues associated with ASS whilst preventing the current south-to-north drying of the swamp and transition of the wetland to a woodland community.

Whilst the substantial impacts to the swamp’s substrate cannot be reversed, the restoration of a functional hydrological regime across the swamp will allow for the re-colonization of modified areas with a range of species currently persisting in small pockets throughout the swamp, thus restoring a degree of diversity and function to the wetland overtime.

To achieve the goals and objectives, the following actions are proposed:

A. Ensure surface flows into the swamp are sufficient to maintain year-round waterlogging within the top metre of the swamp plain. Flows however should not result in inundation of the swamp plain for a continuous period of more than 6 months, and ideally should be designed to result in continuous seasonal inundation (maximum 30cm depth) of the plain for between 2 – 3 months.

B. Install a limited number of low bund/weirs through sections of the swamp plan. Ideally this would utilise existing tracks and disturbed areas for construction and access. The objective of the bunds would be to block the deeper channels that have formed in the swamp plain and distribute flows across the broader area. While it may be unavoidable in places, it is important to avoid the creation of permanently inundated areas of open water. Gradually vegetation and sediment will fill the existing channels and any small areas of open water created by the bunds and over time start to return the profile of the swamp plain to a fine series of braided channels as believed to have originally occurred.

C. Refill/block-off the fire trench (and other unnecessary drains) and re-establish flow of the southern tributary into the swamp along the original alignment. Given the modification of the substrate, small diversion barriers may be required to direct flows into and through the swamp plain.

D. Considered potential use of the recently-formed open water area at the eastern end of the swamp to treat water quality issues created by ASS. Potential options may include the use of specific wetland species (e.g. *Phragmites australis*) as bio-accumulators to treat water quality issues associated with acid-sulphate and heavy metals. However, such an approach would require further investigation as there is the potential for secondary degradation through the introduction of aggressive species into a damaged ecosystem.

E. Undertake continued monitoring of the swamp against the objectives listed above.

In addition, further investigations are recommended to inform the design of remediation actions and long-term management of Big Swamp. These include:

- Condition assessments in high quality Riparian Fern Scrub and Swamp Gum remnants in the region to establish benchmarks against which monitoring data can be assessed. Existing quadrat plots and transects may be suitable for comparison of damp woodland communities however there is currently a lack of monitoring data related to the Riparian Fern Scrub EVC from the local region.

- Assessment of the connectivity between the shallow and deep aquifer systems and relationship to Big Swamp.

- Survey of the swamp plain profile to inform design of proposed weirs/bunds.

1. Introduction

1.1 Background

Recent technical work (Jacobs, 2018) confirmed that Barwon Water's pumping from the Barwon Downs borefield over the past 30 years is the main cause of a reduction in baseflow (groundwater contribution to streamflow) in the lower reach of Boundary Creek, increasing the frequency and duration of no flow periods. The dry climate experienced in the same period and ineffective management measures were also considered contributing factors.

Lack of flow, especially during summer months has caused:

- Big Swamp to dry out,
- The oxidation of naturally occurring acid sulfate soils in the swamp, and
- The release of acidic water (pH less than 4) downstream of the swamp.

In response to this, Barwon Water was issued with a section 78 Ministerial Notice in September 2018, to legally enforce the development and implementation of a remediation plan for Boundary Creek, Big Swamp and surrounding environments impacted by past groundwater extraction.

A requirement of the s78 Notice includes the need to undertake any necessary environmental assessments to inform the development of the remediation plan due for submission on December 20 2019. Eco Logical Australia (ELA) has been engaged by Barwon Water to undertake an ecological assessment of Big Swamp and provide commentary on how changing the wetting/drying regime in the swamp (from seasonal drying to permanently wet) will impact upon the existing vegetation diversity and condition.

1.2 Study area

The proposed study area covers the wetland and riparian extent of Big Swamp near Yeodene, Victoria within parcels 115A\PP3987 and 1\PS501652 (Figure 1-1). This 22 hectare area is defined by the hydrological influence of Boundary Creek and the dependant ecosystem. Areas outside of the immediate influence of the swamp's hydrology, including those upstream/slope of the swamp and downstream of the parcels identified, are not included in the study area for the purpose of this technical study.

1.3 Goals and objectives

The primary goal of the assessment is to inform the preparation of the remediation plan in accordance with the ministerial notice issued pursuant to Section 78 of the *Water Act 1989*. In this context, remediation is deemed to be "the controls and actions that could be practicably carried out to achieve improved environmental outcomes for Boundary Creek, Big Swamp and the surrounding environment that has been impacted by groundwater pumping at Barwon Downs."

Given this goal, the objectives of this study are:

1. establish the baseline ecological characteristics for Big Swamp through:

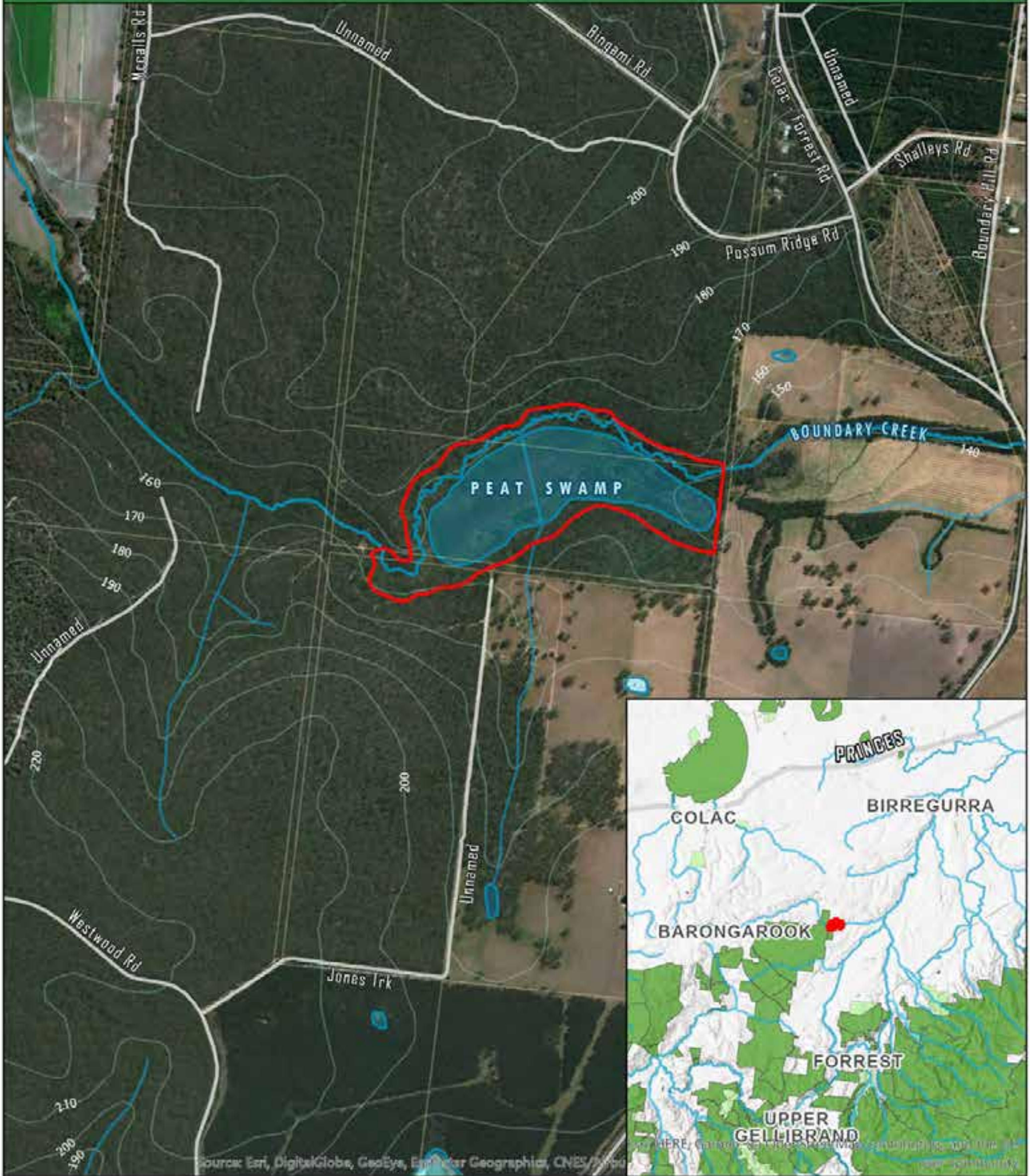
  - site investigations focused on describing the extent and condition of vegetation within and adjacent to the swamp.
  - review of existing literature, imagery and data to determine past ecological conditions within the swamp focusing on pre-extraction and pre-colonisation time periods.

2. Determine the hydrological requirements of past and current vegetation communities and advise likely responses to future surface and groundwater regimes.

3. Provide recommendations to improve ecological outcomes within the swamp, within the context of the broader objectives of the remediation plan. This includes identifying "reasonable targets and/or measures of success to be adopted for the purpose of the implementation of the Plan" (s78 notice).

Figure 1. Location of study area

Big Swamp ecological assessment



Impact sites
Study area
Parcels
Waterbodies
Watercourses
Local roads
Contour 10m

0 0.15 0.3 0.6 Km

Scale 1:12,207

Client name: Barwon Water

Project number: 13815

Date: 21/10/2019

Version: 1

Spatial Reference: GDA 1994 MGA Zone 55

2. Methods

2.1 Literature and data review

A review of existing literature and data was undertaken to extract information relevant to the:

- Past and current ecological and physical conditions of the swamp
- Hydrological requirements of communities and species identified as occurring, or previously occurring, within the swamp.

A bibliography containing documents reviewed for this study is provided at the end of the report.

Information relating to the past ecological and physical conditions of the swamp have been presented in chronological order to align with three time periods:

- Pre-European settlement and modification of the landscape for agricultural production. This is assumed to be prior to 1820, based on European expeditions west of Werribee to identify land suitable for pastoral production in the early 1800s. Conditions within the swamp will be informed by the palynological analysis (still to be completed) and comparison with monitoring data collated over the past 30 years from relatively unmodified wetland ecosystems in the region.

- Post-European settlement in the area up until commencement of extraction from the Lower Tertiary Aquifer via the Barwon Downs borefield. This period extends from the early 1800s through to 1983 when the first major extraction event occurred. Key information to inform changes over this period includes aerial imagery dating back to 1946, botanical studies in the Barwon Downs and greater Otways region and comparison with monitoring data collated over the past 30 years.

- Post-extraction from the Barwon Downs borefield up until the current day (i.e. 1983 to 2019). The change in conditions during this 36-year period has been informed by the numerous technical studies completed during this time, and in particular the last 15 years. This has been complimented with a review of aerial imagery and recent spatial products produced by DELWP.

2.2 Field surveys

A vegetation survey was conducted by ecologists James Garden (ELA) and Karl Just (sub-contractor) on 21 and 22 August 2019. The aim of the field survey was to collect data on:

- Wetland vegetation extent;
- Current floristic composition; and
- Vegetation condition and health.

The entire study area was traversed on foot, during which time the distribution of ecological vegetation classes (EVCs) and associations[1] was mapped using a combination of ground-truthing and interpretation of high-resolution aerial imagery carried into the field. All flora and fauna species observed during the survey were recorded and assigned as either indigenous or introduced, whilst significant species observed were spatially referenced. Geo-referenced photographs were taken throughout the study area of the various vegetation communities and points of interest to allow for future comparison.

2.2.1 Vegetation Condition Assessment

In order to determine the current, relative condition of vegetation within the study area, assessments were carried out using the Index of Wetland Condition (IWC) and Vegetation Quality Assessment (VQA) methods. In general, the VQA is not an accurate method for assessing wetland vegetation due to the paucity of wetland EVC benchmarks and absence of a method for assessing altered wetland processes, whilst the IWC is not applicable to terrestrial vegetation. Both methods were therefore utilised, so that the wetland EVCs of the site were assessed using the IWC and the terrestrial areas using the VQA.

The IWC assessment followed the methods as described in the Index of Wetland Condition Methods Manual version 14 (DELWP, 2018). The IWC assesses the state of the biological, physical and chemical components of the wetland ecosystem and their interactions. The method has six weighted sub-indices based on the characteristics that define wetlands: wetland catchment; physical form; hydrology; soils; water properties; and biota. It is primarily a site/habitat-based assessment although some measures require wetland catchment scale assessment.

The VQA followed the methods as described in the Vegetation Quality Assessment Manual Version-1.3 (DSE 2004). The method has ten weighted sub-indices including Large Trees, Tree Canopy Cover, Lack of Weeds, Understorey, Recruitment, Organic Litter, Logs, Patch Size, Distance to Core Area and Neighbourhood.

These condition assessment methods are designed to provide a relative measure of condition that can be compared across vegetation onsite and against 'typical' benchmarks developed for the broader bioregion (in this case the Otway Plains). Due to the coarse nature of the assessment method and potential influence of both seasonal variations and assessor bias, it is not recommended for ongoing monitoring of vegetation within the swamp. The use of point transects is instead proposed for this purpose with the collection of baseline data during this assessment described below.

2.2.2 Vegetation transects

The vegetation of the study area was sampled using five 50m long vegetation transects aligned from the perimeter of the swamp into the core, crossing various vegetation community boundaries in the process. The start of each transect was permanently marked with a 1500mm high, yellow-capped star picket so that the transects can used for ongoing monitoring.

The location of transects were chosen so as to intersect vegetation association boundaries which are considered to align with environmental gradients or features (e.g. inundation, soils etc). This will allow for the future comparison of floristic diversity and structure associated with the differing vegetation

[1] The term 'association' is used here to describe variation within vegetation classes, consistent with the Zurich-Montpellier tradition of phytosociology.

associations (and therefore underlying environmental drivers), whilst also providing the basis for tracking gradual changes in the extent of vegetation communities over the long-term.

All flora species at each 25cm interval along the transect were recorded. In addition, the ground attribute occurring at each 25cm point was recorded, including one of either bare ground, bryophytes, litter, water and log. The data provides an overall frequency of each plant species and ground attribute occurring across the transect as well as a snapshot of the distribution of functional plant groups and species across wetland gradients. Transect data has been used to inform the dominant species associated with each vegetation association for use in the ecohydrological analysis. It will also provide a baseline for future monitoring of vegetation within Big Swamp.

The results of the transect assessment is provided in Appendix B.

2.3 Palynological study

During the field surveys two cores were taken from the western and eastern ends of the swamp to a depth of 1.5 metres and 2.5 metres respectively. Samples were taken from 10 cm intervals within each core and have been provide to the University of Melbourne for analysis. The results of this study are expected in early 2020 and will be incorporated into this assessment once received.

2.4 Ecohydrological analysis

The ecohydrological analysis builds upon the findings of the literature review and field surveys. Its aim is to determine the water requirements of key species and vegetation communities and their relationship with the past and present hydrological regimes. When combined with hydrological modelling, a prediction of the future extent and composition of wetland vegetation within Big Swamp can be made under differing remediation scenarios.

The steps undertaken to complete this analysis include:

1. Identifying vegetation communities and associated dominant species - Information collected during the field survey was used to inform the type, extent and condition of vegetation associations throughout the swamp. The survey also identified dominant species within each association which are considered critical to the ecological character and function of the wider wetland ecosystem. The loss of these species would therefore represent a fundamental shift in the ecosystem to a different functional state (e.g. aquatic to terrestrial).
2. Defining water requirements for communities and dominant species. This process involved a literature review and included collation of information from the following key sources:
   - Peer-reviewed scientific research, as listed in the bibliography.
   - Technical publications, including Arthur Rylah Institutes' *A Guide to water regime, salinity ranges and bioregional conservation status of Victorian wetland Ecological Vegetation classes* (Frood and Papas 2016).
   - Previous studies, including: Jacobs (2015) which assigned functional groups to species throughout the Barwon Downs region based on previous analyses and Orrelana *et al*. (2012); and, SKM (2009) which identified water dependency on a 5-point scale for 108 species in the region.

- Sinclair *et al*. (2019; Arthur Rylah Institute unpublished dataset) which captures both waterlogging and inundation tolerance for a broad range of species across Victoria.

3. Determining past, current and future water regimes across the swamp using existing monitoring data and surface and ground water models. The ground and surface water models have been produced by Jacobs (2019) and provide key flow and water table metrics including frequency, extent, duration and depth of inundation and variation in water table under differing management scenarios based on water extraction and release upstream of Big Swamp.
4. Establishing a link between dominant species/vegetation communities and past and present hydrological regimes. Based on the data available key metrics will be identified that are assumed to underpin ecosystem function and drive community structure and species distribution across the site. This step combines information from steps 2 and 3.
5. Extrapolating future changes to vegetation composition and structure based on proposed water management scenarios.

The assessment of key water quality indicators and relevance to ecosystem health, particularly for groundwater, has also been made where sufficient information exists.

Using the findings of this analysis, recommendations for ideal watering conditions have been provided to ensure a functional, diverse wetland ecosystem is maintained at the site. Where applicable, other interventional management actions have been recommended to address issues associated with physical changes to the wetland over the past 30 years.

3. Results

3.1 Bio-physical environment

This section describes the bio-physical environment within the swamp and broader region, with a particular focus on hydrology, soils and drivers of change (e.g. fires and landuse). Figure 3-1 provides temporal context to the events describe in the following sections.

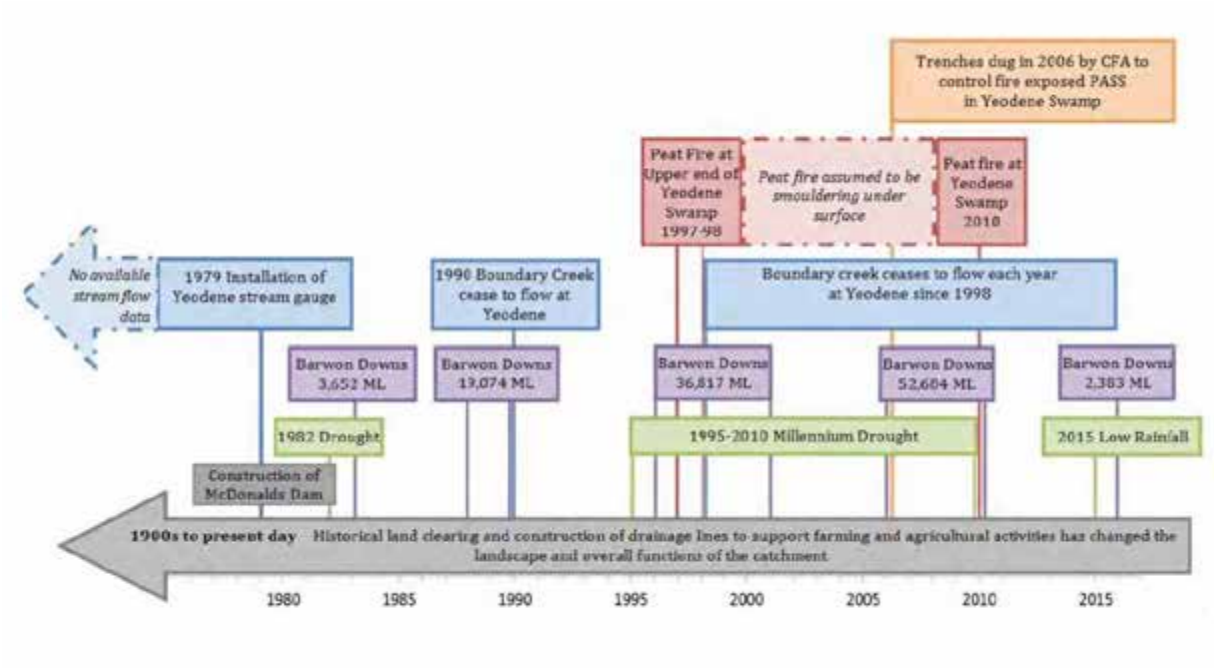


Figure 3-1. Recent events that have affected Big Swamp (Barwon Water 2019)

3.1.1 Regional hydrological context

The Barwon River and its tributaries rise in the Otway Ranges and flow north through Forrest and Birregurra. The Barwon River West Branch and East Branch drain the southern half of the catchment and come together just upstream of the confluence with Boundary Creek. Boundary Creek flows east across the Barongarook High and joins the Barwon River around Yeodene.

The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment. The Otways Coast catchment is a large catchment with many rivers that flow towards the coast. The Gellibrand River is in the Otways Coast catchment and rises near Upper Gellibrand and flows in a westerly direction towards Gellibrand. The Gellibrand River discharges to the ocean at Princetown.

The Barwon Downs bore field is located approximately 70 km south west of Geelong and 30 km south east of Colac. The surrounding land is a mixture of state forest and agricultural land that has been farmed for over a century, resulting in some parts of the landscape being highly modified compared to the surrounding natural environment.

The borefield taps into an underground source of water, known as the Lower Tertiary Aquifer, with depths of up to 600 metres at the borefield. The aquifer covers an area of approximately 500 km2 below the surface and is connected to the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment near Gellibrand. Barongarook High is the main recharge area of the aquifer because of its unconfined nature.

Groundwater and surface water condition is monitored through a series of bores and gauges situated along the main channel of Boundary Creek.

3.1.2 Land-use

The review of literature identified a range of land-use activities and changes across the catchment which has likely impacted the hydrology of Boundary Creek and associated ecology of Big Swamp. A comprehensive list was provided by Carr and Muir (1994), and include:

- widespread clearing of catchments or sub-catchments, notably the greater part of Boundary Creek catchment, post European settlement in the area. This has led to increased runoff and moisture availability in creeks along drainage lines, and more rapid runoff
- increased runoff resulting from soil compaction and reduced infiltration on cleared land by cattle trampling
- draining of swampy areas throughout the catchment, which likely resulted in greater flooding or waterlogging of downstream substrates
- much higher water use by plantations of Radiata Pine (*Pinus radiata*) compared with indigenous vegetation leading to reduced ground water percolation downslope
- oxidation and loss of water holding peats resulting in increased runoff and greater fluctuations of runoff
- impounding of water in farm dams.

The key water uses in the catchment are surface water extraction from Boundary Creek for pasture/crop irrigation and stock watering, and ground water extraction from the Lower Tertiary Aquifer via the Barwon Downs borefield.

Whilst there is insufficient data to quantify the extraction of surface water from the creek, ground water extraction has been carefully monitored with five extraction events occurring since the borefield was commissioned in 1983. These include extractions of:

- 3,652 ML from February to April in 1983 due to drought;
- 19,074 ML during a long-term pump test in the late 1980s;
- 36,817 ML during the 1997 - 2001 drought;
- 52,684 ML during the 2006 – 2010 millennium drought, and
- 3,449 ML in 2016 to boost storages after a record dry summer.

The licence to operate the Barwon Downs borefield was issued by Southern Rural Water in 2004 and was due to expire in June 2019. Barwon Water submitted a groundwater licence renewal application to Southern Rural Water in late November 2018, however, the licence application for the Barwon Downs borefield was withdrawn in March 2019 over concerns about the environment and a commitment to the remediation of historical impacts caused by groundwater pumping.

3.1.3 Climate

There have been significant changes in long-term climatic conditions across the Boundary Creek catchment. The cumulative departure of rainfall from the mean demonstrates these multi-decadal trends (Figure 3-2). Increasing trends indicate periods of above average rainfall whereas the declining trends indicate drought periods. In the first half of the 20th century, before the extraction of groundwater from the Barwon Downs bore field, there was an extended period of reduced rainfall from 1900 to 1955. This was followed by a period of increased rainfall between 1955 and 1997 which spans the period before and after the implementation of the bore field (1985). Recent droughts include one 1982-1983 and the millennium drought between 1995 and 2010, and below average rainfall between 2014 and 2017.

Future climate projections for the Barwon basin indicate that there will be ongoing reductions in annual rainfall, with corresponding reductions in available runoff. Median projections forecast a 5% reduction in annual rainfall from present and more conservative predictions are as high as 20% reduction. The corresponding catchment runoff median reduction is predicted to be 22%, with conservative predictions forecasting a 48% run off reduction by the year 2065 (DELWP 2016).

Figure 3-2. Cumulative deviation from mean annual rainfall at Forest State gauge (BOM gauge 090040) (Jacobs 2017)

3.1.4 Surface water

There is also seasonal, spatial and interannual variability in surface flow at Big Swamp. The seasonal variation is due to changes in rainfall and evapotranspiration whereas the spatial variation in surface flow is due to changes in topography and the degree of groundwater connectivity (discussed further in section 3.1.5). Finally, the interannual variability in surface flow is determined by intermittent pumping from the Barwon Downs bore field and to a lesser extent, a drying climate.

The streamflow in Boundary Creek above Big Swamp has been monitored since 1979 (Figure 3-3). There were additional stream gauges installed above and below McDonald's Dam in 1979 with an interval between 1994-2014 where gauges fell into disrepair (Jacobs, 2018). Historically, Boundary Creek stream flow is lower in summer than in winter due to seasonal fluctuations in rainfall and subsequent surface run off. Spot gauging reveals that stream flow is more than 4-5 times higher in August than May. The loss of streamflow was estimated to range between 2.9 ML/day in May and 9.9 ML/day in August 2017. These volumes of water were representative of the swamp re-wetting after a period of no flow. It is estimated that the majority of the loss is recharge to groundwater with evapotranspiration making up less than 1 ML/day during these months (Jacobs, 2017).

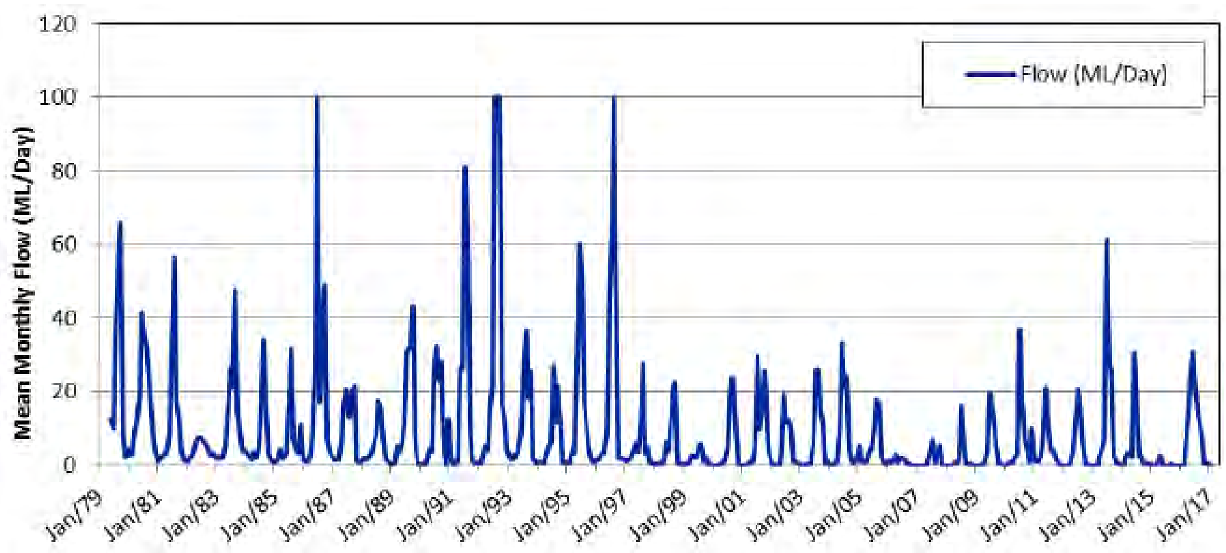


Figure 3-3. Average monthly flow in Boundary Creek at Yeodene (Jacobs 2017)

The spatial variation in surface flow across Big Swamp has been influenced by changes in the topography as a result of direct and indirect intervention. There was dramatic change in the stream flow when McDonald's Dam was installed in 1979. The dam has a storage capacity of 160 ML and is a source of evaporation and flow retardation in the catchment. Furthermore, a fire trench installed in 2006 around the southern and eastern edge of the swamp intersected an ephemeral drainage line that would have provided surface flows to the central part of the swamp. Whilst limited, surface flows from this source are likely being diverted along the trench to the eastern end of the swamp.

The decline of soil structure and woody vegetation cover has increased susceptible to erosion within the swamp during high flow events. This erosion appears to have led to the formation of a single channel through the swamp plain with sediment being transported and deposited at the eastern end of the swamp. The resulting 'sediment plug' may have been the driver for the formation of a small pool of standing water which now persists year-round in this location.

This channelization of the swamp plain is a concern as it may reduce the dispersion of water across the swamp during low to moderate flow events, as shown in preliminary modelling conducted by Jacobs (Figure 3-4). Importantly, the western end of the swamp does not appear to have been as adversely affected by conditions over past 20 years and the interaction between main channel and swamp, including overflow events inundating the plain, appears to be functioning well. Based on the surface flow modelling of this western-most section of the swamp, it can be surmised that much of the swamp plain may have consisted of a similar network of small braided channels. The result would have been a much broader dispersal of surface flows across the plain prior to the fires.

The long-term interannual streamflow is characterised by a declining base flow and an increase in the frequency of no flow periods. Since monitoring commenced in 2014, flows downstream of McDonalds Dam during the warmer months (November to April) was significantly less than 2 ML/day (Jacobs, 2018). Figure 3-3 shows a significant step change in surface flows in Boundary Creek at the Yeodene gauge in 1998. Groundwater modelling of Boundary Creek shows significant drawdown of groundwater impacting stream flow (Jacobs, 2017). Previous literature has shown that this decline in stream baseflow is primarily due to the groundwater extraction from the Barwon Downs borefield over the past 30 years (Jacobs, 2018). However, a dry climate and ineffective management measures were also deemed to be contributing factors.

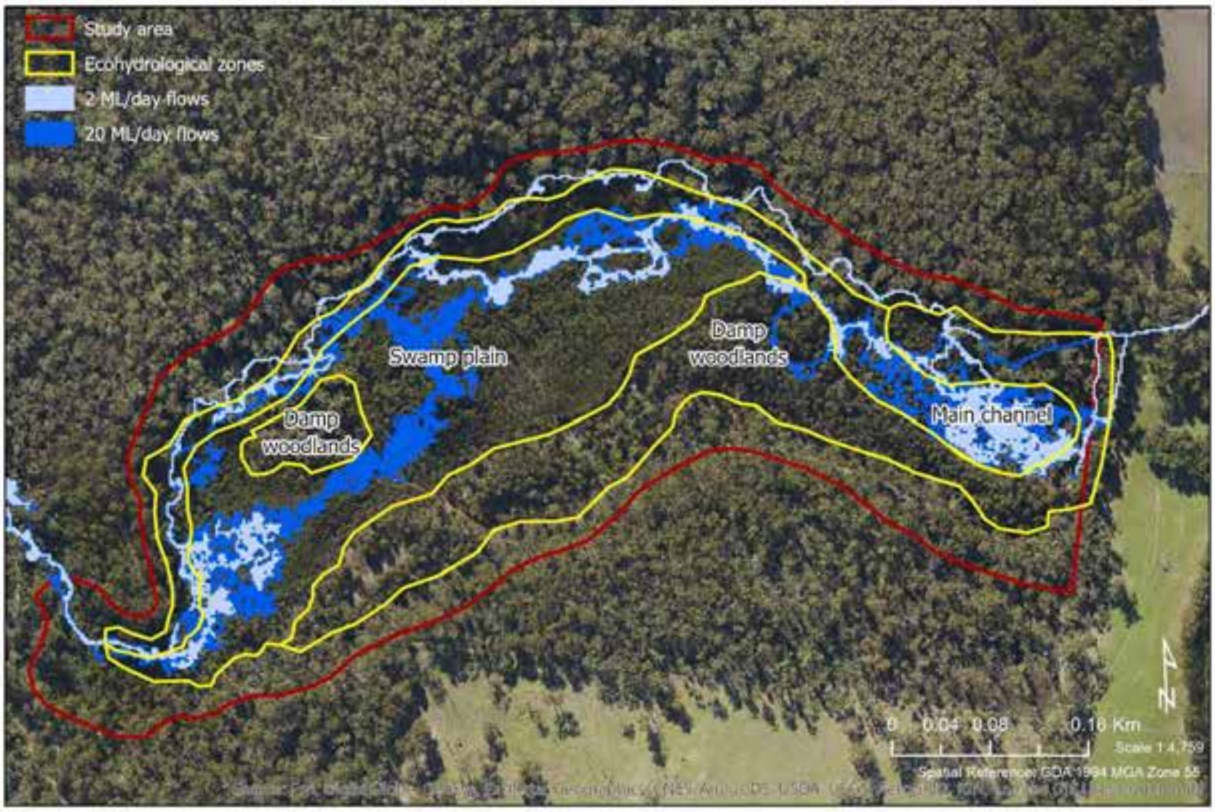


Figure 3-4. Modelled surface flows (2ML and 20ML / day) through Big Swamp

3.1.5 Conceptualisation of the hydrogeology at Big Swamp

Jacobs (2017) have summarised the conceptualisation of current water dynamics in the vicinity of Big Swamp (Figure 3-5). The key findings from Jacobs (2017) include:

- Saturated alluvial sediments are likely to be present upstream of Big Swamp as a localised perched aquifer.
- Depth to water table in the regional aquifer is 10-15 m below ground level upstream of Yeodene Swamp.
- Saturated sediments in Big Swamp are hydraulically separated from the underlying regional aquifer (LTA) by the aquitard.
- The eastern end of swamp comprises saturated alluvial deposits overlying aquitard.

- The aquitard thins to the west and is absent upstream of the swamp, however the exact location where the aquitard is absent is not known. Shallow bores indicate that the western end of the swamp the alluvial deposits overlie the regional aquifer.
- Immediately downstream of McDonalds Dam to the Damplands the spot flow measurements indicate the creek could be gaining water. Inflows to the creek are likely to be result of surface runoff from the wider catchment and potential inflow from the local (perched) alluvial aquifer. This is new information and improves the conceptualisation of the Reach 2.
- The Damplands and Big Swamp were observed to be losing water to groundwater, which is consistent with the existing conceptualisation.
- Reach 3 of Boundary Creek is variable gaining/losing to groundwater, consistent with the existing conceptualisation.
- The greatest losses of surface water occur through the Damplands and Big Swamp. This is estimated to range between 2.9 ML/day in May and 9.9 ML/day in August 2017. These volumes of water are representative of the swamp re-wetting after a period of no flow. It is estimated that the majority of the loss is recharge to groundwater with evapotranspiration making up less than 1 ML/day during these months.
- Evaporation losses will be higher during the summer months and could be up to 2.5 ML/day.

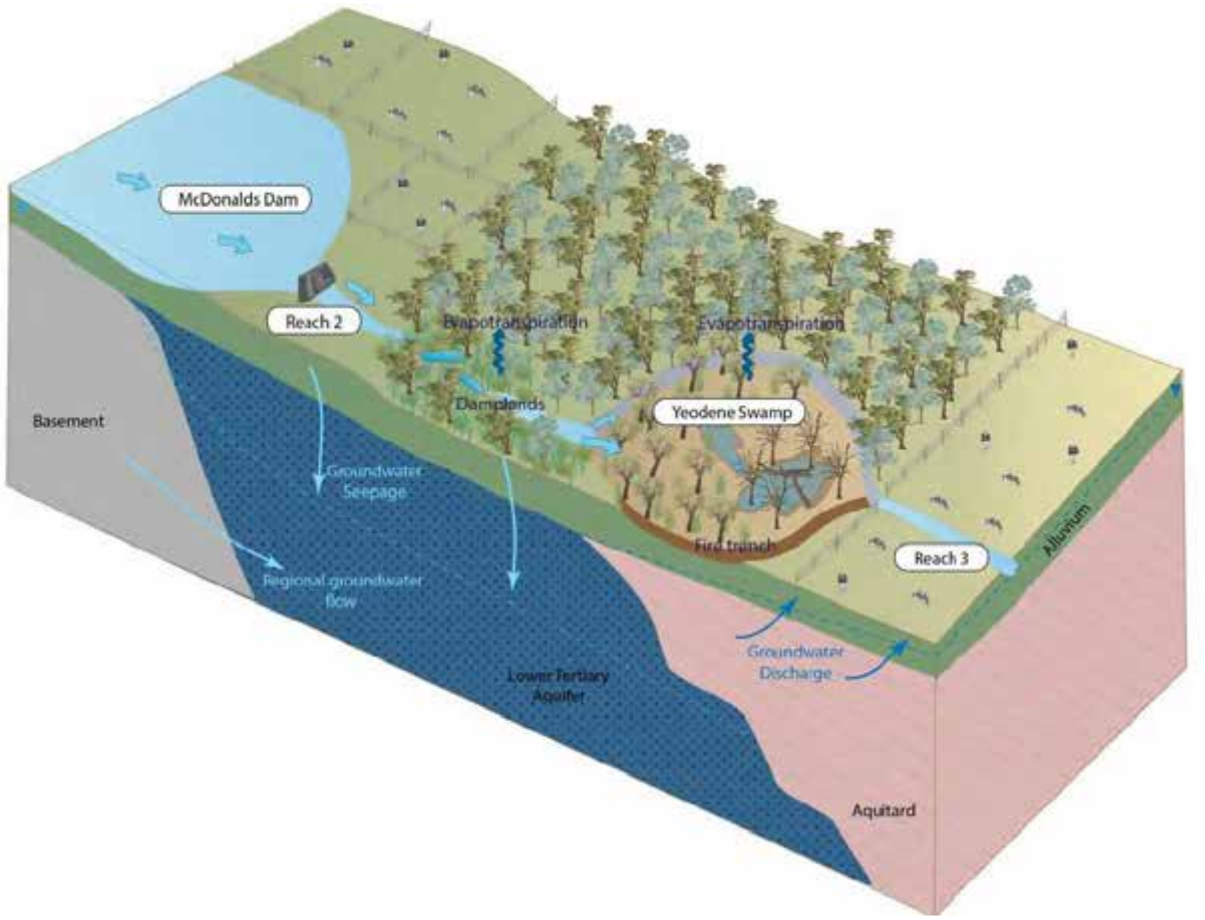


Figure 3-5. Working conceptualisation of the hydrogeology of Big Swamp (Jacobs, 2017)

3.1.6 Groundwater

The hydrogeology of the site is characterised by shallow perched aquifers, aquitards and the deep lower tertiary aquifer. The degree of interconnectivity between the shallow aquifer, deep aquifers and Boundary Creek, in relation to the water levels within Big Swamp, is the subject of ongoing investigation. Conceptual long-section diagrams are shown in Figure 3-6.

Big Swamp is formed from saturated sediments that are separated from the underlying regional aquifer (Dilwyn Formation) by a less permeable, silty-clay aquitard (Mid-Tertiary Aquitard) (Jacobs 2017). The hydrogeological features vary across the swamp and this is particularly apparent when examining the NDVI data which shows flourishing vegetation in the eastern part of the swamp during dry periods, indicating evapotranspiration dependent on the groundwater available (Jacobs, 2016). The eastern end of the swamp is comprised of saturated alluvial deposits overlying an aquitard. The aquitard thins to the west and is absent upstream of the swamp, however, the exact location where the aquitard is absent is not known (Jacobs 2017). Shallow bores indicate that alluvial deposits overlie the regional aquifer at the western end of the swamp. Saturated alluvial sediments are also likely to be present upstream of Big Swamp as a localised perched aquifer (Jacobs 2017). Furthermore, a stream gauge in the eastern section of the swamp has been unaffected by dramatic changes in streamflow providing further evidence for the presence of a shallow aquifer recharged by vertical seepage through the swamp and Boundary Creek.

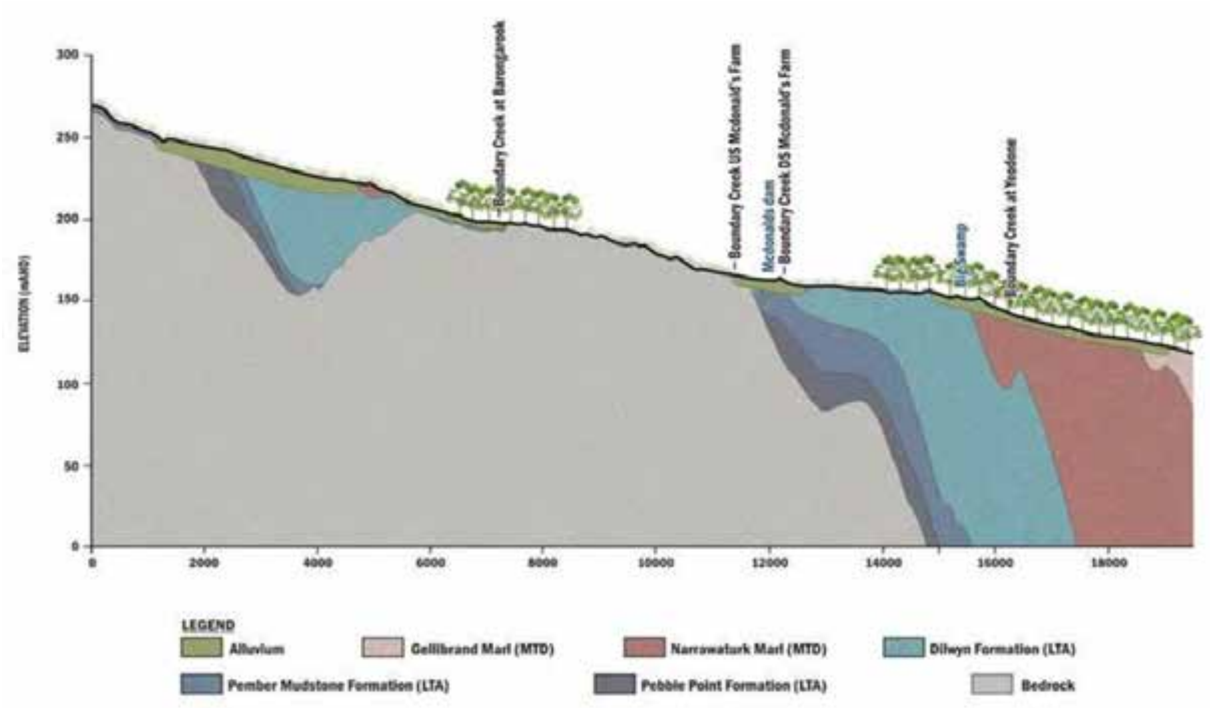


Figure 3-6. Long section along Boundary Creek (Jacobs 2017)

Since European settlement of the area, there has been significant land use change as parts of the catchment have been cleared for agricultural purposes. While this is unlikely to have affected the hydrostratigraphy, land clearing could have altered groundwater levels in the swamp, however, there is no scientific evidence to support this. Hydrogeological monitoring data from Big Swamp before the Barwon bore field installation in 1985 is sparse. There are observations from landholders recorded by

Gardiner (2012) that state there was water consistently in Boundary Creek until the 1990s. Recent groundwater monitoring shows that groundwater levels in Big Swamp have recently fallen.

Studies have confirmed that pumping from the Barwon Downs borefield over the past 30 years is the main cause of a reduction in baseflow (groundwater contribution to streamflow) in the lower reach of Boundary Creek, increasing the frequency and duration of no flow periods (Jacobs, 2018). Groundwater modelling shows that Boundary Creek, which discharges into Big Swamp, was previously gaining water from groundwater and is now losing water to groundwater (Jacobs, 2018). There are also significant seasonal changes in groundwater levels at Big Swamp due to evapotranspiration (i.e. water use by plants) over the summer period when water requirements are at their highest, representing seasonal variation in the groundwater levels as shown in the monitoring borehole data (Jacobs, 2015).

Preliminary modelling of current groundwater levels within the Swamp by Jacobs is presented in Figure 3-7.

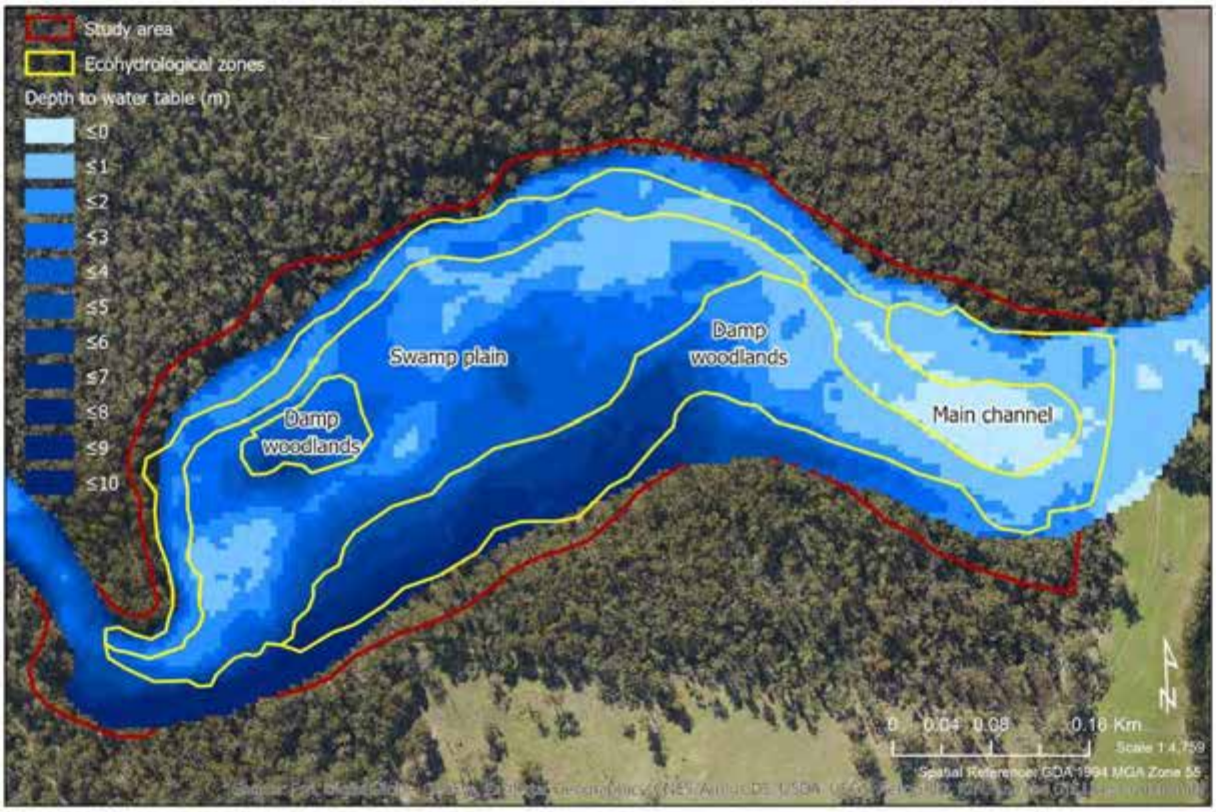


Figure 3-7. Groundwater modelling of Big Swamp

3.1.7 Groundwater-surface water connectivity

Surface water and groundwater are intimately connected at Big Swamp and Boundary Creek. Bore data collected from immediately upstream of Big Swamp (YS06 and YS05) and within the swamp at the eastern (YS02) indicates that the flow between surface water and groundwater at Big Swamp varies seasonally, with different parts of the system gaining and losing throughout the year (Table 4-5 and Fig. 3-1). During the first flow, Boundary Creek Reach 2 and the Swamp are both losing whereas during the Winter high flow, Big Swamp is neutral.

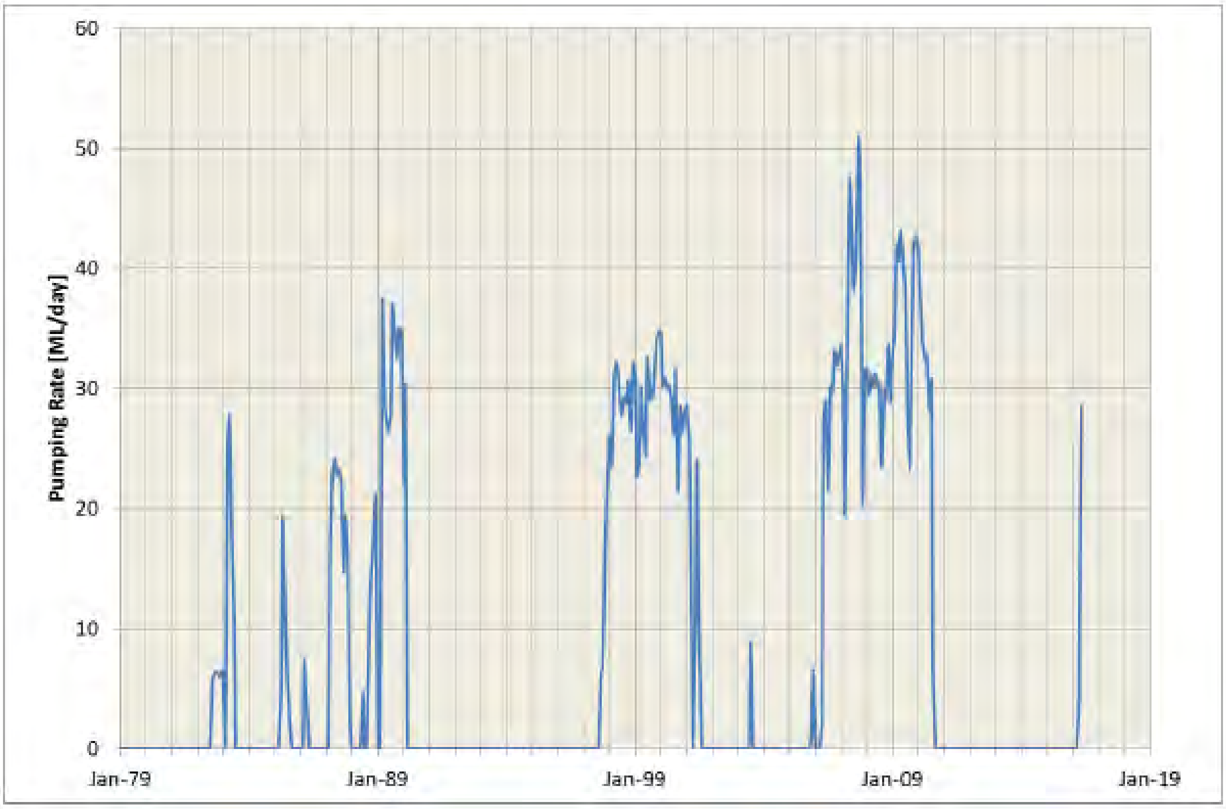


Figure 3-8. Combined borefield extraction for the Barwon Downs production wells

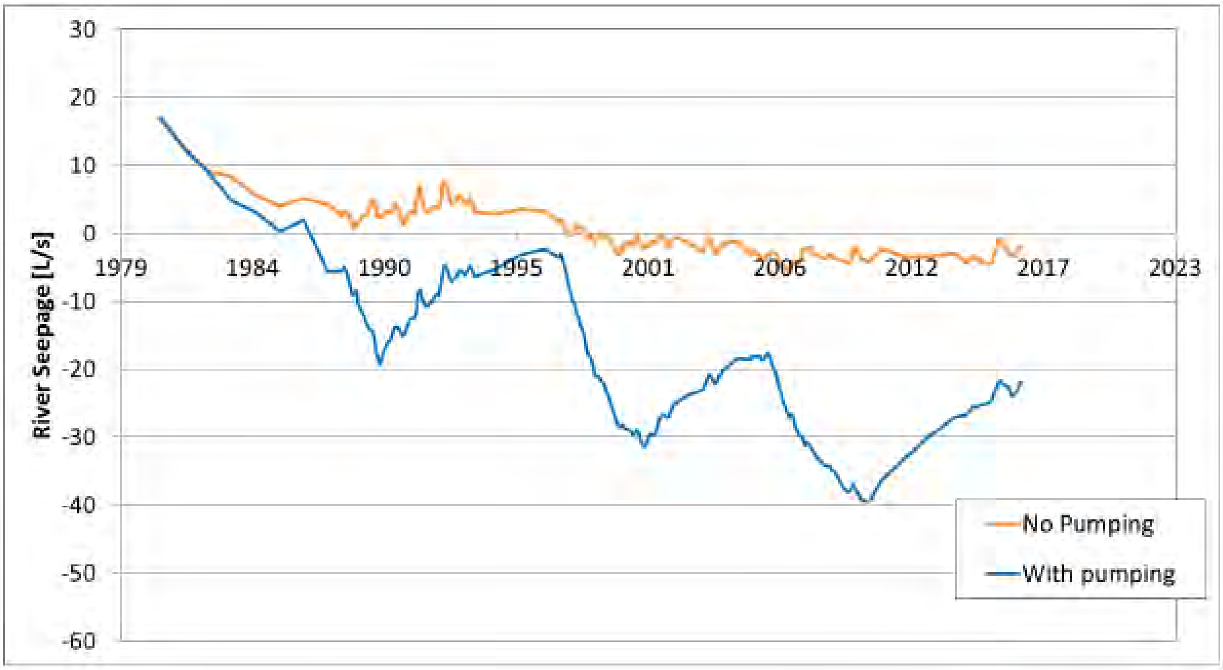


Figure 3-9. Modelled (predicted) baseflow contribution to Boundary Creek (Reach 2) with and without pumping (Jacobs 2018)

This connectivity between the groundwater and surface water is further demonstrated by the groundwater model (Jacobs, 2018). The combined extraction rate ranges up to 50 ML/day and there are periods of high extraction intermittently from 1983-1989, and consistently between 1998-2001 and 2006-2011 (Figure 3-8). Figure 3-9 shows the modelled river seepage for Boundary Creek Reach 2 during the period 1979-2016 under two different scenarios: “no pumping” and “with pumping”. Under the “no pumping” scenario, the river seepage declines steadily. Whereas under the “with pumping” scenario, the river seepage declines in a rebounding pattern, where the river seepage declines steeply and then partially recovers. Comparing Figure 3-8 with Figure 3-9 illustrates the likely impact of pumping in the Barwon Downs borefield on river baseflow. The trend in lost river seepage corresponds with periods of increased extraction. Overall, this demonstrates that the surface water in Boundary Creek Reach 2 upstream from Big Swamp is losing significant amounts of water to the groundwater when the Barwon bore field is under extraction.

3.1.8 ASS and water quality

Potential acid sulphate soils (PASS) form under reducing conditions in water logged soils, such as in submerged humous-rich soils. The reduced sulfur combines with any iron present to result in pyrite-containing acid sulphate soils (ASS) that remain inert and do not have a negative environmental impact unless they are exposed to air, in which case the pyrite minerals are oxidised and can release sulfuric acid. The introduction of this sulfuric acid into an aquatic system lowers the water pH which generally has negative impacts on the surrounding aquatic biomass.

The literature shows there have been significant declines in pH of surface water in Boundary Creek since 1999 (Jacobs 2017) and as early as 1993 (Gardiner, 2012). This decrease in pH was due to the drying of acid sulphate soils in Big Swamp. EAL (2011) found extremely high acidic soil conditions in areas of permanently or seasonally exposed wetland in Big Swamp and classified these soils as “Inland Acid Sulphate Soils”. Consistent with the effects of acid sulphate soils, the most significant changes in water quality occur through Big Swamp and included reduced pH, increased salinity, and increased concentrations of sulphate and dissolved metals. High flow conditions (> 15 ML/day) did not significantly dilute the acidic inputs or the concentration of dissolved metals.

A study conducted by Jacobs (2017) showed that groundwater quality was also affected by acid sulphate soils, particularly in the centre of the swamp, with the downstream swamp area less affected. However, the groundwater upstream of the swamp and in Reach 3 was almost unaffected by the negative consequences of the acid sulphate soils.

3.1.9 Soils

Jacobs were engaged in 2019 to undertake a program of soil sampling to a depth of 6 metres across 17 sites within Big Swamp. The sampling indicated that clays and silts are the dominant lithologies throughout the swamp with discrete sands present along the southern edge and western end. Clay was dominant through the upper reaches of the swamp, while in the lower reaches silt dominated. This is consistent with the occurrence of alluvial deposits (Jacobs 2019).

The majority of soil samples contained organic carbon, with 24% classified as mineral soils with organics, 43% as organic soils and 8% as peat (Jacobs 2019).

Charring and the occurrence of burnt material within soil profiles was limited to the upper 0.5 m of the soil profiles in cores taken towards the western portion of the swamp (Jacobs 2019). Soils that have been burnt in recent fires are characterised by a reddish humus, ash at ground level and embedded charcoal at varying depths (Jacobs 2015) Plate 1). On the terrace to the south of the swamp plain, and in the eastern end of the swamp, soils consistent of an extremely friable loamy sand to a depth of more than a metre (Plate 2).

Consistent with observations of peat soils made by Gibbons and Rowan (1993), the drying of the swamp has resulted in a collapse of pore structure and slumping. This has likely been exacerbated by sub-surface peat fires further reducing soil bulk density. This decline in structure may have led to erosion within the swamp as discussed in Section 3.1.4 above. The decline in soil structure has also likely impacted infiltration rates.

Plate 1. Soils within the swamp plain of Big Swamp

Plate 2. Soils from the terraces above the swamp plain

3.1.10 Fires

Reduced inflows and a lowering of the water table since groundwater extraction commenced has led to a drying of the surface and sub-surface layers within the swamp. The high carbon content in these soils (51% of soils sampled had an organic carbon content > 15%) can lead to ignition in low moisture conditions resulting in sub-surface fires smoulder for long periods of time. This increased susceptibility to prolonged and sustained burning is evident in the intermittent fires that have occurred within the swamp over the past 20 years. Soil sampling indicates that organic content and charring was most prevalent in the western half of the swamp correlating to the swamp plain and associated scrub communities.

In 1997, an escaped surface fire burnt over 1 hectare of the swamp resulting in the loss of mature trees and the presence of hot ash beds across the area. In 1997 and 1998, hazard reduction fires were ignited to secure the area, with a fire escaping from the swamp in May 1998.

A large (2m wide x 2m deep) trench was constructed along the southern and eastern edge of the Swamp to prevent further sub-surface fires escaping to surrounding areas. There was a long dry period between 1998 and 2006, with a small upstream fire occurring in 2006. The majority of the swamp was burnt intermittently between 1998 and 2010 (Jacobs, 2017). These fires have severely depleted organic-rich layers throughout the swamp and resulted in a substantial change in the structure and composition of the soils.

In 2010, SKM advised the local agencies that creating a dam to flood the area and control the subterranean fires could have negative environmental consequences such as further mobilisation of acidic sulphate soil and heavy metals into Boundary Creek. Sprinkler systems were installed along the southern edge of the swamp to contain the subterranean fire and prevent spread to surrounding areas during high fire risk periods.

3.2 Historic vegetation communities

3.2.1 Pre-European settlement

A palynological analysis of two cores taken from the western and eastern ends of the swamp is currently being undertaken by the University of Melbourne. This analysis may shed light on the nature of pre-European vegetation communities within the swamp. The results of this study will be incorporated into this assessment once completed in early 2020.

3.2.2 Pre-extraction

Information describing the nature and extent of vegetation within the swamp prior to extraction is limited. The primary source of reference are two aerial images taken in 1946 and 1969 along with descriptions of wetland and riparian vegetation communities from the region in the literature. Based on this information, these images appear to show three distinct vegetation communities within the swamp boundary prior to extraction commencing in 1983 (Figure 3-10 and Figure 3-11):

A. Homogenous, dense, low vegetation located within the central portion of the swamp, which may represent a scrub, sedge-, rush- or grassland community. Potential candidates include:
   - Wet-verge Sedgeland (EVC 932), as identified during the field survey (Section 3.3.1)
   - A low or open Riparian Fern Scrub community as described by Frood (2019).
   - A low sedge-dominated community similar to Sub-community 6.2: Pithy Saw-sedge (*Lepidosperma longitudinale*) Sedgeland or Sub-community 6.3: Fine Twig-sedge (*Baumea arthrophylla*) Sedgeland described from other swamps in the region (Carr and Muir 1994). An aerial image of sub-community 6.2 taken in 1993 is provided in Plate 3.
   - Alternatively, the low vegetation may be representative of a cleared and/or grazed swamp plain, which may explain the potential fence and/or drainage line, closely aligned with the current northern parcel boundary, visible in the 1946 image.

B. A homogenous, tall scrub at the western end of the swamp, likely comprised of *Melaleuca squarrosa* and *Leptospermum* species with a varied understorey of either sedges and/or ferns. This vegetation likely corresponds to the Riparian Fern Scrub community described by Frood (2019) and identified during the field survey in 2019. This community was previously included in forms of Riparian Scrub and Swamp Scrub, with the latter still being common in many contexts throughout the region. This community has also previously been described by Carr and Muir (1994) as Community 5.0: Scented

Paperbark (*Melaleuca squarrosa*) – Wholly Tea-tree (*Leptospermum lanigerum*) Swamp Forest or Scrub.

C. Damp woodlands of varying height and canopy cover along the southern edge and across the eastern end of the swamp. This vegetation type may in fact represent several distinct riparian and low-slope woodland or forest communities or ecotones. It is likely this vegetation type closely aligns with the 'Community 4.0 Swamp Gum (*Eucalyptus ovata*) Forest' described by Carr and Muir (1994) from Porcupine Creek, which occurs on "floodplains, particularly braided streams, swampy flats and swamp margins" with "organic rich, brown silty clay loams". Historically, the woodlands are likely to have supported several *Eucalyptus* species, including Swamp Gum, Manna Gum, Messmate and Brookers Gum, as could be elicited from dead stags still remaining and small pockets of woodland unaffected by the fires.

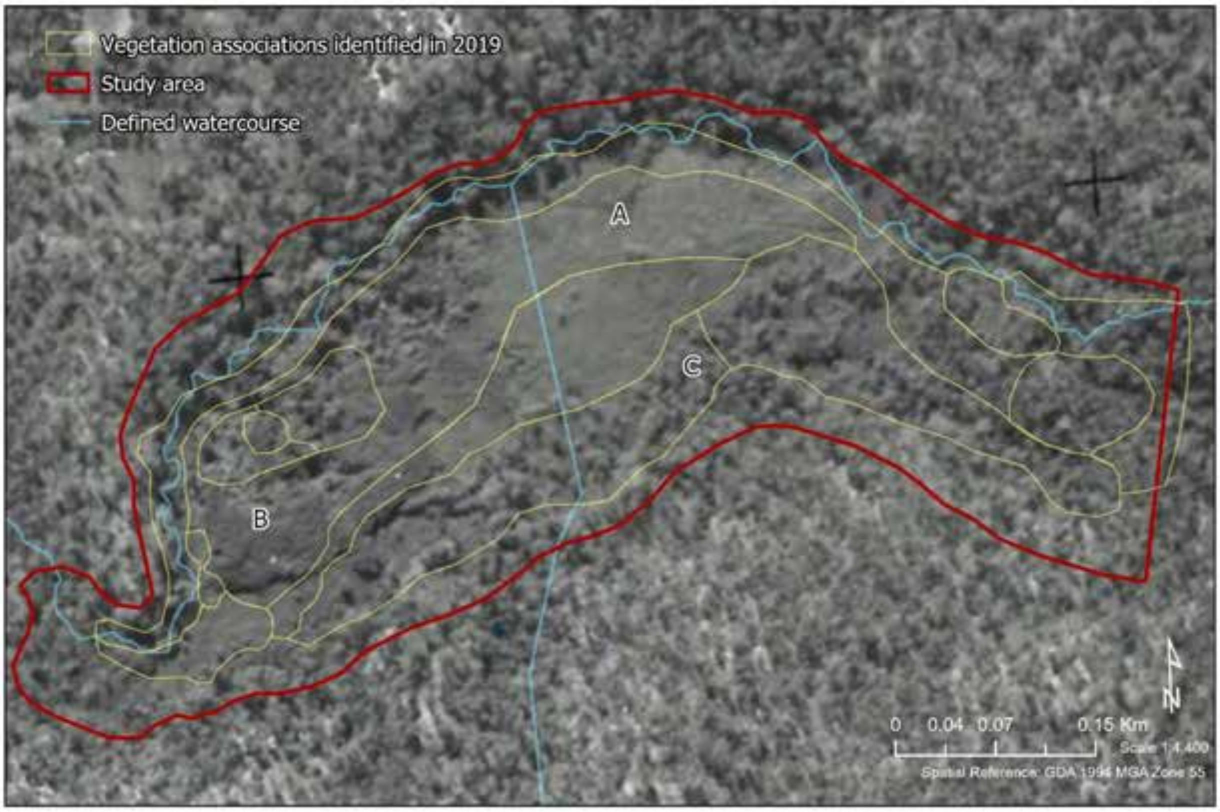


Figure 3-10. Aerial imagery of Big Swamp from 1946

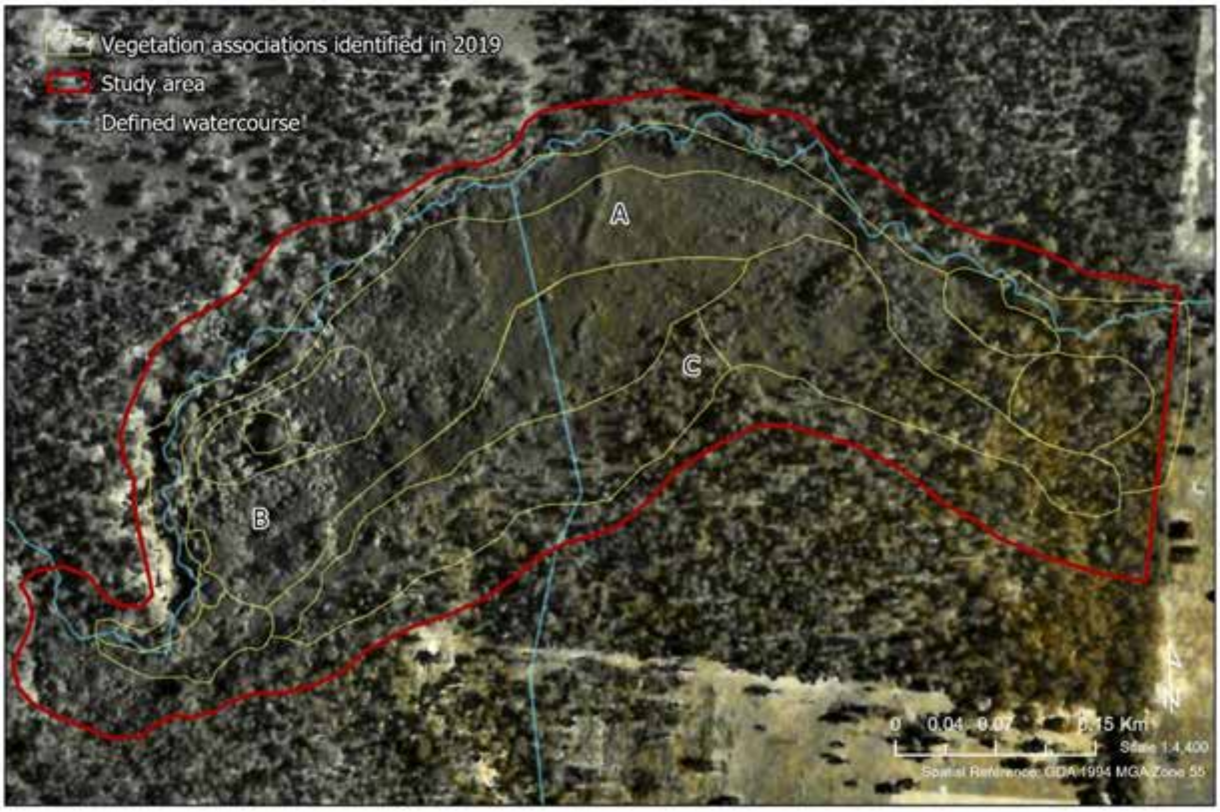


Figure 3-11. Aerial imagery of Big Swamp from 1969

Plate 3. Aerial photo of a Barwon Downs swamp dominated by Fine Twig-sedge (*Baumea arthrophylla*) (Carr and Muir 1994)

3.2.3 Post-extraction

Extraction from the Barwon Downs borefield commenced in 1983 however significant extraction did not occur until 1988 when 19,074 ML was extracted over a two-year period. Subsequently, large extraction events occurred between 1996 - 2001 (36,817 ML) and 2006 - 2010 (52,648 ML).

The nature and extent of vegetation within Big Swamp at the start of the extraction period can be elicited from aerial imagery capture in 1991 (Figure 3-12) and the vegetation surveys undertaken in 1993 by Carr and Muir (1994). Based on this, the following is assumed:

- Three main vegetation communities are present within the swamp at the start of the extraction period. As previously described in Section 3.3.2, this includes a dense scrub, sedge-, rush- or grassland community (A), a taller scrub community (B) and damp woodlands (C).
- A woodland community appears to have established along the main channel (D).
- There has been minor changes in the extent of each community over the past 40 year (i.e. 1946 to 1991), with tall scrub vegetation appearing to have expanded eastwards into the central section of the swamp. There also appears to be a change in structure within the damp woodland community with a loss of large trees and a denser (potentially lower) canopy of young Eucalypts or scrub expanding throughout the area.

Over the next 15 years (1994 – 2010) the swamp underwent significant change due to reduced surface flows, as a result of groundwater extraction and the Millennium drought, and subsequent fires, first across the western end in 1998 and then through the centre of the swamp in 2010. The consequences can be seen in the substantial loss of vegetation cover across the western end of the swamp by 2004 and then throughout the entire swamp by 2011 (Figure 3-13 and Figure 3-14). At this point in time the vegetation communities within the swamp are assumed to be substantially modified and in a state of regeneration. It appears all trees have been burnt and either fallen or remained standing as dead stags, with the understorey likely to be restricted to a few native or introduced species adapted to colonisation in post-disturbance environments (e.g. Prickly Tea-tree and Austral Braken). An open water pool has formed at the eastern end of the swamp by 2011, potentially behind a sediment plug formed due to the erosion of exposed soils upstream.

With several wet years since the end of the drought in 2011, and cessation of fire within the swamp, vegetation has re-established across the area with immature woodland (A) and scrub (B) communities visible three years later in 2014 (Figure 3-15). Transect data recorded in 2015 from regenerating scrub provides an indication of the low diversity present within the swamp, with the only native species recorded being Swamp Gum, Prickly Tea-tree, Bracken and Annual Fireweed (*Senecio glomeratus*) (Jacobs 2015) (Plate 4).

The extent of the woodland and scrub communities still largely aligns with those seen pre-extraction, with the exception that the potential low scrub or sedgeland community (that may have been present in the center of the swamp) has been replaced by a modified scrub. Regeneration of scrub also appears to vary across the site, with low cover still visible through central sections of the swamp in 2016 (A; Figure 3-16). This may be cause by changed drainage patterns, due to post-fire erosion and collapse of soil layers, reducing water availability at these locations, or poor conditions for regeneration due to changes in soil or water chemistry.

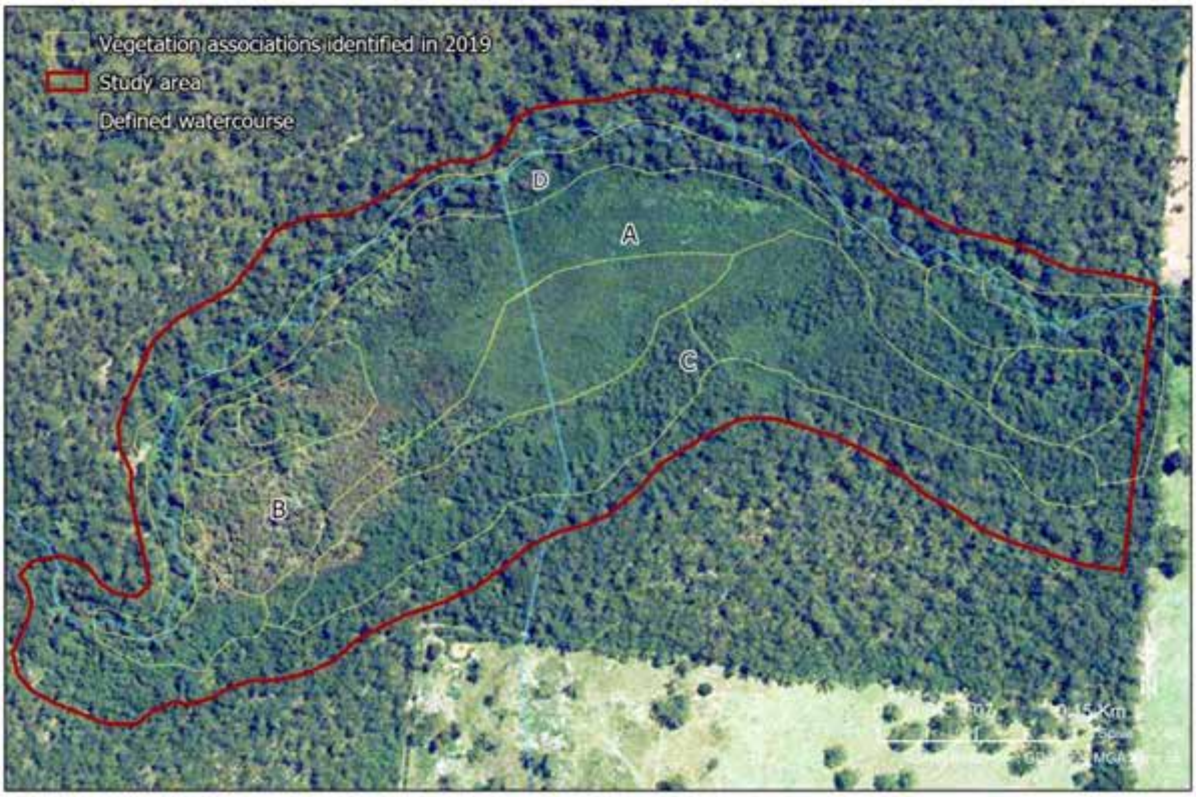


Figure 3-12. Aerial imagery of Big Swamp from 1991

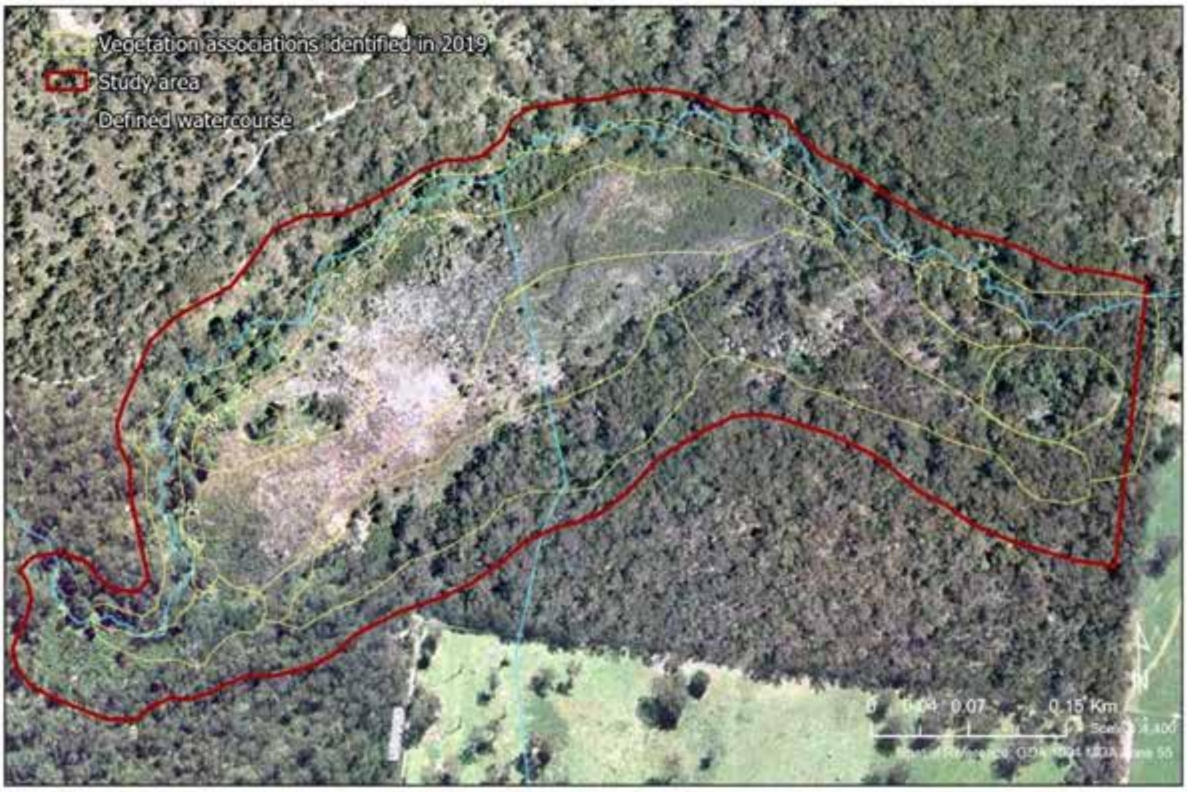


Figure 3-13. Aerial imagery of Big Swamp from 2004

Plate 4. Scrub regrowth within the swamp post-fire (charred, moss covered soil present in foreground) (Jacobs 2015)

Figure 3-14. Aerial imagery of Big Swamp from 2011

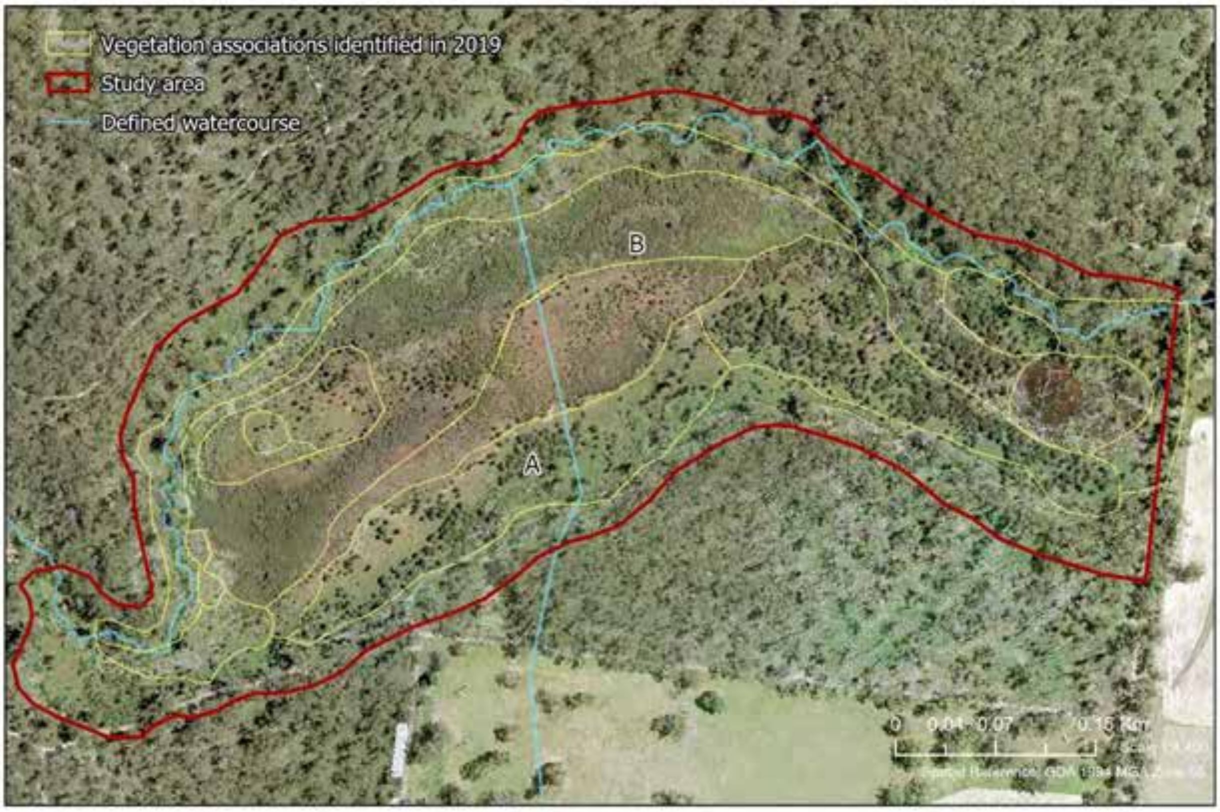


Figure 3-15. Aerial imagery of Big Swamp from 2014

Figure 3-16. Aerial imagery of Big Swamp from 2016

3.3 Current vegetation communities

3.3.1 Vegetation communities

Ecological Vegetation Classes (EVCs) are broad groupings of plant communities that share similar geographic, climatic and edaphic conditions. Each EVC has an adopted benchmark that allows assessment of the approximate condition of the vegetation using the Vegetation Quality Assessment (VQA) method. However, the VQA only has limited benchmarks for wetland plant communities, despite there being a very wide diversity of wetland types across Victoria. In contrast, the Index of Wetland Condition assessment, which was only developed in the mid 2000's, lists over 140 wetland benchmarks.

For this study, the chosen method was to utilise the Index of Wetland Condition benchmarks wherever possible, even if these are not assessable using the VQA. Four EVCs were recorded within the study area, one of which does not have a VQA benchmark (Wet Verge Sedgeland). These EVCs are described below.

Riparian Fern Scrub (EVC A120)

Riparian Fern Scrub is a recently described EVC that is distinguished from the similar Riparian Scrub by the taller canopy and more diverse ferny understorey. Riparian Fern Scrub is endangered and restricted to the Otway Ranges and possibly higher rainfall areas of the Gippsland Plain (Frood unpublished). This EVC was dominant throughout the study area where occurring on humous-rich soils influenced by the underlying perched watertable (Plate 5 and Plate 6).

The majority of the EVC has been significantly modified by reduced surface flows and subsequent fires which burnt deeply into the soil, leading to loss of humous layers, collapse of soil structure and significant soil erosion. This process very likely removed much of the original ground layer vegetation. The most heavily affected areas were dominated by Prickly Tea-tree (*Leptospermum continentale*) or Scented Paperbark (*Melaleuca squarrosa*) with occasional patches of Austral Bracken (*Pteridium esculentum*) and/or Red-fruit Saw-sedge (*Gahnia sieberiana*), with very minimal associated ground-layer species. More intact patches occurred in the far south-west of the study area in areas apparently less affected by the fires, containing Woolly Tea-tree (*Leptospermum lanigerum*) and a ground layer dominated by various sedges such as Tall Sedge (*Carex appressa*) and Tassel Sedge (*Carex fascicularis*). Areas closer to the main channel contained a braided system of channels and supported a higher cover of sedges and ferns, including additional species such as Spreading Rope-rush (*Empodisma minus*) and Scrambling Coral-fern (*Gleichenia microphylla*). Many of the understorey species, particularly patches of *Carex* and *Gahnia,* had recently died, possibly the result of acid-sulphate conditions. Weed cover was generally very low throughout the EVC.

Three vegetation associations were identified for this EVC (Table 3-1 and Figure 3-17).

Table 3-1. Riparian Fern Scrub vegetation associations identified within Big Swamp in 2019

Vegetation associations	Description	Floristic diversity	Structural diversity	Dominant species
High-diversity riparian fern scrub (RFS120-A)	A structurally and floristically complex riparian scrub exhibiting a diversity of fine-scale variation.	High	Moderate-high	Woolly Tea-tree (*Leptospermum lanigerum*), Tall Sedge (*Carex appressa*), Tassel Sedge (*Carex fascicularis*)

Vegetation associations	Description	Floristic diversity	Structural diversity	Dominant species
Dry riparian fern scrub (RFS120-B)	Dense to open scrub with a ground layer of Bracken, occasional emergent *Eucalyptus ovata*.	Low	Low-moderate	Prickly Tea-tree (*Leptospermum continentale*), Scented Paperbark (*Melaleuca squarrosa*), Austral Braken (*Pteridium esculentum)*
Wet riparian fern scrub (RFS120-C)	Dense scrub with little or no understorey, interspersed with narrow channels supporting a low-diversity of sedges and ferns. Occasional emergent *Eucalyptus ovata.*	Low-moderate	Low-moderate	Prickly Tea-tree (*Leptospermum continentale*), Scented Paperbark (*Melaleuca squarrosa*), Red-fruit Saw-sedge (*Gahnia sieberiana*)

Swampy Riparian Woodland (EVC 83)

Swampy Riparian Woodland occurred along the channel and adjacent terraces of Boundary Creek and shared a broad ecotone with the adjacent Riparian Fern Scrub (Plate 7). This vegetation contained a scattered tree layer, which may be reduced in cover due to past fires, dominated by Swamp Gum (*Eucalyptus ovata*)*,* Brooker's Gum (*Eucalyptus brookeriana*) and Manna Gum (*Eucalyptus viminalis*). There was often a secondary tree layer containing Woolly Tea-tree (*Leptospermum lanigerum*), Hazel Pomaderris (*Pomaderris aspera*) and Scented Tea-tree (*Melaleuca squarrosa*). The creek channel supported aquatic and semi-aquatic forbs and sedges including Common Water-ribbons (*Cycnogeton procerum*), Wing Pennywort (*Hydrocotyle pterocarpa*), Broad Water-milfoil (*Myriophyllum amphibian*), Small River Buttercup (*Ranunculus amphitrichus*) and Tassel Sedge (*Carex fascicularis*). Ferns dominated some areas, with prominent species including Fishbone Waterfern (*Blechnum nudum*), Hard Water-fern (*Blechnum wattsii*), Soft Tree-fern (*Dicksonia antarctica*) and Scrambling Coral-fern (*Gleichenia microphylla*). Weed cover was generally low along the channel although the riparian terraces contained grassy weeds such as Yorkshire Fog (**Holcus lanatus*).

Two vegetation associations were identified for this EVC (Table 3-2 and Figure 3-17).

Table 3-2. Swampy Riparian Woodland vegetation associations identified within Big Swamp in 2019

Vegetation associations	Description	Floristic diversity	Structural diversity	Dominant species
High-diversity Swampy Riparian Woodland (SRW83-A)	Following the main channel, this structurally and floristically complex riparian woodland exhibits a diversity of fine-scale variation.	High	High	Swamp Gum (*Eucalyptus ovata*), Brooker's Gum (*Eucalyptus brookeriana*), Woolly Tea-tree (*Leptospermum lanigerum*), Hazel Pomaderris (*Pomaderris aspera*), Common Water-ribbons (*Cycnogeton procerum*), Soft Tree-fern (*Dicksonia antarctica*)
Flooded Swampy Riparian Woodland (SRW83-B)	A flooded section of woodland with only dead stags persisting. Wetland and aquatic vegetation has begun to colonise shallow sections.	Low	Low	N/A

Wet Verge Sedgeland (EVC 932)

Wet Verge Sedgeland is a tussock dominated sedgeland found in cooler areas of Victoria (DELWP 2016). A small area of this EVC was mapped in the western portion of the study area to the east of Boundary Creek (Plate 8). The patch shared floristic affinities with the adjacent Riparian Scrub but woody species were mostly absent and the vegetation was dominated by relatively dense Tall Sedge (*Carex appressa*) and Tassel Sedge *(Carex fascicularis*). Associated species included White Purselane (*Montia australasica*), Common Spike-sedge (*Eleocharis acuta*), Rushes (*Juncus* spp.) and Slender Knotweed (*Persicaria decipiens*).

A single vegetation association was identified for this EVC (Table 3-3 and Figure 3-17).

Table 3-3. Wet Verge Sedgeland vegetation association identified within Big Swamp in 2019

Vegetation associations	Description	Floristic diversity	Structural diversity	Dominant species
Wet Verge Sedgeland (WVS932-A)	A dense, low sedgeland with a diverse, but low cover of rushes and herbs throughout.	Moderate	Low	Tall Sedge (*Carex appressa*) and Tassel Sedge *(Carex fascicularis).*

Damp Sands Herb-rich Woodland (EVC 3)

A large area that was predominately distributed on the lower slopes to the south and east of the main swamp was dominated by young Swamp Gum (*Eucalyptus ovata*) with a very species-poor understorey containing Austral Bracken (*Pteridium esculentum*) and Red-fruit Saw-sedge (*Gahnia sieberiana*) (Plate 9). Whilst this community has been described as Damp Sands Herb-rich Woodland due to its current structural and floristic characteristics (which is likely a result of changes in hydrology and recent fires), this vegetation is considered to represent a derived state of the Community 4.0 Swamp Gum (*Eucalyptus ovata*) Forest described by Carr and Muir (1994). This community has been identified throughout the region on the lowest slopes in association with braided streams, swampy flats and swamp margins, and is believed to have occupied the southern margin and eastern end of Big Swamp prior to extraction commencing.

Two vegetation associations were identified for this EVC (Table 3-4 and Figure 3-17).

Table 3-4. Damp Sands Herb-rich Woodland vegetation associations identified within Big Swamp in 2019

Vegetation associations	Description	Floristic diversity	Structural diversity	Dominant species
Modified, open Damp Sands Herb-rich Woodland (DSHW3-A)	A highly modified, immature woodland comprised of small stands of recruiting Swamp Gum interspersed with open, treeless areas of Austral Braken.	Low	Low	Swamp Gum (*Eucalyptus ovata*) and Austral Braken (*Pteridium esculentum)*
Modified, closed Damp Sands Herb-rich Woodland (DSHW3-b)	A modified, dense woodland of recruiting Swamp Gum. While generally supporting a limited understorey, small pockets of diversity were observed throughout.	Low-moderate	Low-moderate	Swamp Gum (*Eucalyptus ovata*), Austral Braken (*Pteridium esculentum) and* Prickly Moses (*Acacia verticillata*)

Lowland Forest (EVC 16)

Lowland Forest surrounded Big Swamp upslope from areas historically effected by water-logging or inundation (Plate 10). This vegetation was dominated by Messmate Stringybark (*Eucalyptus obliqua*) and Manna Gum (*Eucalyptus viminalis*) with a high cover of Austral Bracken (*Pteridium esculentum*). Prominent shrubs included Silver Banksia (*Banksia marginata*), Prickly Moses (*Acacia verticillata*), Sweet Bursaria (*Bursaria spinosa*) and Grey Tussock-grass (*Poa sieberiana* var. *hirtella*).

A single vegetation association was identified for this EVC (Table 3-5 and Figure 3-17).

Table 3-5. Lowland Forest vegetation association identified within Big Swamp in 2019

Vegetation associations	Description	Floristic diversity	Structural diversity	Keystone species
Lowland Forest (LF16-A1)	A diverse woodland with varied canopy cover dominating the drained, eastern-most edge of the swamp. Likely colonised the area due to draining of the swamp downstream.	High	High	Brooker's Gum (*Eucalyptus brookeriana*), Hazel Pomaderris (*Pomaderris aspera*), Soft Tree-fern (*Dicksonia antarctica*)

Plate 5. Riparian Fern Scrub EVC (dry association)

Plate 6. Riparian Fern Scrub EVC (wet association)

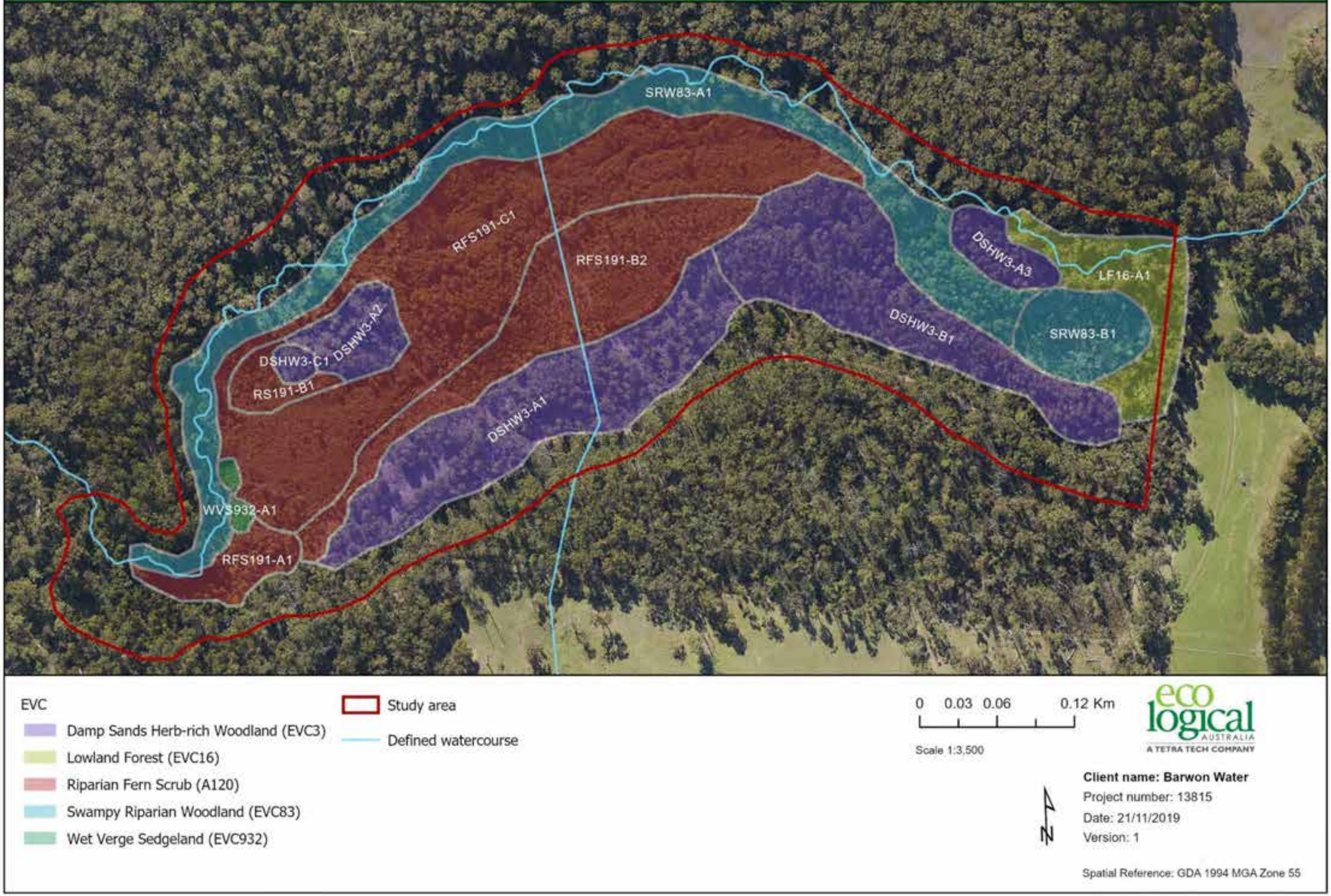
Plate 7. Swampy Riparian Woodland EVC

Plate 8. Wet-verge Sedgeland EVC

Plate 9. Damp Sands Herb-rich Woodland EVC

Plate 10. Lowland Forest EVC

Figure 3-17. Current Ecological vegetation Classes and associations in Big Swamp (2019)



3.3.2 Wetland vegetation condition

The condition of wetland communities within Big Swamp was assessed using the IWC method, as described in Section 2.2.1. As this method is only applicable to wetland EVCs for which an IWC benchmark exists, the assessment was limited to areas of Riparian Fern Scrub and Wet-verge Sedgeland with the study area.

Some challenges to applying the IWC method at Big Swamp were encountered, as the wetland has been affected by some uncommon processes which are difficult to apply to the assessment. For example:

- the IWC does not consider acid sulphate conditions,
- severe sub-surface fires as has occurred at Big Swamp are rare in Victoria, and the resulting effects on soil and bathymetry are not well covered in the assessment.
- the effects of the fires in reducing wetland extent are difficult to accurately assess, and
- assessing the hydrological changes to groundwater wetlands can be challenging without long-term bore data.

Following discussion with one of the lead authors of the IWC, consultant ecologist Doug Frood (who has also recently conducted a survey at Big Swamp [Frood 2017]), the following measures were adopted for the current assessment:

- The process of the sub-surface fire effectively reducing organic layers within the soils and the associated wetland vegetation has been considered a 'reduction in wetland area'.
- The effect of drying and sub-surface fires, and subsequent decline of soil bulk density has been considered a change in bathymetry.
- The apparent change from a near permanently saturated (boggy) wetland to a much drier state has been considered a change to both the season of inundation and the water regime category.
- The acid sulphate conditions have been assessed using the water properties sub-index, and the salinity change was considered high, even though this measure normally relates to an increase in Electrical Connectivity (EC).
- Large areas of Prickly Tea-tree in the areas affected by the fires were considered invasive and part of an 'altered process' rather than a component of EVC Riparian Fern Scrub.

Given the above assumptions, the overall IWC score for Big Swamp was 5, which has a linguistic descriptor of 'moderate' (Table 3-6). The assessment scores are provided in Appendix C with the results of each sub-index discussed below. Vegetation condition across the wetland is shown in Figure 3-18.

Wetland Catchment

The Wetland Catchment sub-index received a score of 18, which has a linguistic descriptor of 'Excellent'. This high score resulted from the fact that the wetland buffer (250m from wetland edge) of Big Swamp is predominately nature conservation reserve, with a small percentage (approximately 20%) comprised of low-density grazing.

Table 3-6. Index of Wetland Condition results for Big Swamp, September 2019

Wetland	Big Swamp			
Bioregion	Otway Plain			
Sub-index	**Score**	**Condition Category**	**Weight**	**Adjusted score**
Wetland catchment	18	Excellent	0.26	4.68
Physical form	8.75	Poor	0.08	0.70
Hydrology	0	Very Poor	0.31	0.00
Water properties	7	Poor	0.47	3.29
Soils	6	Poor	0.07	0.42
Biota	13.72	Moderate	0.73	10.02
Total				**19.11**
Overall IWC Score		**Moderate**		**5**

Physical Form

The Physical Form sub-index received a score of 8.75, which has a linguistic descriptor of 'Poor'. This score resulted from reduction of the original wetland area by approximately 45%, caused by hydrological change and subsequent fires, as well as a major change to the wetland bathymetry caused by post-fire erosion and soil collapse and the cutting of a channel on the southern side.

Hydrology

The Hydrology sub-index received a score of 0, which has a linguistic descriptor of 'Very Poor'. This score resulted from the fact that there has been a change to the season of inundation (from inundated-boggy for most of the year to only seasonally inundated) and a change in the water regime category (from 'permanent to 'periodically inundated').

Water Properties

The Water Properties sub-index received a score of 7, which has a linguistic descriptor of 'Poor'. This score resulted from the fact that there has been only low nutrient enrichment (e.g. from feral pigs and agricultural runoff within the catchment), however the change to salinity levels was scored as 'high' due to the acid sulphate conditions. Note that the salinity assessment normally relates to an increase in Electrical Connectivity (EC), but because there is no sub-index within the IWC to assess the impact of acid sulphate soils this was considered the best way to assess this measure (Doug Frood pers. comm. December 2019).

Soils

The Soils sub-index received a score of 6, which has a linguistic descriptor of 'Poor'. This index scored poorly due to the altered state of the soil layer caused by previous sub-surface fires.

Biota

The Biota sub-index received a score of 13.72, which has a linguistic descriptor of 'Moderate'. This score was a combination of the loss of canopy and understorey species from areas of dry Riparian Fern Scrub in degraded parts of the swamp, combined with less impacted wet associations and intact remnants persisting at the western end of the swamp. Weed cover was low across the wetland.

Discussion of IWC results

Although only a rapid assessment method, the IWC assessment provided a snapshot of the overall health of Big Swamp, highlighting the ecological health of separate components of the system. It is apparent from the results that the changes in hydrology and subsequent fires have been one the largest contributors to reducing the condition score, through depleting the diversity and cover of indigenous species and causing severe impacts to the soil structure and health. Although large parts of the wetland have been significantly modified, the overall score of the wetland was increased due to the presence of an intact buffer and catchment, low weed cover throughout the wetland and the presence of some areas of the wetland that are still in moderate condition.

With regards to the condition of specific vegetation associations mapped in the swamp, the IWC assessment shows a marked decline in vegetation structure and health within the Dry Riparian Fern Scrub association (RFS120-B) on the southern edge of the swamp plain (Table 3-7; Figure 3-17). This is likely attributed to poor recovery post-fire resulting in a reduced canopy cover and loss of understorey lifeforms. Whilst severely impacted by a range of soil and water quality issues, the wet Riparian Fern Scrub association (RFS120-C) in the swamp plain still contained a diversity of life forms and structures and scored relatively high on the biota sub-index. Despite this, the relative cover of lifeforms across this association was poor when compared to the areas of high-diversity Riparian Fern Scrub (RFS120-A) and Wet-verge Sedgeland (WVS932-A) remnants at the western end of the swamp plain.

Table 3-7. Biota condition scores for wetland community associations in Big Swamp

	Vegetation association	Riparian Fern Scrub (RFS120-A)	Riparian Fern Scrub (RFS120-B)	Riparian Fern Scrub (RFS120-C)	Wet-verge Sedgeland (WVS932-A)
	Max. Score	*Score*	*Score*	*Score*	*Score*
Critical Life form groupings	25	21.90	6.25	21.90	19.37
Weeds	25	22	22	22	25
Indicators of altered processes	25	20	5	10	25
Vegetation structure and health	25	25	0	20	25
EVC Sub-total	**100**	**88.90**	**33.25**	**73.90**	**94.37**

3.3.3 Terrestrial vegetation condition

The condition of terrestrial woodland communities within Big Swamp was assessed using the VQA assessment method, as described in Section 2.2.1. The assessment results are provided in Appendix C with a summary presented in Table 3-8. Vegetation condition across the wetland is shown in Figure 3 18.

Terrestrial woodland communities varied considerably in condition across the swamp, with the primary difference being the site condition scores. The area of high-diversity Swampy Riparian Woodland (SRW83-A; Figure 3-17) along the main channel was assessed as being in the best condition, due to its diverse understorey containing a range of lifeforms, presence of large trees in the canopy layer and ongoing recruitment. In comparison, the flooded Swampy Riparian Woodland association (SRW83-B) associated with the open water area in the east of the site had a limited understorey containing primarily rushes and no effective canopy layer.

The primary difference between the two Damp Sands Herb-rich Woodland associations was the greater diversity in the understorey in DSHW3-B, largely attributed to a sparse but present shrub layer which was absent from DSHW3-A. DSHW3-B also supported enough mature trees to achieve a canopy cover score.

Logs scored high across woodland associations due to the prevalence of fallen, burnt trees, with the exception of DSHW3-A. This may be due to the higher frequency of surface and sub-surface fires in this part of the swamp.

All vegetation associations received the same, relatively high, landscape context score due to being within a contiguous patch of bushland connected to a large 'core area' extending northward from the Otway Forest Park.

Table 3-8. Vegetation quality assessment conditions scores for terrestrial woodland associations within Big Swamp

VQA component	Benchmark score	DSHW3-A	DSHW3-B	SRW83-A	SRW83-B
EVC		**Damp Sands Herb-rich Woodland (EVC3)**	**Damp Sands Herb-rich Woodland (EVC3)**	**Swampy Riparian Woodland (EVC83)**	**Swampy Riparian Woodland (EVC83)**
Bioregion		Otways Plain	Otways Plain	Otways Plain	Otways Plain
Condition scores	**75**	**30**	**45**	**58**	**25**
Large trees	10	0	0	6	0
Tree Canopy Cover	5	0	2	3	0
Understorey	25	5	15	20	5
Lack of weeds	15	13	13	9	9
Recruitment	10	5	5	10	3
Organic litter	5	5	5	5	3
Logs	5	2	5	5	5
Landscape scores	**25**	**17**	**17**	**17**	**17**
Patch size	10	8	8	8	8
Neighbourhood	10	4	4	4	4
Distance to core area	5	5	5	5	5
Total	**100**	**47**	**62**	**75**	**42**

Figure 3-18. Vegetation condition across Big Swamp based on IWC and VQA assessment methods

3.3.4 Biodiversity

During the September 2019 flora survey, a total of 108 vascular plant species were recorded across the study area, including 91 (84%) that are indigenous and 17 (16%) that are introduced (Appendix A). Floristic diversity was generally higher in the western section of the site and along the main channel, whereas the central areas most heavily affected by the reduced surface flows and subsequent fires supported only limited plant diversity.

Of the flora species recorded, five are listed as threatened under the Victorian Advisory List (DEPI 2014), although two of these require flowering material to confirm the identification.

Slender Bitter-cress (*Cardamine tenuifolia*)

One plant of Slender Bitter-cress was recorded on swampy flats adjacent to Boundary Creek in the far western portion of the study area (EVC Swampy Riparian Woodland). This species is listed as 'poorly known' in Victoria and there are very few other records for the region. Slender Bitter-cress typically grows in sedgy-herbaceous vegetation of swamps and creek-lines.

Current-wood (*Monotoca glauca*)

Numerous plants of Current-wood were recorded on the slopes to the north of Big Swamp and Boundary Creek within EVC Lowland Forest. This species is listed as 'rare' in Victoria and has been recorded at numerous localities in the Otways region. Current-wood is distributed throughout a range of forested habitats.

Small Sickle Greenhood (*Pterostylis lustra*)

Several leaf rosettes were recorded beneath dense Woolly Tea-tree thickets in the north-western section of the study area that are believed to be Small Sickle Greenhood (*Pterostylis lustra*). This assumption is based on the morphology of the leaves, the fact that very few other greenhoods grow in similar swampy habitats and the presence of nearby database records. However, examination of flowering specimens is required to confirm the identification. Small Sickle Greenhood is listed as 'endangered' in Victoria and as threatened under the *Flora and Fauna Guarantee Act*. The species is only recorded elsewhere in Victoria from similar swampy habitats typically dominated by Woolly Tea-tree (Vicflora online 2019). If the species is present within the swamp, it is very likely that the population was heavily impacted by previous fire events.

Showy Lobelia (*Lobelia beaugleholei*)

Several plants of what was presumed to be Showy Lobelia were recorded along Boundary Creek and adjacent swampy flats in the western portion of the study area. Although the leaf shape matched the species, flowering material would be required to confidently identify this species from other closely related taxa within the Campanulaceae family. Show Lobelia is listed as 'rare' in Victoria and has been recorded on Boundary Creek less than one kilometre from the western end of the study area.

Brooker's Gum (*Eucalyptus brookeriana*)

Several large trees of Brooker's Gum were recorded along Boundary Creek in the eastern section of the site. This species is similar to Swamp Gum but can be distinguished by the taller form, cordate juvenile leaves and discolorous adult leaves. Brooker's Gum is listed as 'rare' in Victoria where it is only known from two disjunct localities, including the northern Otways and Daylesford-Trentham area.

Table 3-9. Summary of listed threatened species recorded within the study area in September 2019

Scientific name	Common name	Status
Cardamine tenuifolia	Slender Bitter-cress	Poorly Known in Victoria
Eucalyptus brookeriana	Brooker's Gum	Rare in Victoria
Lobelia beaugleholei	Showy Lobelia	Rare in Victoria
Monotoca glauca	Current-wood	Rare in Victoria
Pterostylis lustra	Small Sickle Greenhood	Endangered in Victoria, Listed on FFG Act

Fauna

Big Swamp and the surrounding forest contained extensive habitat for various fauna species. A total of 49 fauna species were recorded incidentally during the assessment, including 41 bird, five mammal (three of which are introduced), two frog and one crustacean species (Appendix A). Birds were noted to be relatively abundant during the assessment, with many Crescent Honeyeater (*Phylidonyris pyrrhopterus*) feeding on flowering Swamp Gum (*Eucalyptus ovata*) throughout the swamp. Of the recorded species, one is listed as threatened, this being the Rufous Bristlebird (Otways sub-species) (*Dasyornis broadbenti caryochrous*), listed as near threatened in Victoria and as threatened under the FFG Act. This species was observed near the central section of the swamp on two consecutive days and is likely resident within the study area. The Rufous Bristlebird prefers relatively dense near-coastal vegetation and is near the northern edge of its range limit at Yeodene. Burrows observed in swampy vegetation throughout part of the site possibly belong to a species of Burrowing Cray (*Engaeus* spp.), while the threatened Otways Cray (*Geocharax* gracilis) which has been recorded nearby likely occurs along Boundary Creek. Mammals recorded within the site included a low density of Eastern Grey Kangaroo (*Macropus giganteas*), whilst several feral pigs (*Sus scrofa*) were observed.

4. Ecohydrological analysis

4.1 Water requirements

A detailed description of the ecological vegetation classes identified during the field survey is provided in Section 3.3. This includes identification of dominant species for each vegetation association.

Using this information as the basis for the analysis, a detailed literature review has been conducted to identify water requirements at both a community and species level. The results of the literature review are presented in Table 4-1 (communities) and Table 4-2 (species).

4.2 Swamp hydrology

A detailed description of the physical conditions within the swamp, including hydrology, is provided in Section 3.1. The key surface and groundwater parameters for the swamp are presented below for both pre-extraction and post-extraction timeframes.

4.2.1 Pre-extraction

Prior to the installation of MacDonalds Dam in 1979 and subsequent extraction commencing in 1983, the hydrology of the swamp is assumed to be defined by:

- Seasonal rainfall patterns consisting of dry summers and wet winters. Annual average rainfall is assumed to be 600-700 mm.
- Below average rainfall between 1900 and 1950, switching to above average rainfall in the latter half of the century.
- Surface flows gaining water from the groundwater (baseflow) through Reach 2 prior to entering the swamp.
- Surface flows into the swamp ranging from 2ML/day lows in summer to 20ML/day highs in winter.
- Surface flows through the swamp are primarily focused in the main channel around the northern edge. Where flows exceeded the capacity of the channel, water moved through a series of fine, braided channels across the swamp plain in the eastern and central sections of the swamp. This broadly distributed flow converged with the main channel in the north of the site, before again flowing through a series of more confined channels in the eastern section of the swamp.
- Groundwater within the swamp was influenced by a clay aquitard which thins in the west of the site and is absent upstream of the swamp. As a result, surface water infiltration leads to development of localised perched aquifers, with the overlying alluvium and humous-rich substrates becoming saturated.
- Groundwater tables at or near the surface across much of the swamp, with seasonal variation of 1-2 metres in parts of the swamp.

- Complete drying of soils within the swamp very uncommon, with moisture ranging from saturated to damp throughout the year.

4.2.2 Post-extraction

Following the installation of MacDonalds Dam in 1979, extraction from the borefield commencing in 1983 and major droughts through much of the 1990s and 2000s, changes to the hydrology of the swamp are assumed to include:

- Below average rainfall as a result of drought events in 1982 and between 1995 and 2010 (i.e. the Millennium drought).
- Surface flows losing water to groundwater through Reach 2 prior to entering the swamp (loss of baseflows).
- Yearly cease-to-flow events in summer and reduced winter flows (<20ML/day). Noting that 2ML/day releases have prevented cease-to-flow events in recent years.
- Surface flows through the swamp remain in the main channel around the northern edge. Where flows exceed the capacity of the channel, water moves through the flood plain along a limited number of channels that have been scoured and deepened by increased rates of erosion and decline of soil structure following the numerous fire events. Flows through the swamp still converge with the main channel in the north of the site, before flowing through a narrow band of interconnected channels at the eastern end of the swamp.
- Groundwater across much of the swamp has dropped below 1 metre, with near-surface water table levels only persisting at the eastern-most end. Throughout much of the central and western sections of the swamp, water levels are below 2 metres. This represents an overall drop in the water table across the swamp of between 1 and 2 metres.
- Drying within the swamp has exposed acid-sulphate soils (ASS) down to a depth of 2 metres, with low pH surface and ground water, along with heavy metals, being released. Heavy iron flocculation covering inundated surfaces is also present.

Table 4-1. Water requirements of wetland communities identified within Big Swamp

Community	Description	Typical species	Ecohydrological requirements	Management considerations	Source
Riparian Fern Scrub (EVC 191) / Community 5.0: Scented Paperbark (*Melaleuca squarrosa*) - Woolly Tea-tree (*Leptospermum lanigerum*) Swamp Forest or Scrub	A dense tall shrubby vegetation with a primarily ferny ground-layer, associated with waterlogged and inundation-prone soils with a substantial organic content. Distinguished from Riparian Scrub (EVC 191) and Riparian Thicket (EVC 59) by greater height and more open and diverse ferny understorey. Distinguished from Swamp Scrub by being dominated by Scented Paperbark as well as by understorey character. Localised in the Otway Ranges and probably also higher rainfall parts of the Gippsland Plain (Frood, and Papas 2016).	Usually dominated by *Melaleuca squarrosa*, sometimes with *Leptospermum lanigerum*, with *Eucalyptus ovata* generally a relatively minor component where present. Ferns are conspicuous, variously including *Blechnum minus, Blechnum nudum, Blechnum wattsii, Dicksonia antarctica, Gleichenia microphylla, Histiopteris incisa, Hypolepis* spp.*, Pteris tremula* and *Todea barbara*. Other species variously include *Gahnia sieberiana, Tetrarrhena juncea, Isolepis inundata, Cycnogeton procerum s.l., Gratiola peruviana, Juncus* spp. (notably *J. procerus* and *J. gregiflorus*), *Myriophyllum pedunculatum* and *Triglochin striatum* s.l. (Frood, and Papas 2016)	In this EVC, the inundation period is not necessarily continuous, varying with rainfall events. Inundation is mostly relatively superficial outside of flooding events but deep waterlogging from groundwater seepage can be more or less permanent. The extent of inundation is sometimes ambiguous due to soft saturated substrates (Frood, and Papas 2016). Comparable vegetation within region exhibits “water table seemingly at or near surface, with free water often present; subject to regular seasonal inundation - whole site could be flooded to c. 20 cm or more for weeks or months. Sites dominated by Woolly Tea-tree tend to have less frequent or briefer periods of inundation.” (Carr and Muir 1994) This EVC is expressed continuously irrespective of seasonal changes to hydrology. **Inundation frequency:** Constant, annual or less frequent but before wetland dries. **Duration of waterlogging:** > 6 months **Duration of inundation:** < 6 months **Inundation depth:** Shallow (< 30 cm)	Protection from drainage and maintenance of groundwater levels are the main considerations relevant to the hydrological requirements of this EVC (Frood, and Papas 2016).	Frood, and Papas (2016), Carr and Muir (1994)
Swampy Riparian Woodland (EVC 83) / Community 4.0: Swamp Gum (Eucalyptus ovata) Forest	Eucalypt dominated woodland vegetation (in mosaic with scrub/reed-beds) associated with very low-gradient streams within areas subject to riparian processes. Typically constitutes linear wetland, but includes drier banks and levees, as for Floodplain Riparian Woodland. Scattered in moister lowland areas.	*Eucalyptus ovata* or *Eucalyptus camphora* subsp. *humeana*, variously *Leptospermum lanigerum*, *Melaleuca ericifolia* (southern Victoria only), *Phragmites australis, Persicaria decipiens, Calystegia sepium* subsp. *roseata, Acacia melanoxylon, Poa labillardierei* and *Poa ensiformis*.	The extent and frequency of inundation of this EVC varies with seasonal/annual rainfall. More prolonged inundation is usually restricted to the lower-lying portions, such as depressions derived from prior channels. Otherwise inundation is mostly relatively brief, following rainfall events, and not necessarily continuous over the wetter months. The habitat may remain waterlogged for substantial periods. Comparable vegetation within region is presumed to have “water table very near surface with some free water present, soil permanently boggy and seasonally inundated.” (Carr and Muir 1994) This EVC is expressed continuously irrespective of seasonal changes to hydrology. **Inundation frequency:** Seasonal inundation (annual or near annual inundation) **Duration of waterlogging:** > 6 months **Duration of inundation:** < 6 months **Inundation depth:** Shallow (< 30 cm)	Management should be primarily about replicating patterns of natural flooding events, in conjunction with maintaining the water-table. It is important to allow natural drainage. If inundation is too sustained, the trees can be at risk of drowning Frood, and Papas (2016).	Frood, and Papas (2016), Carr and Muir (1994)
Damp-sands Herb Rich Woodland	A low, grassy or bracken-dominated eucalypt open forest or woodland to 15 m tall with a large shrub layer and ground layer rich in herbs, grasses, and orchids. Often presents as a somewhat intermediate between Heathy Woodland and other EVCs such as Herb-rich Foothill Forest. Frequently associated with a sand horizon deposited over older, more fertile soil/geology. Trees are able to access the deeper material via their root systems while smaller plants are confined to the less fertile upper layer, promoting heathy elements.	In higher rainfall areas of the Otways region grows in association with Messmate *E. obliqua* and Swamp Gum *E. ovata*. A few scattered shrubs may be present including Coast Beard-heath *Leucopogon parviflorus*, Prickly Moses *Acacia verticillata*, Sweet Bursaria *Bursaria spinosa*, Prickly Tea-tree *Leptospermum continentale*. The ground stratum is dominated by dense Austral Bracken *Pteridium esculentum* above a diversity of forbs, grasses and other graminoids.	Within the Midlands and Otways region Damp Sands Herb-rich Woodland occurs on deep sandy loams, usually associated with adjacent creeks or seasonal lakes and swamps. Effective rainfall is increased by the shallow water tables associated with the creeks that provide adequate moisture to support a rich ground layer of forbs and grasses, including many weed species. Due to its position in the landscape, on terraces above creeks or alluvial flats, aspect and rainfall are of little significance and the community is often ground water dependant. Inundation is not considered a driver for this community.	Maintenance of water tables is required to ensure damp soil conditions are maintained to support canopy species. Drying of surface layers can be tolerated by seasonal waterlogging is required to maintain species diversity in the long-term.	NRE (1999), Tumino and Roberts (1998)

Table 4-2. Water requirements of dominant species identified within Big Swamp

Species	Habitat	Waterlogging[1]			Inundation[1]				GW dependence[2] (Jacobs 2015)	Moisture dependence[3] (SKM 2009)	Summary of water requirements	EVC / vegetation association	References
		<1 month	1-6 months	>6 months	<1 month	1-6 months	>6 months	Permanent					
Acacia verticillata	Moist sandy or clay soils, foothill forests, damp woodlands and forests.	✓	✓		✓				2	3/4	Prefers moist, well-drained soil. Withstands periods of waterlogging and drying in summer. Will not tolerate periods of prolonged inundation.	Damp Sands Herb-rich Woodlands (EVC3)	Bull 2014, Yarra Ranges plant directory,
Blechnum minus	Forested areas, occurring in stream beds, along creek banks and on swamp margins, occasionally growing epiphytically on tree-fern trunks or fallen logs. Juvenile or sterile, suppressed adult plants are commonly found in swampy Tea-tree thickets and along heavily shaded stream margins.	✓	✓	✓					3	2	Moist to wet humus rich soil, tolerates inundation, full sun to semi shade. Roots must remain moist. Tolerates flood events but not inundation.	Riparian Fern Scrub (EVC 191) where inundation is largely absent, Swampy Riparian Woodland (EVC 83)	Vicflora 2019, Bull 2014
Blechnum nudum	Forested stream banks, in deeply shaded gullies and alluvial flats, occasionally in more exposed situations in poorly drained areas.	✓	✓	✓					3	2	Moist to wet humus rich soil, full sun to semi shade. Tolerates flood events but not inundation.	Riparian Fern Scrub (EVC 191) where inundation is largely absent, Swampy Riparian Woodland (EVC 83)	Vicflora 2019, Bull 2014, Yarra Ranges plant directory,
Carex appressa	Riparian, swamps, watercourses, and occasionally in water. Common along watercourses and in wettish depressions almost throughout the State.	✓	✓	✓	✓	✓			4	2/3	Permanent waterlogging. Seasonal flooding related to streamflow. Tolerates flow and periods of prolonged inundation.	Riparian Fern Scrub (EVC 191) where inundation is common, Swampy Riparian Woodland (EVC 83), Wet Verge Sedgeland (EVC 932)	Bull 2014, Vicflora 2019, Hamilton et al. 2013
Carex fascicularis	Edges of wetlands and creeks that are frequently flooded, bases are sometimes submerged, mostly in cooler lowland areas	✓	✓	✓	✓	✓			4	1/2	Moist soils, semi-shade, tolerating prolonged periods of inundation.	Riparian Fern Scrub (EVC 191) where inundation is common, Swampy Riparian Woodland (EVC 83), Wet Verge Sedgeland (EVC 932)	Romanowski 1998, Bull 2014
Dicksonia antarctica	Occurring mostly in forested areas of high rainfall, particularly in shaded gullies and near streams and waterfalls	✓	✓	✓					4	2/3	Moist humus-rich soils, in humid high rainfall areas, southerly and easterly aspects, semi-shade to full sun. Moist to wet soil, roots must remain moist. Does not tolerate inundation.	Swampy Riparian Woodland (EVC 83)	Bull 2014, Vicflora 2019, Yarra Ranges plant directory
Eucalyptus brookeriana	Occurs infrequently on wet sites in the Otway Ranges, commonly on alluvial deposits adjacent to streams and swamps.	✓			✓				4		Sites with relatively high rainfall and fertile soils. Tolerates infrequent water logging and inundation, however will not tolerate prolonged periods of water stress.	Damp Sands Herb-rich Woodlands (EVC3), Lowland Forest (EVC 16)	Vicflora 2019
Eucalyptus obliqua	Mainly a species of cool, well-watered mountain forests, but also common in sandy damp heaths.								2		Prefers seasonal damp soils tolerating periods of prolong drying. Will not persist under regular inundation patterns.	Damp Sands Herb-rich Woodlands (EVC3), Lowland Forest (EVC 16)	Vicflora 2019
Eucalyptus ovata	A widespread species which occurs in poorly drained infertile and clay which may dry out in summer. Prefers sands and clays of swampy flats and poorly drained slopes and hollows.	✓	✓		✓				4	3-4	Able to withstand flooding for several months, however will also grow on well drained sites.	Riparian Fern Scrub (EVC 191) as an emergent, Swampy Riparian Woodland (EVC 83), Damp Sands Herb-rich Woodlands (EVC3) in areas prone to inundation.	Yarra Ranges plant directory, Vicflora 2019
Eucalyptus viminalis	Deep moist loam soils, in valleys or low-lying areas.								3	4-5	Occurs mostly in wetter or seasonally well-watered areas. Tolerant of dry conditions however often dependant on ground water to meet water needs during periods of low rainfall.	Damp Sands Herb-rich Woodlands (EVC3), Lowland Forest (EVC 16), Swampy Riparian Woodland (EVC 83)	EUCLID
Gahnia sieberiana	Occurs in a wide variety of damp to wet sites from heathlands near sea-level to wet mountain forests, usually on sandy or silty alluvial soils. Often found on fringes of ephemeral creeks or areas which may flood in winter.	✓	✓	✓					3	2	Permanent waterlogging. Intolerant of strong flow; No or shallow (<0.2 m) flooding, however will not tolerate prolonged inundation.	Riparian Fern Scrub (EVC 191), Swampy Riparian Woodland (EVC 83), Damp Sands Herb-rich Woodlands (EVC3)	Hamilton et al. 2013, Romanowski 1998
Gleichenia microphylla	Forming scrambling thickets in sunny areas with ample moisture throughout southern Victoria.	✓	✓	✓					3	2	Permanently moist to wet soils in brightly lit position. Not tolerant of inundation however seasonal, low energy flooding possible.	Riparian Fern Scrub (EVC 191) where inundation is largely absent, Swampy Riparian Woodland (EVC 83)	Romanowski 1998, Vicflora 2019
Histiopteris incisa	Heathy woodland, riparian scrub, swampy riparian woodland	✓	✓	✓						4	Prefers moist, well-drained soil. Not tolerant of inundation.	Riparian Fern Scrub (EVC 191) where inundation is absent, Swampy Riparian Woodland (EVC 83)	Bull 2014

Species	Habitat	Waterlogging[1]			Inundation[1]				GW dependence[2] (Jacobs 2015)	Moisture dependence[3] (SKM 2009)	Summary of water requirements	EVC / vegetation association	References
		<1 month	1-6 months	>6 months	<1 month	1-6 months	>6 months	Permanent					
Isolepis inundata	A variable and adaptable species, occurring from brackish swamps near sea-level to shaded mountain gullies, mostly in the southern half of the State.	✓	✓	✓	✓	✓			5	2/3	Moist to wet soils requiring regular seasonal inundation.	Riparian Fern Scrub (EVC 191)	Bull 2014, VicFlora
Leptospermum continentale	Widespread in heath-lands and woodlands, usually on well-drained sandy soils, but also on swamp and stream margins.	✓	✓	✓	✓				3		Tolerates well-drained, moist to wet soils. Seasonal shallow (<0.5 m) flooding but not prolonged inundation. Tolerates weak or low flows.	Riparian Fern Scrub (EVC 191) Swampy Riparian Woodland (EVC 83)	Bull, 2014, Hamilton et al. 2013
Leptospermum lanigerum	Widespread forming thickets in lowland swamps, fringing watercourses in the foothills.	✓	✓	✓	✓	✓			3	2	Requires moist to wet soil conditions. Flood tolerant under weak or low flows. Tolerates seasonally shallow (<0.5 m) flooding. Prolonged inundation is likely to adversely affect plant health.	Riparian Fern Scrub (EVC 191) Swampy Riparian Woodland (EVC 83)	Bull 2014, Vicflora 2019, Zacks et al 2018, Frood and Papas 2016, Hamilton et al. 2013
Melaleuca squarrosa	Mostly in wet and peaty soils, fringing swamps, streambanks and sometimes shaded gullies	✓	✓	✓					4	2	Moist to wet soil, full sun to semi shade. Will tolerate flooding and inundation but regular cycles will result in a decline in plant health over time.	Riparian Fern Scrub (EVC 191) Swampy Riparian Woodland (EVC 83), Damp Sands Herb-rich Woodlands (EVC3)	Zacks et al 2018, Vicflora 2019
Pomaderris aspera	Common in wet and shaded forests on moist, well-drained humus rich acidic soils, semi-shade to full sun.	✓			✓				3		Prefers moist soils. Tolerant of short-duration seasonal waterlogging and inundation.	Swampy Riparian Woodland (EVC 83)	Bull 2014
Pteridium esculentum	Found everywhere except poorly drained soils and heavily shaded sites	✓	✓		✓				2	4/5	Tolerant of both moist and dry soils, however prefers seasonally wet conditions. Tolerant of short-duration seasonal inundation.	Damp Sands Herb-rich Woodlands (EVC3), Lowland Forest (EVC 16)	Bull 2014, Yarra ranges plant directory
Todea barbara	Fern gullies along watercourses in damp forest and wet forest	✓	✓	✓						2	Moist to wet humus rich soil, full sun to semi shade. Tolerates flood events but not inundation.	Riparian Fern Scrub (EVC 191) where inundation is largely absent, Swampy Riparian Woodland (EVC 83)	Bull 2014,
Cycnogeton procerum	Common in still to slow-flowing fresh water to 2 m deep, mostly in permanent swamps, lagoons and streams, but withstands extensive periods of dryness.							✓		1	A permanent aquatic that will tolerate dry conditions by dying back to tuber and resprout once moist. Requires flooding to flower.	Swampy Riparian Woodland (EVC 83)	Romanowski 1998, VicFlora
Triglochin striata	Annual plants of damp soils in seepage areas, winter-wet depressions, estuarine areas.	✓	✓	✓	✓	✓					Prefers damp, water-logged situations, usually in the margins of ponds and lagoons. Likely to be found in freshwater but moderately tolerant of sailne/brackish water. Tolerant of prolonged shallow inundation.	Riparian Fern Scrub (EVC 191) Swampy Riparian Woodland (EVC 83)	Romanowski 1998

[1] Arthur Rylah Institute dataset (Sinclair, unpublished)

Inundation; records the maximum length of time a typical plant naturally endures inundation by water (any depth of water above the substrate surface, fresh or saline); and/or waterlogging near the soil surface (~30cm) and/or encompassing most of the plant's root zone.

[2] SKM (2009) review of moisture dependence:

1 - Obligate aquatic (emergent, submergent on floating) or amphibious species

2 - Requires ± constantly moist or saturated root zone; tolerant of periods of moderate inundation

3 - Occurs in situations with seasonally/intermittently wet root zone but substrate may be relatively dry for part of the year

4 - Occurs in relatively moist environments (e.g. lower slopes, southern aspects or drainage lines) but with freely draining substrates; roots may have access to water table at depth

5 - Opportunistically occurring in wet/moist environments (e.g. on small rises or stumps) but normally considered 'dryland' species; note that ecotypes of the species may be more moisture-dependant that others.

[3] Jacobs (2015) function group definitions:

0 – Not connected to ground and therefore not linked to groundwater (e.g. epiphytes): No ground water dependency.

1 –Obligate terrestrial species requiring well aerated soils and not tolerant of saturating conditions in root zone. Can include shallow rooted and annual weed species making opportunistic use of seasonal water availability: opportunistic groundwater dependency.

2- Terrestrial species sometimes found in GDEs as an opportunistic user of available water. Common in ecosystems outside the GDEs assessed where availability of groundwater is low or non-existent. Includes ferns such as Bracken, shrubs such as Prickly Moses and trees such as Messmate: opportunistic groundwater dependency.

3 - Terrestrial species only found in riparian ecosystems or GDEs. Species require readily available water but are not tolerant of regular inundation: groundwater dependant.

4 - Species requiring at least periodic inundation of root zone for continuing survival: groundwater dependant.

5 - Species requiring regular inundation of root zone for continuing survival: groundwater dependant.

4.3 Ecohydrological assessment

The following analysis compares the historic relationship between water and vegetation with the current conditions measured and modelled within the swamp. For the purpose of the analysis, the study area has been split into three ecohydrological zones which broadly align with the vegetation communities identified onsite (Figure 4-1). A brief discussion of the potential implications of currently proposed remediation actions is provided at the end.

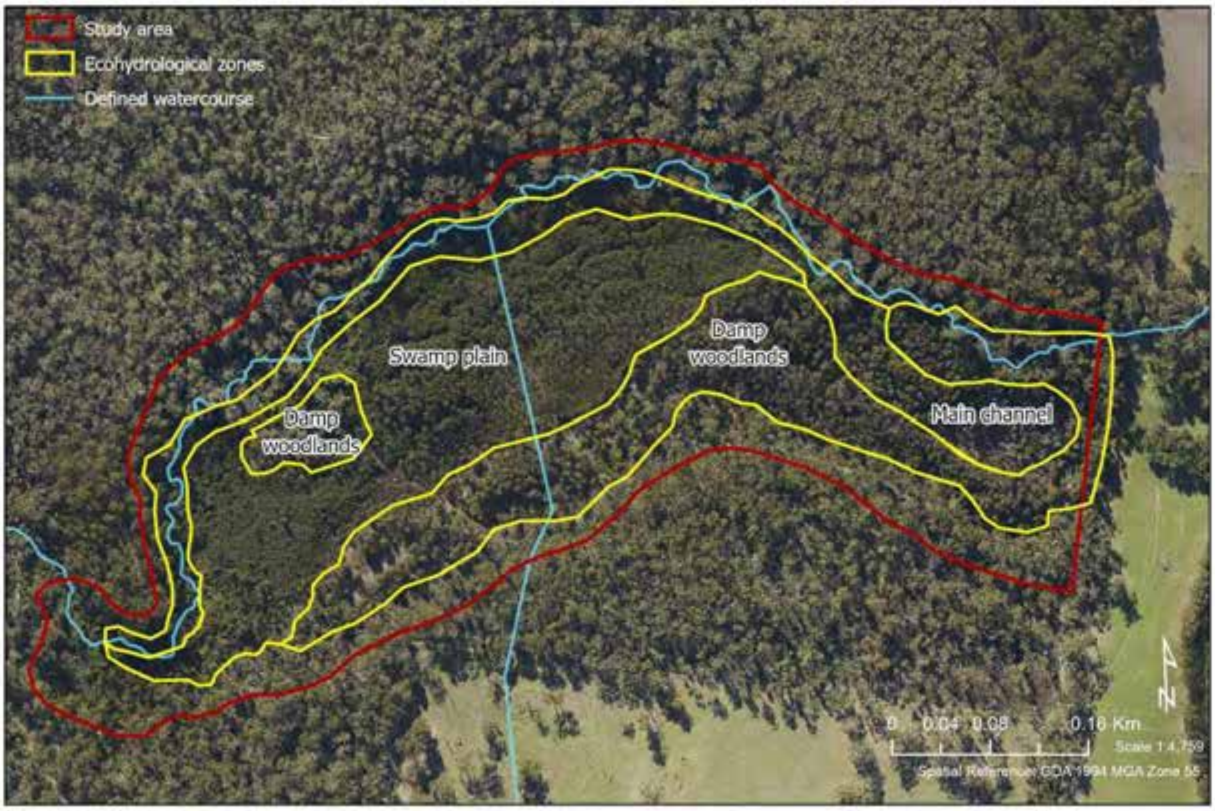


Figure 4-1. Ecohydrolgoical zones within Big Swamp

4.3.1 Swamp Plain

The eastern end of the swamp is dominated by vegetation classified as Riparian Fern Scrub (Figure 3-17). This community requires near-continuous waterlogging of the soil with shallow, often prolonged, periods of inundation (Frood and Papas 2016). Where conditions result in frequent or prolonged inundation, sedges and rushes are likely to become dominant in the understorey. Alternatively, drier conditions would likely see a shift to a fern dominated understorey with emergent trees common.

This correlates with historical evidence indicating that the swamp plain occupied by this vegetation likely consisted of a series of fine, braided channels with substantial inter-channel flow and a broad inundation pattern. The recent development of ASS down to a depth of 2 metres indicates that the soils in this part of the swamp were consistently moist year-round, further aligning with the requirements of this community. The source of historical near-surface waterlogging is difficult to determine with the information available, and therefore may have been a result of water tables at or near the surface, infiltration of surface water or a combination of the two.

Long periods of inundation at the northern end of the swamp, due to the convergence of surface flows (both through the swamp and from the southern tributary) with the main channel, are likely to have contributed to the presence of a low scrub or sedge dominated community in the lowest parts of the swamp plain. Where elevation inhibits prolonged inundation, but provides ample water to maintain waterlogging of the soil, ferns would likely have been present. As elevation increased further to the south and west, and around the small hillock in the north west, vegetation would have dried and graded into a Swamp Gum or Manna Gum woodland fringing the wetland.

In recent years, this part of the swamp has seen significant drying of the substrate, resulting in occasional fires and the loss of vegetation cover. Dominant species such as Prickly Tea-tree and Scented Paperbark have re-colonised the swamp plain post-fire, however this can be attributed to the substantial seed bank likely to have been present and strong post-fire response of these species. Despite the presence of canopy species, understorey species are now virtually absent. A diverse and structurally complex understorey remains only at the west and northern edges of the swamp plain where strong interaction with the main channel likely protected fern and sedge species from the impacts of drying and fires.

The reduced water-table currently present throughout much of the swamp plain is unlikely to support a Riparian Fern Scrub community in the long-term, leading to a gradual shift to a terrestrial damp woodland community over time. Evidence of Swamp Gum encroachment in the form of distinct recruitment cohorts progressively expanding into the swamp plain were observed along the eastern edges and to the east of the small hillock during the field survey (Plate 11). At immediate risk is the Dry Riparian Fern Scrub (RFS120-B) association identified in Figure 3-17.

Plate 11. Swamp Gum regenerating within swamp plain

Whilst there is insufficient information to determine the effects of poor water quality (primarily low pH) on vegetation in this context, the physical influence was visible during field assessments with heavy iron flocculation clinging to all vegetation currently underwater.

4.3.2 Main Channel

Given the narrow and visually discrete nature of the main channel skirting the north of the swamp, there is limited historical information to determine the past condition and nature of this vegetation. Despite this, it can be surmised that this community is likely to have been the least affected by drying of the swamp due to reliable access to surface water during low flow events.

The community observed during field assessments was classified as Swamp Riparian Woodland and exhibited a high level of structural and floristic diversity along the majority of the channel's length. This vegetation type can be highly variable and shares much in common with riparian and swamp scrub communities. Species tolerant of seasonal inundation, such as Swamp Gum and Hazel Pomaderis were present along much of the northern edge of the channel, with the southern side variously alternating between a broad ecotone with the adjacent Riparian Scrub and damp forested sections supporting trees and a range of ferns.

Whilst diverse, this community is likely reliant predominantly on surface flows through the main channel and associated infiltration into the surrounding ground layer. The depth of the channel and variation in elevation along the banks means inundation of this community may have been limited to seasonal floods and localised depressions. Tall forest species less tolerant of inundation, such as Brooker's Gum and Manna Gum, where also present further up the bank as the community shifted into Lowland Forest.

Surface flow modelling undertaken by Jacobs (2019) indicates that even under relatively low flows (e.g. 2ML / day) water persists in the channel. As a result, this community is likely to be more tolerant of long-term reductions in surface flows and the associated reduction in water tables within the swamp. However, should cease-to-flow events continue for extended periods, as has occurred in recent years, this community is to likely to be affected through a reduction in species diversity and encroachment by Lowland Forest species.

4.3.3 Damp woodlands

Historically, woodlands dominated the eastern end of the wetland, small hillock in the north-west and southern edge of the swamp. Whilst this is still the case, this community has been heavily affected by the dry conditions and fire with an absence of mature trees throughout. The community is now a dense stand of Swamp Gum less than 30 years old with a limited understorey.

Historically, the woodlands are likely to have supported several Eucalyptus species, including Manna Gum, Messmate and Brookers Gum, as well as Swamp Gum. The understorey would also have been diverse, with structure and floristics likely to have varied considerably throughout due to changes in elevation, and hence depth to water table, along with proximity to surface flows and inundation.

Based on winter surface flows (20ML/day) modelled by Jacobs (2019), these communities are unlikely to have experienced inundation in normal years. They would still have been heavily dependent on ground water with near-constant access to water between 5 - 10 metres below the surface (Jacobs 2016). These conditions are likely to have been a strong driver of this community and differentiated it from the Lowland Forest EVC on the slopes above.

Currently, this community is in a state of transition, with species tolerant of wet conditions (e.g. Swamp Gum) expanding into the scrub dominated areas of the swamp. Without the restoration of ground water levels, opportunities may be created for Lowland Forest species to colonise this area as the canopy matures and thins. In time this would have the effect of reducing the overall extent of the wetland as the surrounding forests move in.

Measures recommended to protect ecological values are provided below (Section 5.2).

5. Conclusions

5.1 Discussion

The ecology of Big Swamp is complex and intricately linked to the hydrology of the site. The hydrology is in turn informed by a range of factors including soils, topography and climate, as well as surface water use upstream and ground water extraction from the underlying deep aquifer leading to greater rates of surface water infiltration throughout the catchment.

Historically, the swamp is likely to have supported a diverse wetland ecosystem comprised of four distinct vegetation associations:

- A low scrub community through the central and northern sections of the swamp plain. This is likely to be an association of the Riparian Fern Scrub vegetation community which is tolerant of frequent or prolonged inundation and saturated soil conditions, with sedges considered likely to be dominant in the understorey.
- A tall scrub at the western end and fringing the swamp plain, considered to be an association of the Riparian Fern Scrub vegetation community which is differentiated from the above community due to less frequent or prolonged periods of inundation and moist rather than saturated soil conditions. Likely ferns were dominant throughout this association.
- A highly variable, low riparian woodland along the main channels around the northern edge and eastern parts of the swamp. Swamp Gum likely to have been the dominant canopy species, however the community would have included other Eucalypts tolerant of wet conditions as well as a diversity of understorey shrubs, ferns, sedges, rushes and herbs.
- A damp woodland fringing the swamp plain and areas of riparian woodland, primarily along the southern edge and across much of the eastern third of the swamp outside the influence of existing channels. This varied woodland would have supported a range of tall Eucalypts as co-dominants in an open canopy, over a dense understorey tree / shrub layer.

In addition to the dominant associations listed above, there would have also been small pockets of unique vegetation communities throughout the swamp that persisted due to a combination of local conditions. An example of this is the small patch of Wet Verge Sedgeland which was identified at the western end of the swamp during field surveys.

From as early as the 1800s, the swamp has been affected by changing land and water use as vegetation clearance and agricultural practices expanded across the region. This activity has continued to the current day, with the extraction of ground water from the deep Tertiary aquifer, and subsequent reduction in surface flows into the swamp, the most recent pressure on the system. Unfortunately, the cumulative effects have come to a head over the past 20 years with drought conditions triggering intensive ground water extractions and severely limiting surface flows into the swamp. The result was the drying of the swamp through the 1990s and 2000s. While difficult to ascertain, the this drying may have commenced prior to groundwater extraction as the installation of MacDonalds Dam would have changed the flow regime along Boundary Creek from the late 1970s. As the water table dropped and drying occurred, both the vegetation and underlying soil layers rich in organic carbon became susceptible to fire, with two major events occurring in 1998 and 2011. The latter fire resulted in an almost complete loss of vegetation cover across the swamp, substantially altering the structure of the communities throughout. Subsequently, it appears erosion of the swamp plain, likely driven by large rainfall events combined with exposed post-fire soils, has concentrated surface flows into a primary channel that now bisects the plain. The resulting eroded sediment appears to have in part accumulated at the eastern end of the swamp in the form of a plug, leading to the formation of a small pool of standing water which now persists year-round. This chain of events is presented in Figure 5-1.

Whilst there is likely to have been a gradual shift in community structure and composition since European settlement, and even prior due to decadal shifts in climate, the last 30 years has seen significant and potentially irreversible changes to the ecology of the Swamp. The fires have had the greatest direct impact on vegetation, resulting in a reduction of both floristic and structural diversity across the swamp plain and damp woodlands. While a high cover of canopy species has regenerated in both these areas, the understorey is absent in many places and where it has recovered consists almost exclusively of a few common species. Fires are a natural phenomenon in the Australian landscape, even in swamps, and are therefore not necessarily considered a degrading event that would have long term consequences for the Swamp's ecosystem. However, when combined with a distinct shift in the hydrological regime, widespread modification of the under lying substrate due to drying and sub-surface fires and the development of acid sulfate conditions, the consequences are potentially severe in the long term. Two major trends, which can currently be observed in the swamp, will likely continue and result in a shift in the composition of vegetation and associated habitat across the swamp. These include:

- Restriction of flows through the swamp plain to a narrow, central channel, that in the worst-case scenario may only flow intermittingly during seasonal, high rainfall events. Combined with a continuing failure to restore a near-surface water table across much of the plain, the current Riparian Fern Scrub community is likely to reduce in extent to a narrow band limited by proximity to the remaining channels (i.e. one or two through the plain and the main channel along the northern edge). Vegetation outside of this band will in time be replaced by damp woodlands, with Swamp Gum progressively colonising the plain and eventually forming a mature canopy. The resulting consequence will be a significant depletion of the extent of the Riparian Fern Scrub and simplification of the floristic and structural diversity likely to have been present prior to extraction. In a worst-case scenario, the encroachment of woodlands may have a feedback effect, leading to further drying of the swamp plain as species with higher evaporation rates establish and mature. This could theoretically lead to the permanent loss of the Riparian Fern Scrub community from the swamp in the long term. Given climatic trends towards lower average annual rainfall, this scenario cannot be discounted.
- Similar to the Riparian Fern Scrub, a failure to restore ground water levels across the swamp may also see the encroachment of the surrounding Lowland Forest into areas historically dominated by damp woodlands. Whether the overall extent of the damp woodlands will change is difficult to say, however it will have the effect of reducing the extent of the swamp and ecosystem as a whole.

The other unknown factor when predicting the future ecology of the ecosystem is the effects of fires on soil structure and composition, and associated ASS issues, both in-situ and as low pH surface and ground water. While information on the impacts is limited, it is likely these factors will continue to limit the diversity of understorey species within the swamp, either directly due to unsuitable conditions, or indirectly by promoting the establishment of species which may outcompete those indigenous to the site.

5.2 Remediation

Remediation of the swamp recognises that the original, pre-extraction condition cannot be practicably attained, either via an interventionalist or hands-off approach. The aim is therefore to improve ecological values to a satisfactory end-point. In order to provide a definition of this state, the following is proposed as the remediation goal for Big Swamp:

> *"Ensure the long-term persistence of a diverse, functional wetland community across the pre-extraction swamp's full extent"*

While the swamp does not currently meet this goal, it can reasonably be assumed that should suitable hydraulic regimes be returned, communities will re-establish a degree of structural and floristic diversity over time. Supporting this hypothesis is the persistence of floristic elements in the western end of the swamp and along the main channel which currently contain a high diversity of lifeforms and species in sufficient numbers to allow for re-colonisation of the swamp as conditions improve. Complimenting this is the distinct lack of introduced species within the swamp, despite the substantial disturbance that has occurred over the past 20 years. It is also widely recognised that wetland communities are particularly resilient to modification provided suitable conditions are re-established within an acceptable timeframe. Whether this remains the case for Big Swamp, given the multiple issues confronting it, is difficult to say.

To achieve the above goal, the following objectives are proposed to address the negative trends identified within the swamp. These objectives, which can also be considered 'health indicators' or 'success measures', include:

- No further encroachment of terrestrial woodland into the swamp plain over the next 15 years.
- No encroachment of Lowland Forest dominant species into areas of Damp Forest over the next 15 years.
- No loss of structural or floristic diversity along the main channel and western end of the swamp over the next 15 years.
- Increase diversity of understorey species within swamp plain, with a focus on ferns and sedges, over the next 25 years

Monitoring of these objectives can be achieved through repeat transect surveys of those established during the field survey (Appendix B) every two years. To cover all relevant ecological gradients identified in the study and ensure sufficient data is available to assess the objectives listed above, an additional three transects are recommended as follows (Figure B1, Appendix B):

- Transect 6 located at the northern-most point of the swamp crossing the Main channel into swamp plain.
- Transect 7 located in the South-east quadrant intersection Damp Forest and Swampy Riparian Forest immediately to the west of the open-water pool.
- Transect 8 located on the southern side of the swamp, beginning in Lowland forest and moving into areas of Damp Forest.

Figure 5-1. Chain of event flow chart for Big Swamp

Given the significant and fundamental changes that have occurred to the substrate across much of the swamp as a result of sub-surface fires and subsequent erosion and soil collapse, a focus on flow intervention is unlikely to be sufficient to restore ecological function to the site (with the long-term aim of allowing pre-extraction wetland communities to return). Physical works may therefore be required to distribute the flow of water evenly across the swamp plain to mitigate the effects of drying and subsequent colonisation by woodland communities.

Whilst specific quantities are still to be determined, this assessment indicates rehabilitation of the swamp will be more reliant on surface flows than restoration of groundwater levels. Raising groundwater levels also has the unwanted potential to liberate additional acidity from ASS from depth to the surface, further exacerbating the current issue. The wetting of the swamp from the 'top down' using surface flows, in association with physical works to distribute flows across the swamp, will help to contain immediate issues associated with ASS whilst preventing the current south-to-north drying of the swamp and transition of the wetland to a woodland community.

Whilst the substantial impacts to the swamp's substrate cannot be reversed, the restoration of a functional hydrological regime across the swamp will allow for the re-colonization of modified areas with a range of species currently persisting in small pockets throughout the swamp, thus restoring a degree of diversity and function to the wetland overtime.

Active management of the vegetation onsite, either through removal or revegetation, is not recommended until the effects of flow intervention are known. Whilst swamp communities currently exhibit dense cohorts of recruits in many places, this is a symptom of post-fire regeneration, and will naturally self-regulate overtime as the vegetation matures. Limited 'thinning' of trees in woodland areas as a complimentary measure may be of benefit to promote and hasten the establishment of large mature trees, which will in-turn suppress dense woody growth. This however is not considered a priority or critical to achieving the stated objectives. Furthermore, removal of trees within the swamp plain will be ineffective without restoration of a suitable hydrological regime and has the potential to further degrade the existing community through disturbance associated with harvesting.

Given suitable canopy species have effectively re-colonised much of the site since the fire, both within scrub and woodland areas, revegetation is not considered a viable management option in this context. Many of the understorey species currently absent from degraded areas are difficult to propagate and will be a challenge to plant-out and maintain given the dense vegetation and issues associated with access. As the wider area supports both diverse native forest, woodlands and high-quality wetland remnants along the main channel and upstream, the priority is ensuring conditions are suitable to facilitate natural re-colonisation of the swamp and damp forests from these existing sources. Given the dynamic nature of wetlands, and assuming appropriate conditions are restored, re-colonisation of disturbed areas will occur relatively quickly, with a measurable increase in species diversity expected over a 20-30 year period.

To achieve the goals and objectives, the following actions are proposed:

A. Ensure surface flows into the swamp are sufficient to maintain year-round waterlogging within the top metre of the swamp plain. Flows however should not resulted in inundation of the swamp plain for a continuous period of more than 6 months, and ideally should be designed to result in continuous seasonal inundation (maximum 30cm depth) of the plain for between 2 – 3 months.

B. Install a limited number of low bund/weirs through sections of the swamp plan. Ideally this would utilise existing tracks and disturbed areas for construction and access. The objective of the bunds would be to block the deeper channels that have formed in the swamp plain and distribute flows across broader area. While it may be unavoidable in places, it is important to avoid the creation of permanently inundated areas of open water. Gradually vegetation and sediment will fill the existing channels and any small areas of open water created by the bunds and over time start to return the profile of the swamp plain to a fine series of braided channels as believed to have originally occurred.

C. Refill/block-off the fire trench (and other unnecessary drains) and re-establish flow of the southern tributary into the swamp along the original alignment. Given the modification of the substrate, small diversion barriers may be required to direct flows into and through the swamp plain.

D. Considered potential use of the recently-formed open water area at the eastern end of the swamp to treat water quality issues created by ASS. Potential options may include the use of specific wetland species (e.g. *Phragmites australis*) as bio-accumulators to treat water quality issues associated with acid-sulphate and heavy metals. However, such an approach would require further investigation as there is the potential for secondary degradation through the introduction of aggressive species into a damaged ecosystem.

E. Undertake continued monitoring of the swamp using the established and proposed transects. Consideration should be given to establishing comparable monitoring transects in wetlands with similar EVCs as a control to monitor broader climatic changes on vegetation.

The indicative locations of remediation actions are shown in Figure 5-2.

A secondary impact, however, of the re-flooding of the swamp plain is the potential for further decreases in surface elevation as voids created in the soil due to the burning of organic material are flooded and collapse. This may further exacerbate issues associated with channelization and drying of parts of the swamp plain and will need to be considered when designing the low bunds.

In addition, further investigations are recommended to inform design of remediation options and long-term management of Big Swamp. These include:

- Condition assessments in high quality Riparian Fern Scrub and Swamp Gum remnants in the region to establish benchmarks against which monitoring data can be assessed. Existing quadrat plots and transects may be suitable for comparison of damp woodland communities however there is currently a lack of monitoring data related to the Riparian Fern Scrub EVC from the local region.

- Assessment of the connectivity between the shallow and deep aquifer systems and relationship to Big Swamp.

- Survey of the swamp plain profile to inform design of proposed weirs/bunds.

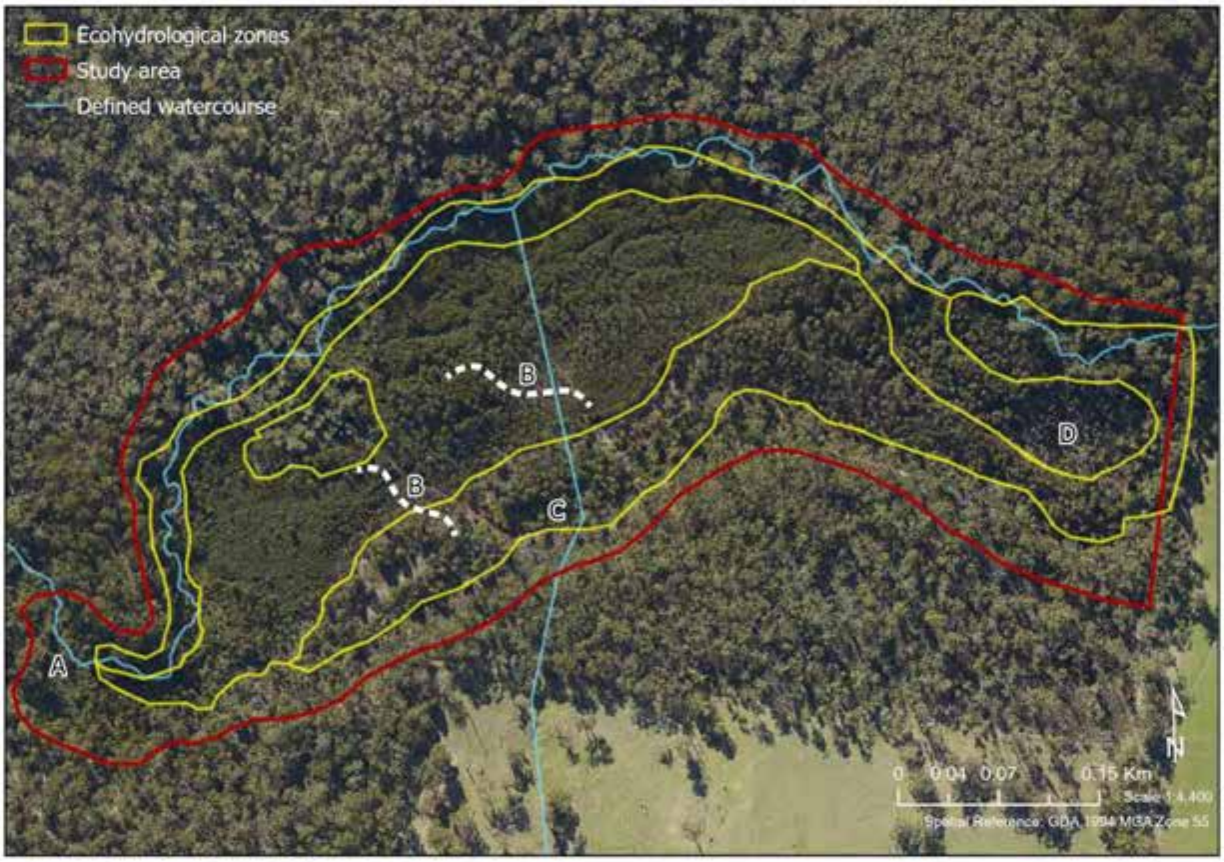


Figure 5-2. Indicative locations of remediation measures within Big Swamp

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Appendix A Species list

Table A1. Flora recorded in Big Swamp

Origin	Scientific name	Common name	Lifeform	VROT	FFG
	Acacia melanoxylon	Blackwood	S		
	Acacia stricta	Hop Wattle	S		
	Acacia verticillata	Prickly Moses	S		
	Acaena novae-zelandiae	Bidgee-widgee	MH		
*	*Acetosella vulgaris*	Sheep Sorrel	H		
*	*Agrostis capillaris*	Brown-top Bent	G		
*	*Agrostis stolonifera*	Creeping Bent			
	Alternanthera denticulata s.s.	Lesser Joyweed	MH		
	Amyema pendula	Drooping Mistletoe			
*	*Anthoxanthum odoratum*	Sweet Vernal-grass			
	Banksia marginata	Silver Banksia	S		
	Blechnum minus				
	Blechnum nudum	Fishbone Water-fern	GF		
	Bursaria spinosa	Sweet Bursaria	S		
	Cardamine tenuifolia				
	Carex appressa	Tall Sedge	Se		
	Carex fascicularis	Tassel Sedge	Se		
	Carex gaudichaudiana	Fen Sedge	MNG		
	Cassinia aculeata	Common Cassinia	S		
*	*Centaurium erythraea*	Common Centaury			
	Centipeda cunninghamii	Common Sneezeweed	MH		
*	*Cerastium glomeratum s.s.*	Sticky Mouse-ear Chickweed			
*	*Cirsium vulgare*	Spear Thistle			
	Clematis aristata	Mountain Clematis	S/C		
	Coprosma quadrifida	Prickly Currant-bush	S		
	Cycnogeton procerum	Common Water-ribbons	Herb		
*	*Cyperus eragrostis*	Drain Flat-sedge			
	Cyperus gunnii subsp. gunnii	Flecked Flat-sedge	Se		
	Dichondra repens	Kidney-weed	SH		
	Dicksonia antarctica	Soft Tree-fern	TF		
	Empodisma minus	Spreading Rope-rush	Se		
	Epacris impressa	Common Heath	S		
	Epilobium billardierianum	Variable Willow-herb	MH		

Origin	Scientific name	Common name	Lifeform	VROT	FFG
	Eucalyptus falciformis	Western Peppermint	T		
	Eucalyptus obliqua	Messmate Stringybark	T		
	Eucalyptus ovata var. ovata	Swamp Gum	T		
	Eucalyptus viminalis subsp. viminalis	Manna Gum	T		
	Euchiton involucratus s.s.	Star Cudweed	MH		
	Euchiton japonicus	Creeping Cudweed	MH		
	Gahnia sieberiana	Red-fruit Saw-sedge	Se		
*	*Galium aparine*	Cleavers			
	Galium leiocarpum	Maori Bedstraw	MH		
	Geranium potentilloides	Soft Crane's-bill	MH		
	Geranium sp. 2	Variable Crane's-bill	MH		
	Gleichenia microphylla	Scrambling Coral-fern	GF		
	Glyceria australis				
	Gratiola peruviana	Austral Brooklime	MH		
	Gynatrix pulchella s.s.	Hemp Bush	S		
	Histiopteris incisa	Bat's Wing Fern	GF		
*	*Holcus lanatus*	Yorkshire Fog			
	Hydrocotyle hirta	Hairy Pennywort	SH		
	Hydrocotyle muscosa				
	Hydrocotyle pterocarpa	Wing Pennywort	SH		
*	*Hypochaeris radicata*	Flatweed			
	Hypolepis ragulosa		GF		
	Isolepis fluitans	Floating Club-sedge	MNG		
	Isolepis inundata	Swamp Club-sedge	MTG		
	Juncus amabilis	Hollow Rush	MTG		
	Juncus pauciflorus	Loose-flower Rush	MTG		
	Juncus procerus	Tall Rush	LTG		
	Juncus sarophorus	Broom Rush	MTG		
	Lachnagrostis filiformis s.s.	Common Blown-grass	MNG		
*	*Leontodon saxatilis*	Hairy Hawkbit			
	Lepidosperma elatius	Tall Sword-sedge	LTG		
	Lepidosperma laterale var. laterale	Variable Sword-sedge	MTG		
	Leptospermum continentale	Prickly Tea-tree	S		
	Leptospermum lanigerum	Woolly Tea-tree	S		
	Leptostigma reptans	Dwarf Nertera	SH		
	Lobelia ?beaugleholei	Showy Lobelia	SH		

Origin	Scientific name	Common name	Lifeform	VROT	FFG
	Lobelia anceps	Angled Lobelia	SH		
	Lomandra filiformis subsp. coriacea	Wattle Mat-rush	MTG		
	Lomandra longifolia subsp. longifolia	Spiny-headed Mat-rush	MTG		
	Luzula meridonalis				
	Lycopus australis	Australian Gipsywort	LH		
	Melaleuca squarrosa	Scented Paperbark	S		
	Microlaena stipoides var. stipoides	Weeping Grass	MNG		
	Monotoca glauca	Currant-wood	S	r	
	Montia australasica	White Purslane	MH		
	Olearia lirata	Snowy Daisy-bush	S		
	Opercularia varia	Variable Stinkweed	SH		
	Ottelia ovalifolia subsp. ovalifolia	Swamp Lily	MH		
	Oxalis exilis	Shady Wood-sorrel	SH		
	Oxalis perennans	Grassland Wood-sorrel	SH		
	Ozothamnus ferrugineus				
	Persicaria decipiens	Slender Knotweed	MH		
*	*Poa annua*	Annual Meadow-grass			
	Poa labillardierei	Common Tussock-grass	MTG		
	Poa sieberiana var. hirtella	Grey Tussock-grass	MNG		
	Poa tenera	Slender Tussock-grass	MNG		
	Pomaderris aspera	Hazel Pomaderris	S		
	Pteridium esculentum	Austral Bracken	GF		
	Pterostylis ?lustra	Small Sickle Greenhood	SH	e	L
	Pterostylis melagramma	Tall Greenhood	SH		
	Pterostylis pedunculata	Maroonhood	SH		
	Ranunculus amphitrichus	Small River Buttercup	MH		
	Ranunculus repens				
*	*Rubus anglocandicans*	Common Blackberry			
	Senecio glomeratus	Annual Fireweed	MH		
	Senecio linearifolius	Fireweed Groundsel	LH		
	Senecio minimus	Shrubby Fireweed	MH		
*	*Sonchus asper s.s.*	Rough Sow-thistle			
*	*Stellaria media*	Chickweed			
	Stellaria pungens	Prickly Starwort	MH		
	Tetrarrhena distichophylla	Hairy Rice-grass	MNG		
	Tetrarrhena juncea	Forest Wire-grass	LNG		

Origin	Scientific name	Common name	Lifeform	VROT	FFG
	Todea barbara	Austral King-fern	GF		
*	*Trifolium subterraneum*	Subterranean Clover			
	Triglochin striata	Streaked Arrowgrass	MH		
	Veronica calycina	Hairy Speedwell	SH		
	Viola hederacea sensu Entwisle (1996)	Ivy-leaf Violet	SH		

Table A2. Fauna recorded in Big Swamp

Origin	Common name	Scientific name	Group	VROT	FFG
	Australian King-Parrot	*Alisterus scapularis*	Bird		
	Australian Magpie	*Cracticus tibicen*	Bird		
	Australian Shelduck	*Tadorna tadornoides*	Bird		
	Australian Wood Duck	*Chenonetta jubata*	Bird		
	Black Kite	*Milvus migrans*	Bird		
	Brown Thornbill	*Acanthiza pusilla*	Bird		
	Common Brush-tail Possum	*Trichosurus vulpecula*	Mammal		
	Common Froglet	*Crinis signifera*	Frog		
*	Common Starling	*Sturnus vulgaris*	Bird		
	Crescent Honeyeater	*Phylidonyris pyrrhopterus*	Bird		
	Crested Shrike-tit	*Falcunculus frontatus*	Bird		
	Crimson Rosella	*Platycercus elegans*	Bird		
*	Dog	*Canis familiaris*	Mammal		
	Eastern Grey Kangaroo	*Macropus giganteus*	Mammal		
	Eastern Rosella	*Platycercus eximius*	Bird		
	Eastern Spinebill	*Acanthorhynchus tenuirostris*	Bird		
	Eastern Yellow Robin	*Eopsaltria australis*	Bird		
	Freshwater Cray	*Engaeus sp.*	Crustacean		
	Galah	*Eolophus roseicapillus*	Bird		
	Golden Whistler	*Pachycephala pectoralis*	Bird		
	Grey Butcherbird	*Cracticus torquatus*	Bird		
	Grey Fantail	*Rhipidura albiscapa*	Bird		
	Grey Shrike-thrush	*Colluricincla harmonica*	Bird		
	Laughing Kookaburra	*Dacelo novaeguineae*	Bird		
	Little Raven	*Corvus mellori*	Bird		
	Long-billed Corella	*Cacatua tenuirostris*	Bird		
	Mistletoebird	*Dicaeum hirundinaceum*	Bird		

Origin	Common name	Scientific name	Group	VROT	FFG
	New Holland Honeyeater	*Phylidonyris novaehollandiae*	Bird		
	Noisy Miner	*Manorina melanocephala*	Bird		
	Olive Whistler	*Pachycephala olivacea*	Bird		
	Pacific Black Duck	*Anas superciliosa*	Bird		
	Pied Currawong	*Strepera graculina*	Bird		
*	Pig	*Sus scrofa*	Mammal		
*	Red Fox	*Vulpes vulpes*	Mammal		
	Red Wattlebird	*Anthochaera carunculata*	Bird		
	Rufous Bristlebird (Otways Subspecies)	*Dasyornis broadbenti caryochrous*	Bird	nt	L
	Satin Bowerbird	*Ptilonorhynchus violaceus*	Bird		
	Silvereye	*Zosterops lateralis*	Bird		
	Southern Brown Tree-frog	*Litoria ewingii*	Frog		
	Spotted Pardalote	*Pardalotus punctatus*	Bird		
	Striated Pardalote	*Pardalotus striatus*	Bird		
	Sulphur-crested Cockatoo	*Cacatua galerita*	Bird		
	Superb Fairy-wren	*Malurus cyaneus*	Bird		
	Wedgetail eagle	*Aquila audax*	Bird		
	Welcome swallow	*Hirundo neoxena*	Bird		
	White-browed Scrubwren	*Sericornis frontalis*	Bird		
	White-eared Honeyeater	*Lichenostomus leucotis*	Bird		
	White-naped Honeyeater	*Melithreptus lunatus*	Bird		
	White-throated Treecreeper	*Cormobates leucophaea*	Bird		
	Willie Wagtail	*Rhipidura leucophrys*	Bird		
	Yellow-faced Honeyeater	*Lichenostomus chrysops*	Bird		

Appendix B Transect data

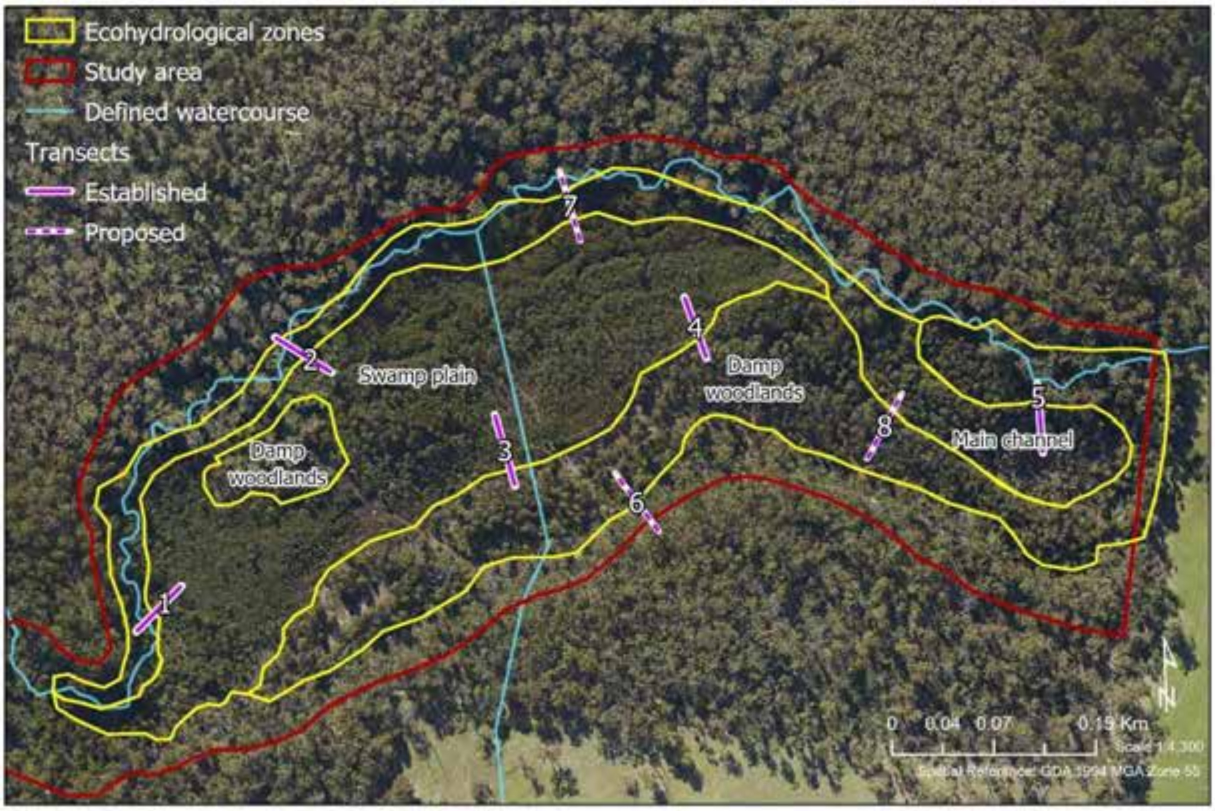

Figure B1. Locations of established and proposed transects in Big Swamp

Table B1. Results of vegetation transects undertaken in Big Swamp in September 2019

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
0.25	*Carex appressa, Lepidosperma elatius*	Litter	*Gahnia sieberiana, Holcus lanatus*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter	*Lepidosperma elatius*	Litter
0.5	*Lepidosperma elatius*	Litter	*Tetrarrhena juncea, Lepidosperma elatius*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Microlaena stipoides var. stipoides*	Litter	*Lepidosperma elatius*	Litter
0.75	*Lepidosperma elatius*	Litter	*Lepidosperma elatius*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Lepidosperma elatius*	Litter
1	*Lepidosperma elatius, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea, Lepidosperma elatius*	Litter	*Eucalyptus ovata*	Bare ground	*Pteridium esculentum subsp. esculentum*	Litter		Litter
1.25	*Lepidosperma elatius*	Litter	*Tetrarrhena juncea, Lepidosperma elatius, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Lepidosperma elatius*	Litter
1.5	*Lepidosperma elatius*	Litter	*Tetrarrhena juncea, Pteridium esculentum subsp. esculentum*	Bryophytes	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter		Litter
1.75	*Lepidosperma elatius, Tetrarrhena juncea*	Litter	*Tetrarrhena juncea, Lepidosperma elatius*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Anthoxanthum odoratum*	Litter	*Holcus lanatus*	Litter
2	*Lepidosperma elatius, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Logs		Bryophytes

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
2.25	*Lepidosperma elatius, Pteridium esculentum subsp. esculentum, Olearia lirata*	Litter	*Tetrarrhena juncea*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Tetrarrhena juncea*	Litter
2.5	*Lepidosperma elatius, Pteridium esculentum subsp. esculentum, Tetrarrhena juncea*	Litter		Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Holcus lanatus*	Litter
2.75	*Lepidosperma elatius, Tetrarrhena juncea*	Litter	*Tetrarrhena juncea*	Logs		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Pomaderris aspera, Tetrarrhena juncea, Senecio minimus*	Litter
3	*Lepidosperma elatius, Olearia lirata, Tetrarrhena juncea, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea*	Litter		Litter	*Eucalyptus ovata*	Litter	*Pomaderris aspera*	Litter
3.25	*Lepidosperma elatius, Tetrarrhena juncea*	Bryophytes	*Tetrarrhena juncea, Pteridium esculentum subsp. esculentum*	Litter		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Pomaderris aspera*	Litter
3.5	*Olearia lirata, Tetrarrhena juncea*	Litter	*Tetrarrhena juncea, Pteridium esculentum subsp. esculentum*	Litter		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Pomaderris aspera, Tetrarrhena juncea*	Litter
3.75	*Tetrarrhena juncea*	Bryophytes	*Senecio minimus, Pteridium esculentum subsp. esculentum*	Litter		Litter	*Eucalyptus ovata*	Litter	*Lepidosperma elatius*	Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
4	*Tetrarrhena juncea*	Bryophytes		Litter		Litter	*Eucalyptus ovata*	Litter	*Lepidosperma elatius*	Litter
4.25		Litter	*Holcus lanatus*	Litter		Bryophytes	*Eucalyptus ovata*	Litter	*Lepidosperma elatius*	Litter
4.5	*Prostanthera lasianthos*	Litter	*Holcus lanatus, Lepidosperma elatius*	Litter		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Lepidosperma elatius*	Litter
4.75	*Prostanthera lasianthos, Pomaderris aspera*	Litter	*Holcus lanatus, Lepidosperma elatius*	Litter		Litter	*Eucalyptus ovata*	Litter	*Tetrarrhena juncea*	Litter
5	*Prostanthera lasianthos, Pomaderris aspera*	Litter	*Lepidosperma elatius*	Litter		Litter	*Eucalyptus ovata*	Litter	*Pteridium esculentum subsp. esculentum*	Litter
5.25	*Prostanthera lasianthos, Pomaderris aspera*	Litter	*Holcus lanatus*	Litter		Litter	*Eucalyptus ovata*	Litter	*Pteridium esculentum subsp. esculentum, Tetrarrhena juncea*	Litter
5.5	*Prostanthera lasianthos, Pomaderris aspera*	Litter	*Holcus lanatus*	Litter		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea*	Litter
5.75	*Pomaderris aspera*	Litter	*Gynatrix pulchella s.l., Holcus lanatus*	Litter		Bare ground	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea*	Litter
6	*Pomaderris aspera*	Litter	*Gynatrix pulchella s.l., Cerastium glomeratum s.l., Acacia melanoxylon*	Bryophytes		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Tetrarrhena juncea*	Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
6.25	*Holcus lanatus, Pomaderris aspera, Tetrarrhena juncea*	Litter	*Gynatrix pulchella s.l., Cerastium glomeratum s.l., Acacia melanoxylon*	Bare ground		Bare ground	*Eucalyptus ovata, Tetrarrhena juncea*	Litter	*Tetrarrhena juncea*	Litter
6.5	*Pomaderris aspera*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Tetrarrhena juncea*	Litter	*Tetrarrhena juncea*	Bryophy tes
6.75	*Rubus anglocandicans, Pomaderris aspera*	Litter	*Gynatrix pulchella s.l.*	Water	*Pteridium esculentum subsp. esculentum*	Bare ground	*Tetrarrhena juncea, Gahnia sieberiana*	Litter		Litter
7	*Pomaderris aspera*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Anthoxanthum odoratum, Acacia verticillata, Gahnia sieberiana*	Litter	*Tetrarrhena juncea*	Bryophy tes
7.25	*Pomaderris aspera*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Acacia verticillata*	Bryophy tes		Litter
7.5	*Holcus lanatus*	Litter	*Gynatrix pulchella s.l.*	Water		Bryophy tes	*Tetrarrhena juncea*	Litter	*Pteridium esculentum subsp. esculentum*	Bryophy tes
7.75		Litter	*Gynatrix pulchella s.l.*	Water		Bryophy tes	*Pteridium esculentum subsp. esculentum*	Litter	*Pteridium esculentum subsp. esculentum, Holcus lanatus*	Litter
8	*Holcus lanatus*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Acacia verticillata*	Litter	*Pteridium esculentum subsp. esculentum, Holcus lanatus*	Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
8.25	*Lepidosperma elatius, Holcus lanatus*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Acacia verticillata*	Bare ground	*Pteridium esculentum subsp. esculentum, Holcus lanatus*	Litter
8.5	*Holcus lanatus*	Litter	*Gynatrix pulchella s.l.*	Water		Litter	*Acacia verticillata*	Litter	*Galium aparine, Pteridium esculentum subsp. esculentum, Holcus lanatus*	Litter
8.75	*Pomaderris aspera, Lepidosperma elatius, Carex appressa*	Litter	*Gynatrix pulchella s.l.*	Water		Litter		Litter	*Eucalyptus brookeriana, Holcus lanatus*	Litter
9	*Pomaderris aspera, Lepidosperma elatius, Carex appressa*	Litter	*Gynatrix pulchella s.l., Carex appressa*	Bare ground		Litter	*Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus brookeriana, Holcus lanatus, Tetrarrhena juncea*	Litter
9.25	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Carex appressa*	Litter		Litter	*Tetrarrhena juncea*	Litter	*Tetrarrhena juncea*	Litter
9.5	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Carex appressa*	Bryophytes		Bryophytes		Litter	*Eucalyptus brookeriana, Tetrarrhena juncea*	Litter
9.75	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Poa tenera, Cerastium glomeratum s.l.*	Litter		Litter		Litter	*Eucalyptus brookeriana, Tetrarrhena juncea*	Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
10	*Pomaderris aspera, Lepidosperma elatius, Rubus anglocandicans*	Litter	*Gynatrix pulchella s.l., Poa tenera, Senecio minimus*	Litter		Litter		Litter	*Eucalyptus brookeriana, Tetrarrhena juncea, Holcus lanatus*	Litter
10.25	*Pomaderris aspera, Lepidosperma elatius, Carex appressa*	Litter	*Gynatrix pulchella s.l., Galium aparine, Poa tenera*	Litter		Litter		Litter	*Holcus lanatus*	Litter
10.5	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Acacia verticillata*	Litter	*Pteridium esculentum subsp. esculentum*	Litter		Litter	*Pteridium esculentum subsp. esculentum, Holcus lanatus*	Litter
10.75	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Acacia verticillata*	Litter		Litter	*Pteridium esculentum subsp. esculentum*	Litter	*Holcus lanatus*	Bryophy tes
11	*Pomaderris aspera, Lepidosperma elatius*	Litter	*Gynatrix pulchella s.l., Acacia verticillata, Cerastium glomeratum s.l.*	Litter		Litter		Litter	*Tetrarrhena juncea*	Litter
11.25	*Leptospermum continentale, Lepidosperma elatius*	Litter	*Acacia verticillata*	Litter	*Pteridium esculentum subsp. esculentum*	Bare ground	*Eucalyptus ovata*	Logs		Logs
11.5	*Leptospermum continentale, Lepidosperma elatius*	Litter	*Pomaderris aspera, Lepidosperma elatius, Carex appressa*	Litter		Litter	*Eucalyptus ovata*	Logs	*Tetrarrhena juncea*	Logs

Point	Transcript 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
11.75	*Leptospermum continentale, Lepidosperma elatius*	Litter	*Pomaderris aspera*	Litter		Bryophytes	*Eucalyptus ovata*	Litter		Logs
12	*Pomaderris aspera*	Litter	*Pomaderris aspera*	Logs		Litter	*Eucalyptus ovata*	Litter	*Tetrarrhena juncea*	Litter
12.25	*Pomaderris aspera*	Litter	*Leptospermum continentale*	Logs		Bryophytes	*Eucalyptus ovata*	Logs	*Tetrarrhena juncea*	Litter
12.5	*Pomaderris aspera, Carex appressa*	Litter	*Carex appressa*	Litter	*Eucalyptus ovata*	Bryophytes	*Eucalyptus ovata*	Logs	*Tetrarrhena juncea*	Litter
12.75	*Pomaderris aspera*	Litter	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter		Litter
13	*Pomaderris aspera, Carex appressa, Leptospermum continentale*	Litter	*Leptospermum continentale, Carex appressa*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Senecio glomeratus*	Litter		Water
13.25	*Pomaderris aspera, Lycopus australis, Carex appressa, Leptospermum continentale*	Water	*Leptospermum continentale, Carex appressa*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter		Water
13.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Water
13.75	*Carex fascicularis*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Water
14	*Carex fascicularis*	Water	*Leptospermum continentale, Holcus lanatus*	Litter	*Eucalyptus ovata*	Bare ground	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter

Point	Transcript 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
14.25	*Cycnogeton procerum s.s.*	Water	*Leptospermum continentale, Hydrocotyle hirta*	Bryophytes	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
14.5	*Cycnogeton procerum s.s.*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
14.75	*Cycnogeton procerum s.s.*	Water	*Tetrarrhena juncea*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
15	*Cycnogeton procerum s.s., Leptospermum continentale, Leptospermum lanigerum*	Water	*Holcus lanatus*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
15.25	*Cycnogeton procerum s.s., Leptospermum continentale, Leptospermum lanigerum*	Water	*Holcus lanatus*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
15.5	*Cycnogeton procerum s.s., Leptospermum continentale, Leptospermum lanigerum*	Water	*Holcus lanatus, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
15.75	*Cycnogeton procerum s.s., Leptospermum continentale,*	Water	*Leptospermum continentale,*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
	Leptospermum lanigerum		*Pteridium esculentum subsp. esculentum*							
16	*Leptospermum continentale, Leptospermum lanigerum*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter
16.25	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Litter		Litter
16.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Logs		Water
16.75	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Hydrocotyle pterocarpa*	Water	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Logs		Water
17	*Lobelia beaugleholei, Leptospermum lanigerum*	Water		Water	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Logs		Water
17.25	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Hydrocotyle pterocarpa*	Water	*Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus brookeriana*	Litter
17.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Acacia melanoxylon*	Water		Litter	*Eucalyptus ovata*	Litter		Litter
17.75	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata*	Litter		Litter

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
18	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Acacia melanoxylon*	Water		Litter	*Eucalyptus ovata*	Litter		Water
18.25	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Water
18.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata*	Litter		Water
18.75	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Lobelia beaugleholei*	Water		Litter	*Eucalyptus ovata*	Litter		Water
19	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Carex appressa*	Water		Bryophytes	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Water
19.25	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Carex appressa*	Water	*Pteridium esculentum subsp. esculentum*	Bryophytes	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Water
19.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Carex appressa*	Water	*Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Litter		Water
19.75	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water
20	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water
20.25	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Carex appressa*	Litter	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
20.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale, Carex appressa*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water
20.75	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water
21	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Logs		Water
21.25	*Alternanthera denticulata s.l., Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata*	Logs		Water
21.5	*Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Water
21.75	*Lycopus australis, Carex appressa, Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter	*Juncus procerus*	Water
22	*Carex appressa, Leptospermum lanigerum*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter	*Juncus procerus*	Water
22.25	*Carex appressa, Leptospermum lanigerum*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Litter	*Juncus procerus*	Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
22.5	*Carex appressa*	Water	*Leptospermum continentale, Galium ciliare subsp. Terminale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata*	Bryophy tes	*Juncus procerus*	Water
22.75	*Todea barbera, Carex appressa*	Water	*Leptospermum continentale, Galium ciliare subsp. Terminale*	Litter	*Eucalyptus ovata*	Litter	*Pteridium esculentum subsp. esculentum*	Litter	*Juncus procerus*	Water
23		Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Bryophy tes		Water
23.25	*Holcus lanatus, Carex appressa*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter		Litter		Water
23.5	*Leptospermum continentale, Ranunculus amphitrichus, Alternanthera denticulata s.l., Carex appressa*	Water	*Leptospermum continentale, Carex appressa*	Water	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Pteridium esculentum subsp. esculentum*	Bryophy tes		Water
23.75	*Leptospermum continentale*	Water	*Leptospermum continentale, Carex appressa*	Water	*Eucalyptus ovata*	Litter	*Pteridium esculentum subsp. esculentum*	Bryophy tes		Water
24	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Litter		Litter		Water

Point	Transcect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
24.25	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Litter	*Gahnia sieberiana*	Litter		Water
24.5	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Logs	*Gahnia sieberiana*	Litter		Logs
24.75	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Litter	*Gahnia sieberiana*	Litter		Water
25	*Carex fascicularis*	Water	*Leptospermum continentale, Carex appressa*	Litter	*Eucalyptus ovata, Leptospermum continentale*	Litter	*Gahnia sieberiana*	Litter		Water
25.25	*Carex fascicularis*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Leptospermum continentale*	Litter		Bryophytes		Water
25.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Gahnia sieberiana*	Litter		Litter		Water
25.75	*Carex fascicularis*	Water	*Leptospermum continentale, Carex appressa*	Water	*Gahnia sieberiana*	Litter		Litter		Water
26	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Gahnia sieberiana*	Bryophytes		Litter		Water
26.25	*Carex appressa, Cyperus gunnii*	Water	*Leptospermum continentale*	Water	*Gahnia sieberiana*	Litter		Litter		Water
26.5	*Carex appressa, Cyperus gunnii*	Water	*Leptospermum continentale*	Water		Litter		Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
26.75	*Carex appressa, Cyperus gunnii*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata*	Litter		Water
27	*Carex appressa, Cyperus gunnii*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata*	Litter		Water
27.25	*Cyperus gunnii*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Bare ground	*Eucalyptus ovata*	Litter		Water
27.5	*Cyperus gunnii*	Water	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter		Water
27.75	*Carex fascicularis, Cyperus gunnii*	Water	*Leptospermum continentale*	Litter	*Leptospermum continentale, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter		Water
28	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Water
28.25	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter		Water
28.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Melaleuca squarrosa*	Logs	*Gahnia sieberiana*	Litter		Logs
28.75		Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum*	Litter	*Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
29	*Melaleuca squarrosa, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter		Water
29.25		Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter		Water
29.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Bryophytes	*Gahnia sieberiana*	Litter		Water
29.75	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Bryophytes	*Gahnia sieberiana*	Litter		Water
30	*Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Litter	*Gahnia sieberiana*	Litter		Water
30.25	*Carex appressa*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata, Leptospermum continentale*	Bryophytes	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
30.5	*Carex appressa*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
30.75	*Carex appressa*	Water	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
31	*Carex appressa*	Water	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
31.25	*Carex appressa*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
31.5	*Carex appressa*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
31.75		Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
32	*Carex appressa*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
32.25		Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Gahnia sieberiana*	Litter		Water
32.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Logs	*Pteridium esculentum subsp. esculentum*	Bryophytes	*Gahnia sieberiana*	Litter		Water
32.75	*Carex fascicularis*	Water	*Leptospermum continentale*	Water		Bryophytes	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Logs
33	*Carex fascicularis*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Water
33.25	*Carex fascicularis*	Water	*Leptospermum continentale*	Water		Bryophytes	*Eucalyptus ovata, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
33.5	*Carex fascicularis*	Water	*Leptospermum continentale*	Water		Bryophytes	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
33.75	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
34	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
34.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water		Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
34.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water		Logs	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Logs
34.75	*Carex fascicularis, Carex appressa*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
35	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Water
35.25	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Bare ground	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
35.5	*Leptospermum continentale, Carex fascicularis*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Bryophytes	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
35.75	*Leptospermum continentale, Carex appressa*	Water	*Leptospermum continentale*	Water	*Eucalyptus ovata*	Bryophytes	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
36	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
36.25		Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
36.5		Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Bryophytes	*Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
36.75	*Leptospermum continentale, Carex appressa*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
37	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
37.25	*Leptospermum continentale, Cyperus eragrostis*	Water	*Leptospermum continentale*	Litter		Litter	*Eucalyptus ovata, Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Water
37.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Gahnia sieberiana*	Litter		Water
37.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water		Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
38	*Leptospermum continentale, Persicaria decipiens*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
38.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
38.5	*Leptospermum continentale, Acacia melanoxylon, Alternanthera denticulata s.l.*	Water	*Leptospermum continentale*	Water	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water

Point	Transcript 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
38.75	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Bare ground	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
39	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Bare ground	*Melaleuca squarrosa*	Bryophytes	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
39.25	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Eucalyptus ovata, Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
39.5	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Eucalyptus ovata, Gahnia sieberiana, Gahnia sieberiana*	Litter		Water
39.75	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Bare ground	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Leptospermum continentale, Pteridium esculentum subsp. esculentum, Gahnia sieberiana, Eucalyptus ovata*	Litter		Water
40	*Leptospermum continentale, Acacia melanoxylon*	Water	*Leptospermum continentale*	Bare ground	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Eucalyptus ovata, Gahnia sieberiana*	Litter		Water
40.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Bare ground	*Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
40.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
40.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Bare ground		Litter	*Pteridium esculentum subsp. esculentum, Gahnia sieberiana*	Litter		Water
41	*Leptospermum continentale*	Water	*Leptospermum continentale*	Bare ground	*Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
41.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
41.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
41.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
42	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Bryophytes	*Gahnia sieberiana*	Litter		Water
42.25	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
42.5	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Leptospermum continentale, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
42.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bryophytes	*Gahnia sieberiana*	Litter		Water
43	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
43.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bryophytes	*Pteridium esculentum subsp. esculentum, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
43.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Melaleuca squarrosa*	Litter	*Pteridium esculentum subsp. esculentum, Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
43.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
44	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
44.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
44.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata, Melaleuca squarrosa*	Litter	*Gahnia sieberiana*	Litter		Water
44.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
45	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
45.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
45.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
45.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Bare ground	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
46	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Leptospermum continentale, Gahnia sieberiana*	Litter		Water
46.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter	*Eucalyptus ovata*	Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
46.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Gahnia sieberiana*	Litter		Water
46.75	*Leptospermum continentale*	Litter	*Leptospermum continentale*	Litter		Litter	*Gahnia sieberiana*	Litter		Logs
47	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bryophytes	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
47.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Gahnia sieberiana*	Litter		Water
47.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
47.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Gahnia sieberiana*	Litter		Water
48	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water

Point	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover	Species	Ground cover
48.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
48.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
48.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bryophytes	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
49	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bryophytes	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
49.25	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
49.5	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
49.75	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Litter	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water
50	*Leptospermum continentale*	Water	*Leptospermum continentale*	Litter		Bare ground	*Melaleuca squarrosa, Gahnia sieberiana*	Litter		Water

Appendix C Condition assessment results

Table C1. General information

Wetland Name	Big Swamp
Bioregion	Otway Plain
Projection/Datum	UTM S
Zone	54
Eastings	735394
Northings	5743969
Area (hectares)	6.95
Was the whole wetland assessed?	Yes
Assessors	Karl Just and James Garden
Date Assessed	7/09/2019
Agency	Barwon Water

Inundation Status of Wetland	
Water Cover	
Dry or moist soil	20%
Saturated soil	70%
Water Cover	10%
Unknown	0
Wetland Phase	Full
If dry, number of years dry	0

Table C2. Index of wetland condition results

Bioregion	Otway Plain			
Sub-index	**Score**	**Condition Category**	**Weight**	**Adjusted score**
Wetland catchment	18	Excellent	0.26	4.68
Physical form	8.75	Poor	0.08	0.70
Hydrology	0	Very Poor	0.31	0.00
Water properties	7	Poor	0.47	3.29
Soils	6	Poor	0.07	0.42
Biota	12.48	Poor	0.73	9.11
Total				**18.20**
Overall IWC Score		**Moderate**		**5**

Table C3. Wetland catchment index

Wetland Buffer Assessment		
	Description	**Score**
Average buffer width (metres)	>50	2
% of wetland perimeter with buffer	>95	5
	Wetland buffer assessment score	10
Percentage of land in different land use intensity classes adjacent to the wetland		
Land Use Intensity Class	**% of adjacent land in each land use intensity class**	**Result**
Very High	0	0
High	0	0
Medium	20	40
Low	10	30
Very Low	60	240
	Sum of results	**310**
	Adjacent Land use Score	**8**
Wetland catchment sub-index score (wetland buffer score + adjacent land use score)		**18**

Table C4. Physical form index

Reduction in Wetland Area		
	% reduction in wetland area	**Score**
Percentage of reduction in wetland area	25 to 50	6
Does the shape of the wetland boundary differ from Wetland 1994 layer or more recent mapping?	n/a	
Activities leading to a change in wetland bathymetry		
Excavation of the wetland bed (e.g. channels, dams, dredging)	Yes	
Land forming (e.g. raised-bed cropping, laser-levelling, building mounds, aqueducts, tracks)	No	
Severity of bathymetry changes		
Severity rating	**% of wetland area**	**Score**
High	60	0
Medium	20	1
Low	10	0.75
None	10	1
	Change in bathymetry score	**2.75**
Physical form sub-index score (reduction in wetland area score + change in bathymetry score)		**8.75**

Table C5. Hydrology index

Water Source	River or stream	✓
	Surface runoff	
	Ground Water	✓
	Artificial Channel	
Activities that change the flow regime of the water source	River regulation	
	Activities that change surface drainage patterns	✓
	Activities that change groundwater levels	✓
	Regulation not associated with maintaining or restoring reference condition	
Activities that change the wetland water regime	Activity that changes the flow regime of the water source	
	Obstruction or regulation of natural water flow to wetland	
	Obstruction or regulation of natural water outlets	✓
	Drainage of water from the wetland	
	Disposal of water into the wetland	
	Extraction of water directly from the wetland	
	Activities that permanently raise the water level (e.g. damming the wetland or constructing levees to restrict the spread of water)	
	Activities leading to an increase in groundwater height	
	Activities leading to a decrease in groundwater height	✓
Severity of change on water regime components		
	Severity of Change	**Score**
Timing	Change to another season	0
Water Regime Category	Change in Category	0
	Sum of Severity Score	0
	Hydrology sub-index score	**0**

Table C6. Water properties and soil index

WATER PROPERTIES - Extant	
Activities leading to nutrient enrichment	
Point source inputs (channel or pipe of urban/industrial/ agricultural nutrient-rich water to the wetland)	
Application of fertilizer to wetland	
Runoff of nutrients to wetland (e.g. from fertilizer application or grazing)	✓
Grazing of wetland by livestock and feral animals	✓
Aquaculture	

Nutrient Enrichment Score (If there are activities, is the likelihood of an increase in nutrients in the wetland low (score = 7), moderate (score = 5) or high (score = 0). If there are no activities, score = 10.)	7	
Water quality observations		
Evidence of a change in Salinity		
		Score
Is there evidence that the wetland has increased in salinity? (AS)	No	0
Is there evidence of saline water intrusions from the marine environment via groundwater and/or storm surges?	No	0
Is the brackish or fresh wetland within 250 m of a salinity discharge site?	No	0
Is saline water delivered to a fresh or brackish wetland or is (unnatural) freshwater delivered to a saline wetland?	No	0
	Salinity Score	**0**
	Water properties sub-index score (Nutrient Enrichment Score + Salinity Score)	**7**

SOILS - Extant		
Activities that causes soil disturbances		
Pugging by livestock		
Disturbance/pugging by feral animals (e.g. pigs, rabbits, deer, horses)	✓	
Carp mumbling		
Trampling by humans		
Cultivation		
Driving of vehicles in the wetland	✓	
Soil disturbance severity	**% of soil**	**Score**
High	60	0
Medium	10	1
Low	20	3
None (100% of soil)	10	2
	Soil Sub-index Score	**6**

Table C7. Wetland biota index

Vegetation association		Riparian Fern Scrub (RFS120-A)	Riparian Scrub (RFS120-B)	Riparian Scrub (RFS120-C)	Wet-verge Sedgeland (WVS932-A)
	Max. Score	*Score*	*Score*	*Score*	*Score*
Critical Life form groupings	25	21.90	21.90	6.25	19.37
Weeds	25	22	22	22	25
Indicators of altered processes	25	20	10	5	25
Vegetation structure and health	25	25	20	0	25
EVC Sub-total	100	88.90	73.90	33.25	94.37
Adjusted EVC Score (EVC/5)	20	17.78	14.78	6.65	18.90
Area of wetland covered by EVC (%)		6%	62%	31%	1%
Wetland EVC Score		1.07	9.16	2.06	0.19
Total Wetland Biota Score				**12.48**	

[1] Zones shown in Figure 3

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- Final Report
- December 2019

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Contents

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Executive Summary

Austral Research and Consulting investigated the extent of impacts from Big Swamp on surface water, sediments and the macroinvertebrate community structure in Boundary Creek and the upper Barwon River in Spring 2019. Sediment and water samples were collected and delivered to the laboratory for analysis with a specific focus on metals and the impacts of pH on these analytes from the East and West Barwon Rivers, Boundary Creek downstream of Big Swamp, and the Barwon River down to Winchelsea. Surface water and sediment results suggest that the drying and wetting of Big Swamp has mobilised Aluminium, Cadmium, Iron, Lead and Zinc in the Barwon River but this impact is not recorded downstream of Birregurra. Whilst waterway health in Boundary Creek remains impacted by Big Swamp and the macroinvertebrate community composition in the Barwon River is altered immediately downstream of the confluence, impacts detected in the sediment and water samples in the Barwon River were not reflected in overall waterway health indices. Continued monitoring of Boundary Creek and the upper Barwon River during the remediation process is recommended to provide feedback as to the success of remediation works.

1. Introduction

Austral Research and Consulting (Austral) have been contracted by Barwon Water to undertake an investigation into the sediment and water quality and macroinvertebrate condition of the upper Barwon River with regard to the extent of impact of low pH inflows from Boundary Creek.

This survey will determine a baseline for ongoing monitoring of the Barwon River as part of a remediation plan required by a section 78 Ministerial Notice by:

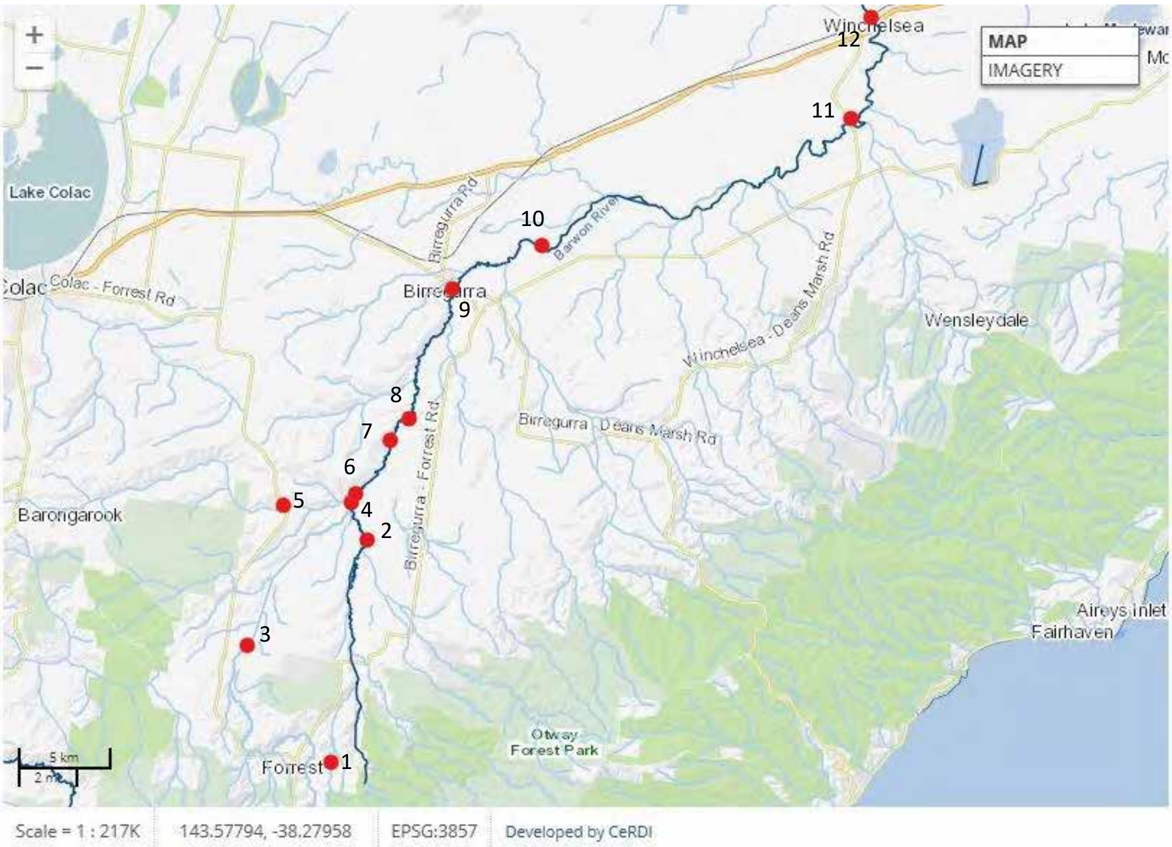
- Assesing the spatial extent of surface water effects resulting for acidic discharge from Boundary Creek in the Barwon River,
- Determining if acidic discharge from Boundary Creek has affected sediment in the Barwon River and if so, the spatial extent and depth of accumulation, and;
- Assess the potential impact of acidic discharge from Big Swamp at Yeodene on the macroinvertebrate community structure in Boundary Creek and the Barwon River.

1.1. Background

Studies have confirmed that past water extractions from the Barwon Downs borefield by Barwon Water to boost Geelong's water supply in conjunction with a dry climate lead to reductions in flows in lower Boundary Creek (Jacobs, 2017). This in turn caused Big Swamp to dry out activating naturally occurring acid sulfate soils that when rewetted have released acidic water into the lower reaches of Boundary Creek. Boundary Creek joins the Barwon River 3.7km downstream of Big Swamp.

2. Methods

A total of twelve sites were surveyed along East Barwon, West Barwon, and Barwon Rivers in addition to Boundary Creek (Figure 1).



- **Figure 1: Barwon River and Boundary Creek (base map from Waterwatch Victoria)**

2.1. Site Selection

Sites were selected in consultation with Barwon Water to best give an indication of the impact of water coming from Big Swamp on Boundary Creek and particularly the Barwon River. Two sites are on the East Barwon River, one site is on the West Barwon River, one site is on Boundary Creek and eight sites are on the mainstem Barwon River. They incorporate existing Waterwatch sites, upstream sites that are unimpacted by Boundary Creek (sites 1-4) and sites focused on any impacts from Boundary Creek (Table 1).

Site no.	Existing number	Site description	Lat	Long
1	CO_BAR004 (inact.)	East Barwon River @ Kents Road, Yaugher	-38.512196	143.732530
2	New	East Barwon River @ Dewings Bridge Road	-38.434878	143.747933
3	CO_WES010	West Barwon River @ 7 bridges Road	-38.474669	143.689396
4	New	Barwon River immediately u/s of Boundary Ck conf.	-38.418236	143.742025
5	CO_BOU009	Boundary Creek, Colac-Forrest Road	-38.421122	143.710475
6	New	Barwon River immediately d/s of Boundary conf.	-38.416717	143.742383
7	New	Barwon River u/s CO_BAR016	-38.402291	143.757554
8	CO_BAR016	Barwon River @ Colac-Lorne Road	-38.388771	143.768956
9	CO_BAR020	Barwon River @ Birregurra	-38.339105	143.790971
10	CO_BAR030	Barwon River @ Conns Lane	-38.325134	143.832385
11	CO_BAR040	Barwon River @ Winchelsea Deans Marsh Road	-38.278018	143.978382
12	CO_BAR060	Barwon River @ Princes Hwy bridge, Winchelsea	-38.240445	143.989326

Table 1: Site locations and descriptions

2.2. Sampling methodology

Macroinvertebrates and sediments were sampled and *in situ* water quality, vegetation, site descriptions and photos were collected, specific methods are detailed below. Water quality samples should be collected monthly and macroinvertebrate samples in Spring and Autumn to ensure temporal trends and environmental variations are being detected (EPA, 2003a).

2.2.1. In-situ water quality

In-situ water quality parameters were measured at each site including dissolved oxygen (mg/l), temperature (^{o}C), specific conductivity (μS/cm) and pH using a YSI ProPlus water quality meter. Turbidity (NTU) and alkalinity (mg/L) were measured using HACH meters and test kits respectively.

2.2.2. Metals in water

Water samples were collected for metals analysis, filtered in the field and kept refrigerated prior to delivery to the NATA accredited Eurofins Laboratory.

2.2.3. Metals in sediments

Sediment samples were collected using a PVC corer from a variety of depositional areas at each site (EPA, 2009). Three cores were taken and separated into surface to 20cm deep and 20cm to 40cm deep components. These depths were chosen as the deeper, below 20cm, samples are more likely to be indicative of pre-pumping metal concentrations than the shallower samples (D. Baldwin 2019, pers. comm., 20 Nov.) The three cores were then mixed into a composite sample for each depth, placed into jars and kept refrigerated prior to delivery to the NATA accredited Eurofins Laboratory to be analysed for metals and pH.

2.2.4. Macroinvertebrates

The benefit of monitoring the biological community is that it is affected by numerous types of toxicants and disturbances and the impacts can be evident over months or years (if two seasons are sampled) unlike chemical testing which may not capture an event.

Macroinvertebrates were collected at each site and photos and site assessment sheets were completed as per Victorian EPA guidelines (EPA, 2003b). In the absence of riffle habitats, two edge samples were collected (L. Metzling 2019 pers. comm. August 12) using a 250µm mesh dip net to sample ten meters of representative habitat at two locations at each site between 2nd and 4th October, 2019. The contents of the net was placed into a white tray to be picked through for 30 minutes with the aim of picking over 100 animals into 70% ethanol for later identification to family level following the Rapid Bioassessment Methodology for Rivers and Streams (EPA, 2003b). Macroinvertebrates were identified in the laboratory in accordance with the guidelines; to class for Oligochaeta and Mites, chironomids to sub-family and all other taxa to family except those that are not included in EPA Victoria biotic calculations (EPA, 2003b).

2.2.5. Site descriptions

EPA Victoria field sampling and habitat assessment sheets were filled out at each site and site photos taken (EPA, 2003b). These have been summarised in Appendix 1.

3. Results

3.1. Water quality

Water samples were collected and *in situ* readings taken at all 12 sites that sediments and macroinvertebrates were collected at and an *in situ* reading was taken on Boundary Creek (site 5.5) immediately upstream of the confluence with the Barwon River. Whilst a single water sample provides a snap shot of what is occurring in the waterway at one point in time, it gives an indication of the current conditions.

Table 2: In-situ water quality data.

Site	Waterway	Sample date	Temp. (°C)	pH	Conductivity (µS/cm)	Specific Conductivity (µS/cm@25°C)	Dissolved oxygen (mg/L)	DO %	Alkalinity	Turbidity
Site 1	East Barwon Rv	04/10/19	13.2	6.2	186.7	240	13.07	123	5	9.09
Site 2	East Barwon Rv	04/10/19	15.5	6.3	544	664	6.8	66.8	10	9.97
Site 3	West Barwon Rv	03/10/19	14.7	5.26	473.4	590.6	7.3	73.5	10	16.3
Site 4	Barwon Rv	03/10/19	17.9	7.4	575	664	9.15	96.4	10	8.01
Site 5	Boundary Ck	03/10/19	12.1	3.94	777	1030	7.43	67.6	0	2.92
Site 5.5	Boundary Ck	03/10/19	14.2	5.55	1165	1285	7.05	68.2	-	-
Site 6	Barwon Rv	03/10/19	14.4	7.34	608	756	7.3	71.3	10	9.43
Site 7	Barwon Rv	03/10/19	13.4	7.9	599	770	7.2	71.7	5	10
Site 8	Barwon Rv	02/10/19	16.2	7.8	660	795	8.8	87.9	10	13.5
Site 9	Barwon Rv	02/10/19	15.4	7.8	1049	1288	9.7	98	15	16.6
Site 10	Barwon Rv	02/10/19	14.6	7.9	1252	1561	8.1	86.1	15	18
Site 11	Barwon Rv	02/10/19	13	7.9	1707	2227	9.23	87	15	26.1
Site 12	Barwon Rv	02/10/19	12.4	8	1788	2364	8.4	82.1	15	19.9

At the time of sampling, pH levels were low in the East and West branches of the Barwon River but had normalised at Site 4 above the Boundary Creek confluence. Whilst Boundary Creek has very low pH at Site 5 (Colac-Forest Road) and remains low immediately upstream of joining the Barwon River, the drop from upstream to downstream of the confluence is only 0.6 pH units and by Site 7, 3km downstream, pH remains constant downstream. Samples taken monthly can be compared to the State Environment Protection Policy (SEPP) Waters of Victoria (2004) objectives that indicate the pH is should be between 6.5 and 8.3 (25^{th} and 75^{th} percentile respectively) for sites 2-12 (Cleared Hills and Costal Plains) and 6.4 to 7.7 (25^{th}-75^{th} percentile) for site 1 (Forests B segment).

- **Table 3: Metal results for water samples (mg/L) and ANZECC water quality guidelines (2000, Table 3.4.1) for trigger values applying to typical *slightly–moderately disturbed systems.***

mg/L	Aluminium	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Mercury	Selenium	Silver	Zinc
Site 1	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.33	< 0.001	0.04	< 0.0001	< 0.001	< 0.005	0.032
Site 2	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.4	< 0.001	0.15	< 0.0001	< 0.001	< 0.005	0.008
Site 3	< 0.05*	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.31	< 0.001	0.31	< 0.0001	< 0.001	< 0.005	0.051
Site 4	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.33	< 0.001	0.15	< 0.0001	< 0.001	< 0.005	0.017
Site 5	10*	< 0.005	< 0.001	0.0002	< 0.001	< 0.001	5.4	< 0.001	0.06	< 0.0001	< 0.001	< 0.005	0.34
Site 6	0.09	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.13	< 0.001	0.17	< 0.0001	< 0.001	< 0.005	0.057
Site 7	0.07	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.15	< 0.001	0.08	< 0.0001	< 0.001	< 0.005	0.013
Site 8	0.1	< 0.005	< 0.001	< 0.0002	< 0.001	0.001	0.23	< 0.001	0.066	< 0.0001	< 0.001	< 0.005	0.015
Site 9	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.22	< 0.001	0.098	< 0.0001	< 0.001	< 0.005	0.01
Site 10	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.22	< 0.001	0.09	< 0.0001	< 0.001	< 0.005	< 0.005
Site 11	< 0.05	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.42	< 0.001	0.1	< 0.0001	< 0.001	< 0.005	< 0.005
Site 12	0.07	< 0.005	< 0.001	< 0.0002	< 0.001	< 0.001	0.56	< 0.001	0.1	< 0.0001	< 0.001	< 0.005	< 0.005
ANZECC	0.05 (>6.5pH) *ID (<6.5pH,)	ID	0.013	0.0002	0.001	0.0014	ID	0.0034	1.2	0.00006	0.005	0.00005	0.008

ID= insufficient data
Shaded exceeds trigger values
**aluminium results where pH is <6.5*

Aluminium and Zinc were the only metals that were found in concentrations higher than the ANZECC (2000) guideline levels of 0.05mg/L and 0.008mg/L respectively. Aluminium is the only metal that is higher downstream of the Boundary Creek confluence than it is upstream of the confluence although this impact appears not to extend past Site 8 at the Colac-Lorne Road. It is not clear from this study what is causing the high reading at Site 12 at Winchelsea. Zinc levels are high above and below the Boundary Creek confluence as are Iron and Manganese levels.

3.2. Sediment surveys

Sediment data provides a historical overview of metals within the waterway.

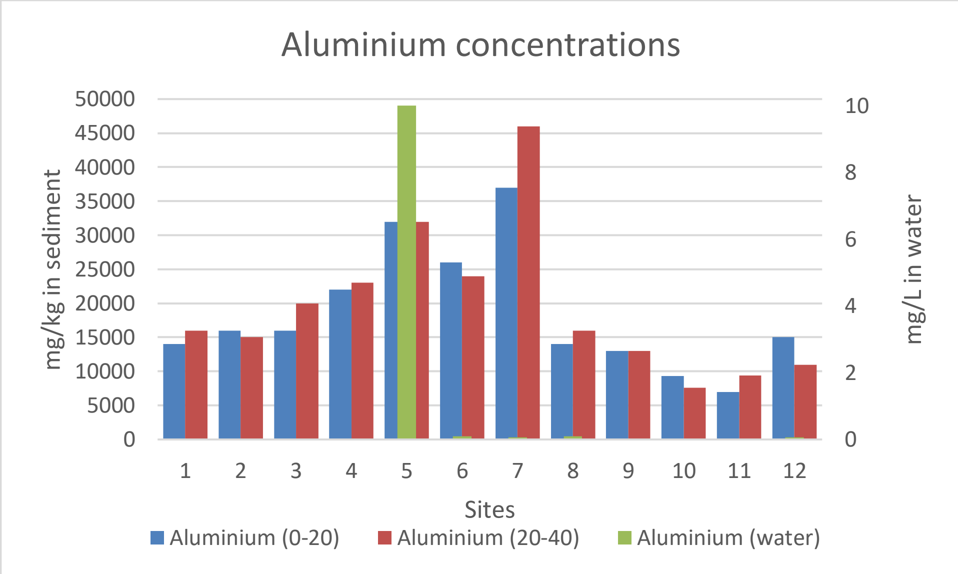
- **Table 4: Metal and pH results for sediment samples at 0-20 and 20-40 cm below surface (mg/kg) and ANZECC (2000) sediment quality guidelines.**

mg/kg	pH	Aluminium	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Mercury	Selenium	Silver	Zinc
SITE 1(0-20)	7.1	14000	< 10	3.6	< 0.4	14	9.6	29000	9.1	1300	< 0.1	< 2	< 0.2	56
SITE 1(20-40)	5.9	16000	< 10	3.6	< 0.4	18	11	30000	11	720	< 0.1	< 2	< 0.2	65
SITE 2(0-20)	6.8	16000	< 10	3.2	< 0.4	16	12	23000	13	540	0.1	< 2	< 0.2	59
SITE 2(20-40)	6.6	15000	< 10	3.4	< 0.4	16	13	23000	13	470	0.1	< 2	< 0.2	58
SITE 3(0-20)	6.3	16000	< 10	4.9	< 0.4	15	15	30000	16	850	0.1	< 2	< 0.2	68
SITE 3(20-40)	6.6	20000	< 10	4.2	< 0.4	17	16	32000	16	680	0.1	< 2	< 0.2	71
SITE 4(0-20)	6.1	22000	< 10	3.6	< 0.4	20	14	29000	13	740	0.1	< 2	< 0.2	74
SITE 4(20-40)	6.5	23000	< 10	3.9	< 0.4	21	15	28000	14	480	0.1	< 2	< 0.2	71
SITE 5(0-20)	4.7	32000	< 10	27	< 0.4	44	12	73000	43	50	0.1	< 2	< 0.2	120
SITE 5(20-40)	5.5	32000	< 10	23	< 0.4	43	10	40000	12	58	0.3	< 2	< 0.2	81
SITE 6(0-20)	6.5	26000	< 10	6	< 0.4	27	12	28000	14	440	0.1	< 2	< 0.2	100
SITE 6(20-40)	6.4	24000	< 10	7.4	< 0.4	25	14	33000	15	470	0.1	< 2	< 0.2	78
SITE 7(0-20)	6.8	37000	< 10	7.9	< 0.4	34	26	38000	19	860	0.1	< 2	< 0.2	75
SITE 7(20-40)	6.9	46000	< 10	17	< 0.4	40	27	60000	23	1100	0.1	< 2	< 0.2	90
SITE 8(0-20)	6.3	14000	< 10	21	< 0.4	32	7.3	56000	15	580	< 0.1	< 2	< 0.2	67
SITE 8(20-40)	6.6	16000	< 10	4.7	< 0.4	17	9.7	28000	12	1000	0.1	< 2	< 0.2	66
SITE 9(0-20)	6.6	13000	< 10	4.3	< 0.4	15	7.5	15000	9.9	320	0.1	< 2	< 0.2	38
SITE 9(20-40)	6	13000	< 10	4.2	< 0.4	17	6.7	13000	11	180	< 0.1	< 2	< 0.2	27

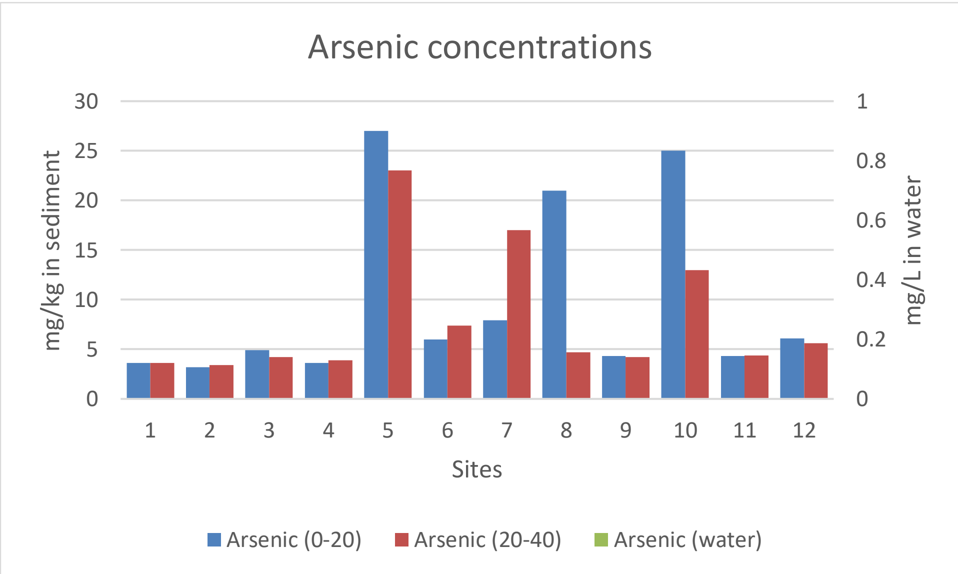
mg/kg	pH	Aluminium	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Mercury	Selenium	Silver	Zinc
SITE 10(0-20)	7	9300	< 10	25	< 0.4	18	6.7	55000	21	540	< 0.1	< 2	< 0.2	43
SITE 10(20-40)	6.3	7600	< 10	13	< 0.4	14	6.3	30000	12	560	< 0.1	< 2	< 0.2	48
SITE 11(0-20)	6.5	7000	< 10	4.3	< 0.4	11	< 5	14000	7.1	280	< 0.1	< 2	< 0.2	24
SITE 11(20-40)	6.5	9400	< 10	4.4	< 0.4	14	5.8	15000	12	330	< 0.1	< 2	< 0.2	26
SITE 12(0-20)	7.4	15000	< 10	6.1	< 0.4	21	8.8	23000	12	280	< 0.1	< 2	< 0.2	38
SITE 12(20-40)	7.3	11000	< 10	5.6	< 0.4	15	7.8	19000	10	330	< 0.1	< 2	< 0.2	35
ANZECC	-	-	2	20	1.5	80	65	-	50	-	0.15	-	1	200

Shaded exceeds trigger values.

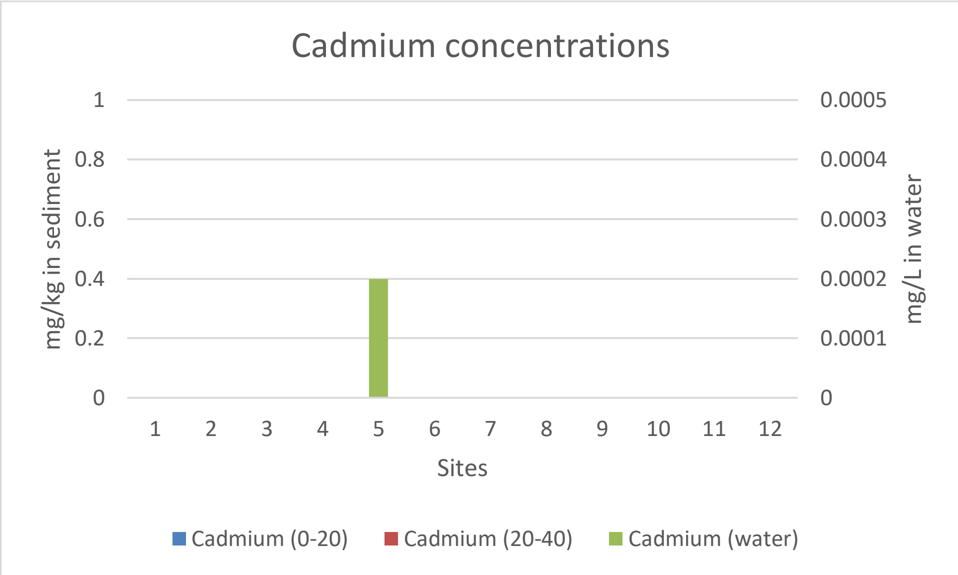
Arsenic and Mercury are the only metals in sediments that exceed the ANZECC trigger values of 20mg/kg and 0.15mg/kg respectively. Mercury exceeds the trigger value in the deep (20-40cm sediments) in Boundary Creek (Site 5) and Arsenic exceeds the trigger value in the shallow and deep sediments in Boundary Creek (Site 5) and the shallow sediments at Site 8 (Colac-Lorne Road) and Site 10 (Conns Lane).



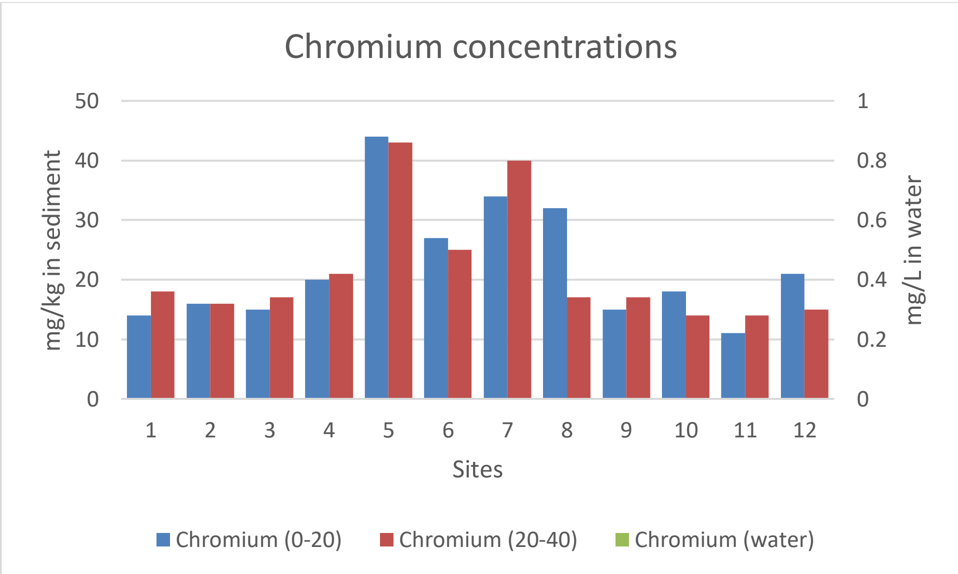
Aluminium was detected in water at sites 5, 6, 7, 8 and 12, exceeding the ANZECC trigger level (0.05mg/L). There was a spike in aluminium concentrations in sediments at sites 5 and 7 though levels are higher in the upper reaches above Boundary Creek than in the lower reaches around Birregurra and Winchelsea suggesting impacts other than from Boundary Creek. The deep and shallow sediments in Boundary Creek, site 5, have similar concentrations of aluminium.



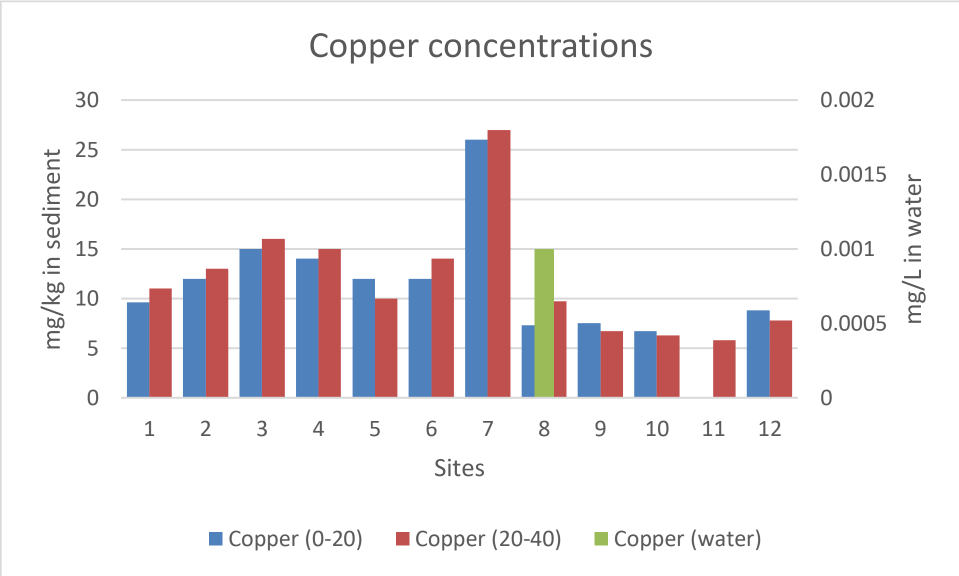
Arsenic was below detectable levels in the water and was over ANZECC guideline levels of 20 mg/kg in the shallow and deep sediments at site 5 and the shallow sediments at site 8 and 10.



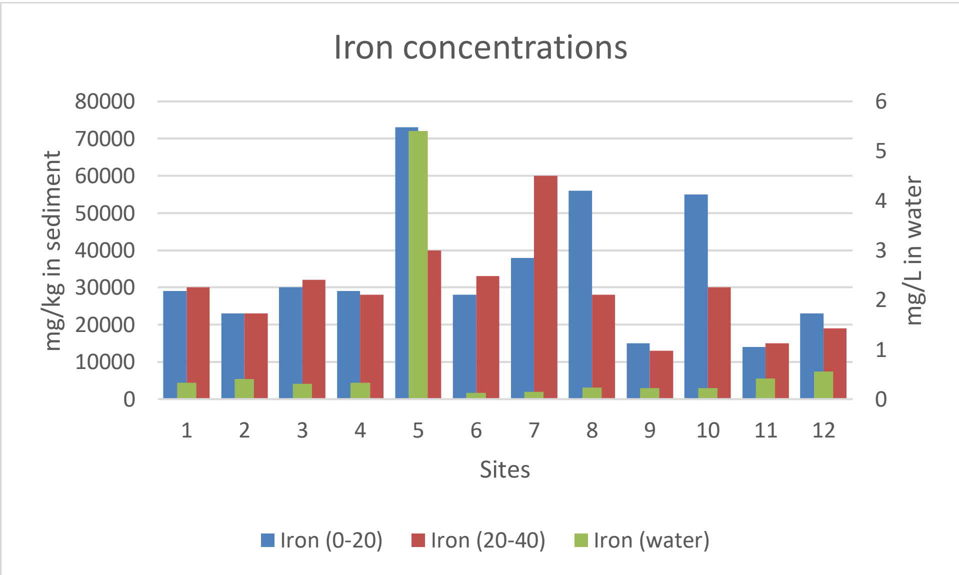
Cadmium was only detected in water at site 5 and was equal to the ANZECC guideline value (0.0002mg/L). Cadmium was not detected in sediments at any of the sites sampled.



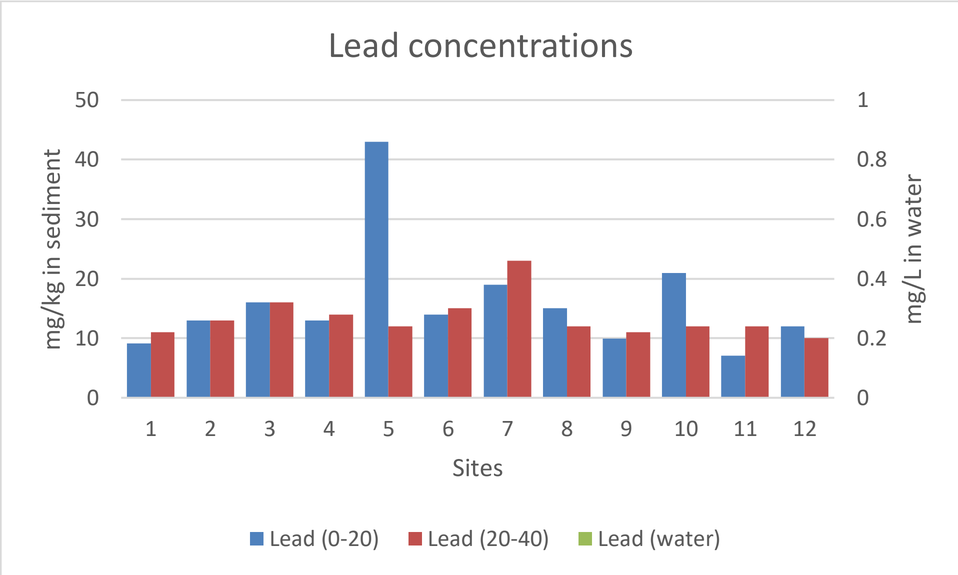
Chromium was not detected in water and despite levels in sediments peaking at sites 5 and 7 they were under ANZECC guideline levels (80mg/kg). Chromium was at similar levels in Boundary Creek (site 5) in the shallow and deeper samples.



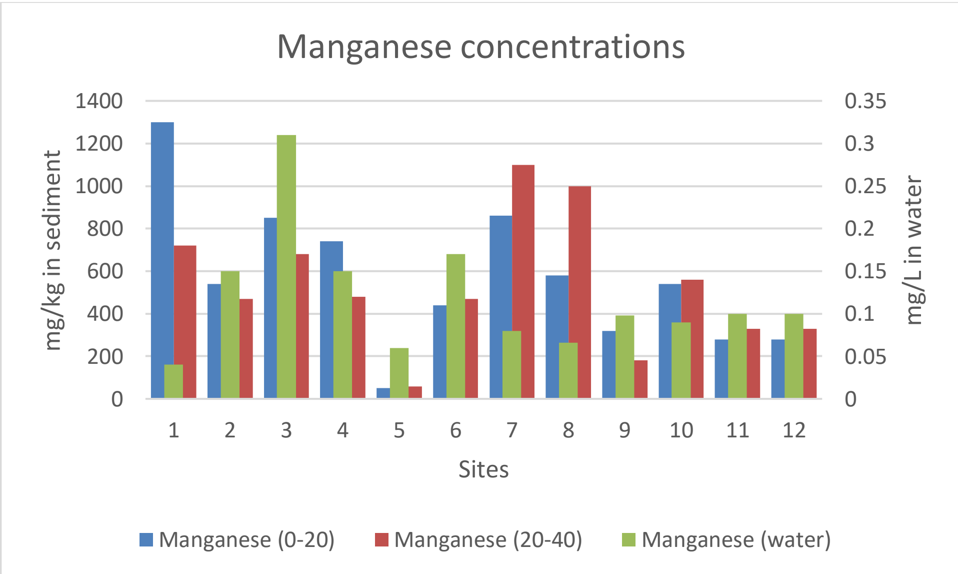
Copper was only detected in water at site 8 at the Colac-Lorne Road, below the ANZECC concentration of 0.0014mg/L. The highest concentrations of copper in sediment were recorded at site 7 and were similar in the shallow and deep samples but all results were well below ANZECC guideline levels (65mg/kg).



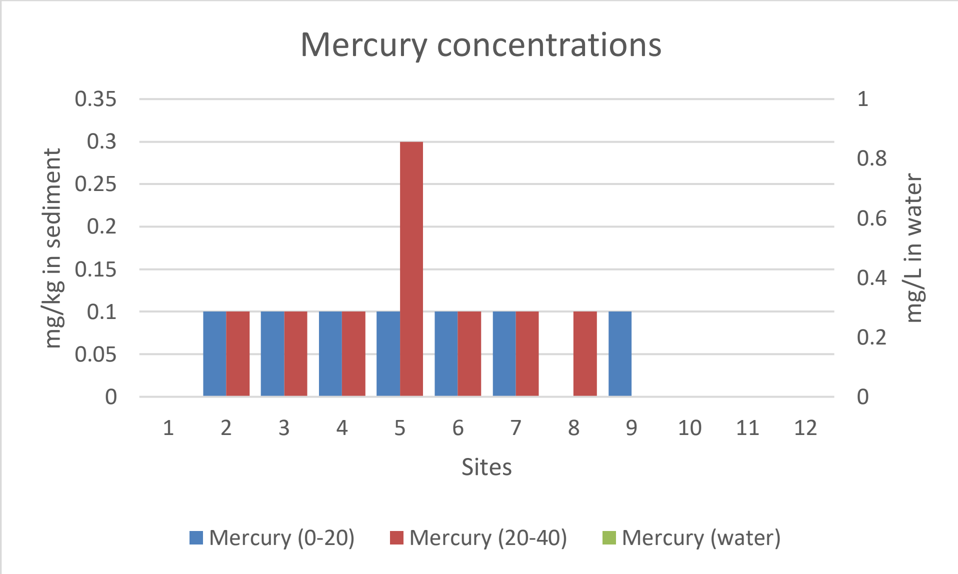
Iron was recorded in the water and sediments at all sites with highest levels in water and shallow sediments at site 5 (Boundary Creek). Iron was higher in the deeper sediments than in the shallow sediments at site 7 and higher in the shallow sediments compared to the deeper sediments at sites 5, 8 and 10.



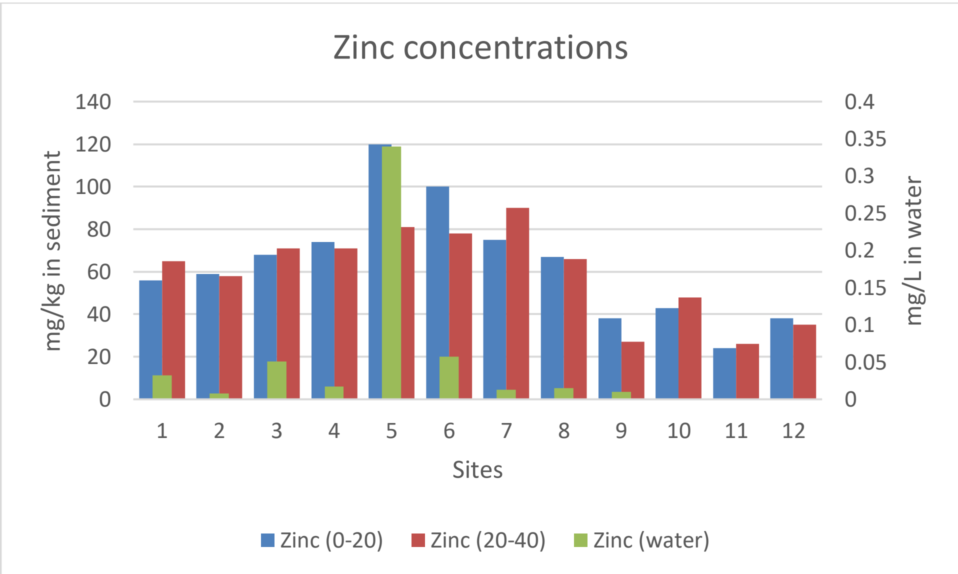
Lead was undetectable in water and was highest in shallow sediments (triple the concentration in the deeper sediments) at site 5 though below ANZECC guideline levels (50mg/kg).



Manganese is a naturally occurring trace element and concentrations in the water are well below the ANZECC guidelines for water (1.2mg/L). There are no ANZECC guidelines for sediments.



Mercury was undetectable in water and in sediment downstream of Birregurra (site 9). It is at detectable limits in sediment (0.1 mg/kg) at site 2-9 but below ANZECC guideline levels of 0.15mg/kg except in the deep sediments at site 5 where it exceeds ANZECC levels.



Zinc concentrations in sediments were below ANZECC level of 200mg/kg at all sites. Levels in water reduce along East Barwon and Barwon until site 6, after Boundary Creek and are undetectable by Conns Lane Birregurra (site 10). Concentrations are higher in shallow sediments at sites 5 and 6 and in deeper sediments at site 7.

3.3. Macroinvertebrate results

Biotic indices such as AusRivAS, SIGNAL, SIGNAL2, EPT (Ephemoptera, Plecoptera, Trichoptera) and taxa richness (number of families and key families) scores were calculated in accordance with EPA Victoria biological objectives (EPA Victoria, 2004). Objectives have been reported but not applied as only the Spring data was collected in this study. A multi dimensional scaling (MDS) plot was also produced to give an indication of how similar the macroinvertebrate community compositions are to each other. A full list of macroinvertebrate families found at each site is in Appendix 2.

AusRivAS scores and bands are considered to give the most accurate assessment of the health of a site as the program compares the test site to a number of reference sites that have similar physical and chemical characteristics but are relatively free of environmental impacts. The score indicates how many macroinvertebrate families were found compared to those found at reference sites. The statewide model for edge habitat in Spring was applied to these samples.

- **Table 5: AusRivAS Bands, Observed/Expected scores and descriptions (AusRivAS Macroinvertebrate Predictive Modelling Version 3.2.2)**

Band	OE 50 score	Description
X	1.20+	More biologically diverse than reference sites
A	0.81-1.19	Reference condition
B	0.42-0.80	Significantly impaired
C	0.05-0.41	Severely impaired
D	0-0.04	Extremely impaired

SIGNAL and SIGNAL2 are biotic indices based on the tolerance or intolerance of biota (macroinvertebrates) to water pollution. Sites with high scores are likely to have low nutrient, salinity and turbidity levels and high oxygen levels. EPA biological objectives use the SIGNAL score but SIGNAL2 is also calculated as it uses updated, refined scores (Chessman, 2003).

- **Table 6: Key to SIGNAL scores**

SIGNAL score	Water Quality
>7	Excellent
6-7	Clean Water
5-6	Mild pollution
4-5	Moderate pollution
<4	Severe pollution

The EPT score indicates the number of families that are sensitive to pollution that are present at the site with a low score usually indicating that there has been some type of disturbance. Together, these scores give a good picture of the health of the waterway at a site and potentially what is causing any disturbance.

Taxa richness, measured by the number of macroinvertebrate families collected, can give a good overview of the health of a waterway. High numbers are associated with diverse habitats present at the site but can also be influenced by mild nutrient enrichment which can increase the food supply. The score can be combined with SIGNAL2 scores as in Figure 2 to help interpret results. The number of Key Families found focuses on which taxa are expected to be in a region and is a similar concept to AusRivAS.

The study area crosses two biological regions. Forests B is characterised by upland reaches in the Otway Ranges where there is some clearing for forestry, grazing and some intensive agriculture. Site 1 falls within Forests B. Cleared Hills and Coastal Plains incorporates lower reaches of the

Barwon River where the region has been substantially cleared for intensive agriculture (EPA, 2004). Sites 2 to 12 are in this region.

- **Table 7: Biological Objectives (EPA, 2004)**

Objective	Number of Families	SIGNAL Index score	EPT Index score	Key Families*	AusRivAS O/E score	AusRivAS Band
Forests B (Region 3)	24	5.8	9	26	0.87-1.13	A
Cleared Hills & Coastal Plains (Region 4)	26	5.5	-	22	0.85-1.15	A

** Only applicable when riffle and edge habitats sampled*

The pollution sensitive Ephemeroptera, Plecoptera and Tricoptera (EPT) macroinvertebrate families are seldom found in waterways within the Cleared Hills and Coastal Plains region, therefore no objectives have been set but numbers have been reported in Table 5. Key Families is similar to the AusRivAS concept although it requires two habitats to be sampled whereas there are models based on single habitats or combined habitats. Key Families should be used if AusRivAS does not give a result for the site due to it being 'outside the experience of the model'.

- **Table 8: Biotic index results.**

Site	Number of Families	SIGNAL	SIGNAL2#	EPT Index score#	Key Families*	AusRivAS O/E score	AusRivAS Band
1	17	4.94	3.53	3	16	Outside the experience of the model	
2	32	5.43	3.25	4	21	0.88	A
3	25	5.63	4.04	6	21	0.95	A
4	22	5.20	3.27	3	17	0.91	A
5	10	4.90	2.90	0	8	Outside the experience of the model	
6	24	5.86	4.08	7	22*	1.07	A
7	32	5.42	3.38	5	24*	0.91	A
8	26	5.38	3.77	6	25*	1.07	A
9	30	5.70	3.73	7	23*	1.12	A
10	21	5.15	3.48	3	19	1.01	A
11	21	5.32	3.90	4	18	0.83	A
12	27	5.54	3.93	6	24*	1.15	A

 # No objective.

☐ Objective met but not applicable as only one season sampled.

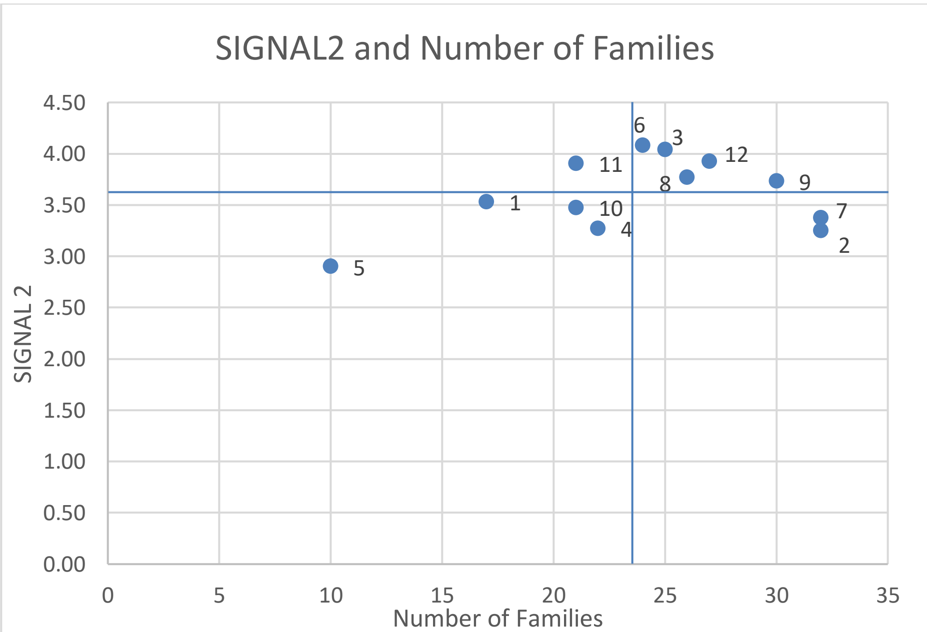
** Objective met but not applicable as only edge habitats sampled.*

Sites 9 and 12 meet the most objectives for ecosystem protection (EPA, 2004) and have the highest AusRivAS score, suggesting that they are the healthiest sites within the upper Barwon River.

Sites 1 and 5 are 'Outside the experience of the AusRivAS model' and site 10 was 'Nearly outside the experience of the model'. This means that based on the environmental data entered, no reference sites can be found to compare to the test site and limited reference sites were found for site 10 therefore the data should be treated with caution. This is more often the case with single season samples than combined over Autumn and Spring and unusual readings such as alkalinity at site 5 may make it difficult to match with reference sites. Sites 1 and 5 are also outliers in that they have SIGNAL scores that indicate they are subject to moderate pollution whereas all other sites are in the mild pollution category (Tables 6 and 8).

Whilst SIGNAL2 scores give an indication of water quality in the river from which the sample was collected, combining the score with the richness score (how many different macroinvertebrate families are present), can provide an indication of the types of pollution and other physical and chemical factors that are affecting the macroinvertebrate community.

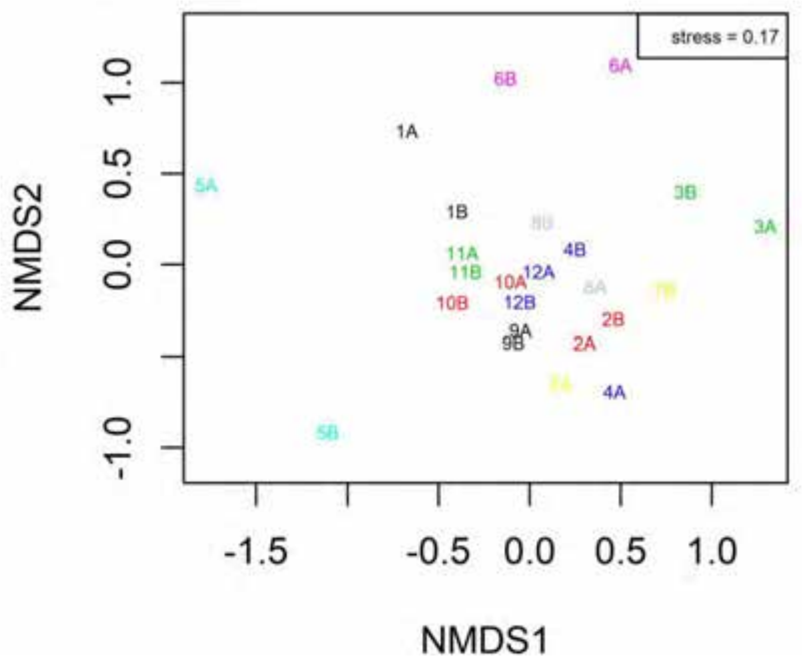
The plot is split into quadrants, the borders chosen to include the healthiest sites in the top right (Quadrant 1) and the quadrants are defined by those boundaries as detailed in Chessman (2003). As there were not any sites without human disturbance, those sites that met or were close to meeting EPA biological objectives for number of families and SIGNAL scores were included in Quadrant 1 and a cross check of which sites had the most EPT families (Table 5) confirmed the quadrant borders.



- **Figure 2 SIGNAL2 index plotted against number of families recorded for each site.**

Sites 3, 6, 8, 9 and 12 have high SIGNAL2 and number of macroinvertebrate families suggesting the habitat and water quality are favorable and stress factors are low. Sites 2 and 7 in the bottom right quadrant have lower SIGNAL2 scores, possibly due to water quality influences but the high number of families present suggest that any toxicants are not present in large amounts. Site 11 in the top left quadrant has high SIGNAL2 scores but fewer number of families. This site is possibly affected by pollution other than what SIGNAL scores are based on (organic, nutrient enrichment or salinity). Sites 1, 4, 5, and 10 have lower SIGNAL2 scores and low numbers of families suggesting that they are subject to a number of impacts.

The MDS (Multidimensional Scaling) plot (Figure 3) shows how similar, or dissimilar, the macroinvertebrate community compositions at each site are to one another based on presence absence data.



■ **Figure 3: MDS plot of families from two edge habitats (A and B) at twelve sites.**

The above MDS plot (Figure 3) shows that sites above and below the Boundary Creek confluence have similar macroinvertebrate families present, with site 3 (East Barwon), site 5 (Boundary Creek), and site 6 (Barwon River immediately downstream of Boundary Creek) having different macroinvertebrate community compositions present.

Site 3 is different to the other sites by being the only one with the damselfly, Synlestidae, present and was also the only site that had the trichopteran (caddisfly), Conoesucidae, present. Site 3 lacked backswimmers (Notonectidae), a family of mayflies (Baetidae) and one family of amphipods (Ceinidae) that were commonly present at other sites though there were other families of each order present. Site 5 is missing many of the families that are present at other sites and is the only site that had the mosquito larvae, Culicidae, present. Site 6 is different to other sites for a number of reasons. It is lacking any snail families, one amphipod family (Janiridae), one beetle family (Scirtidae) and one bug family (Notonectidae) though there are other amphipod, beetle and bug families present at the site. This site is the only one in the study to record yabbies (Parastacidae), and the uncased caddisfly, Hydrobiosidae.

4. Discussion & Conclusion

4.1. Metals

Within the surface water, Aluminium and Cadmium were detected only in Boundary Creek whereas Iron and Zinc were detected in Boundary Creek and the Barwon River both upstream of downstream of the confluence with Boundary Creek. These metals were also found in the sediments . Metals in sediments appear to be impacted by Boundary Creek but there does not appear to be an impact by site 9, Birregurra township, approximately 20km downstream of the Boundary Creek confluence. Within Boundary Creek (site 5), there are historically high (in both the shallow and deeper sediments) concentrations of Aluminium, Arsenic and Chromium suggesting that recent events in Big Swamp have not significantly impacted concentrations of these metals. Concentrations of Iron, Lead and Zinc are higher in shallow sediments than deeper sediments, suggesting that the drying and subsequent rewetting of Big Swamp have increased the concentrations of these sediments. The spike in metals such as Arsenic at Conns Lane, Birregurra (site 10) suggest other catchment activities may be impacting the Barwon River.

4.2. Macroinvertebrates

Big Swamp continues to impact the macroinvertebrate community composition in Boundary Creek as measured at Site 5, Colac-Lorne Road. In a 2014/15 study of Boundary Creek (Austral Research and Consulting, 2015), the site at Colac-Lorne Road recorded the same number of families and EPT families but lower SIGNAL and SIGNAL2 scores (4.5 and 2.7) in Spring compared to scores in 2019 (4.9 and 2.9). This was due to the collection of an individual from a family (Dugesiidae- Flatworm) that is slightly more intolerant of organic pollution than a family that wasn't collected (Oligochaeta- Worm). This indicates that conditions in Boundary Creek in 2019 are similar to that in 2014.

Within the Barwon River, macroinvertebrate community composition is impacted by Boundary Creek immediately downstream of the confluence (shown by the MDS plot) but the overall health at this site (using the biotic indices) and continuing downstream are not adversely impacted. The absence of snails at Site 6 directly downstream is one of the contributors to the difference in macroinvertebrate community composition. Their absence is possibly due to the low pH affecting shell development but has not impacted on other species such as yabbies which were only found at this site and other grazing animals such as amphipods, mayflies and caddisflies are all present.

Four of the five 'healthiest' sites as determined by SIGNAL2 and Number of Families were downstream of the confluence with Boundary Creek and five of the seven sites below the confluence had higher AusRivAS scores than those sites above the confluence. These results suggest that the Barwon River may have recovered from the 2016 fish kill event (Ryan, 2016) and once downstream of Site 6 immediately below the confluence, is not currently being adversely impacted by inflows from Boundary Creek.

4.3. Recommendations

Sampling of metals in the water along the Barwon River during the Boundary Creek remediation works should give an indication of whether they are still being mobilised by the low pH water coming into the system and may be more cost effective than continually sampling sediments. Sediments should be sampled for metals periodically to track whether they are moving downstream or are remaining bound at the site.

Whilst macroinvertebrate communities are at reference condition at all sites excepting Site 1 which was outside the experience of the AusRivAS model for an unknown reason, and Site 5 on Boundary Creek which is severely impacted by the low pH, a second season of sampling in Autumn would give a complete picture and enable comparisons with biological objectives. Continued macroinvertebrate sampling of Boundary Creek will give an excellent indication as to its recovery during remediation works and introducing macroinvertebrate sampling at sites currently monitored by Waterwatch will add to the information already collected from the Barwon River.

5. References

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Appendix 1:

5.1. Site 1- East Barwon River@ Kents Road

	
Site 1: upstream	Site 1: downstream

The East Barwon at Kents Road has diverse habitat with large deep pools and some riffle/ run areas. Willows dominate the riparian zone and are growing within the stream channel. The substrate is a mix of clay and silt with a number of aquatic macrophytes growing in the margins and shallow pool areas. The average stream width at this site was eight meters and was bank full at the time of sampling. The majority of the riparian zone is exotic vegetation, dominated by blackberries, willows and pasture grass. One larval fish was collected as bycatch during macroinvertebrate sampling. A concurrent snapshot study by EnviroDNA (2019) found evidence of platypus at this site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 74 out of 140.

Site1: Sediment cores

5.2. Site 2- East Barwon River@ Dewings Bridge Road

	
Site 2: upstream	Site 2: downstream

The East Barwon at Dewings Bridge Road consists of a slow flowing channel with extensive backwaters. There is very little riparian zone present but a number of submerged and emergent macrophytes provide good habitat. The substrate is a mix of clay and silt with some sand. The average stream width at this site was seven meters and was bank full at the time of sampling. The majority of the riparian zone is pasture grass with stock access on both sides. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 59 out of 140.

Site 2: Sediment cores

5.3. Site 3- West Barwon River@ Seven Bridges Road


Site 3: upstream


Site 3: downstream

The West Barwon River at Seven Bridges Road has large deep pools with a number of large deep backwaters. The average stream width at this site is seven meters, narrow at the top of the surveyed reach and widening into a large pool near the bridge. The substrate is clay and silt mixed with 20% sand. There are some macrophytes present along with trailing bank vegetation, roots and instream large woody debris (primarily willow branches). Willows dominate the riparian zone a mix of shrubs and native and pasture grasses in the understory. Four larval fish were collected as bycatch during macroinvertebrate sampling. A concurrent snapshot study by EnviroDNA (2019) found evidence of platypus at this site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 85 out of 140.


Site 3: Sediment cores

5.4. Site 4- Barwon River upstream of Boundary Creek confluence


Site 4: upstream


Site 4: downstream

The Barwon River immediately upstream of the Boundary Creek confluence is a large slow flowing channel with shallow side sections that support a number of macrophyte beds. The average stream width at this site is nine meters. The substrate is clay and black silt with some large woody debris and filamentous algae present in addition to the macrophytes. Juncus, Typha, Triglochin and Polygonum are all present instream though riparian vegetation is limited to some isolated trees, a narrow native plantation and pasture grass with stock access. The introduced Gambusia (mosquito fish) were collected as bycatch during macroinvertebrate sampling. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 79 out of 140.


Site 4: Sediment cores

5.5. Site 5- Boundary Creek @ Colac- Forrest Road


Site 5: upstream


Site 5: downstream

Boundary Creek at Colac- Forrest Road has a mix of large deep pools, a large shallow pool at the bridge and shallow runs. It was bankfull at the time of sampling with an average stream width of four meters, narrow at the top of the surveyed reach and widening into a large pool upstream of the bridge. The substrate is a mix of cobble, pebble, gravel, sand, clay and silt. There are no macrophytes but there is some filamentous algae and trailing bank vegetation present. The riparian zone is wide and a mix of native and exotic vegetation except the ground cover which is dominated by *Convolvulus* sp. and pasture grasses. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 81 out of 140.


Site 5: Sediment cores

5.6. Site 6- Barwon River downstream of Boundary Creek confluence


Site 6: upstream


Site : downstream

The Barwon River immediately downstream of the Boundary Creek confluence is a narrow deep channel with wide shallow edges dominated by grasses and aquatic macrophytes. The average stream width at this site is five meters and is bank full. It is wide but still with a narrow channel at the top of the surveyed reach and narrowing to a confined channel downstream. The substrate consists of clay and silt with filamentous algae tangled through the macrophyte beds. Macrophyte species are varied with Triglochin, Polygonum, Phragmites, and Juncus all present in addition to trailing grasses. The riparian zone is limited to grasses and scattered native trees and shrubs with stock access to the site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 70 out of 140.


Site 6: Sediment cores

5.7. Site 7- Barwon River upstream of CO_BAR16


Site 7: upstream


Site 7: downstream

The Barwon River upstream of CO_BAR16 adjacent to the northern boundary of the pine plantation has a large deep channel with any shallow areas dominated by beds of Phragmites. The average stream width at this site is seven meters. The substrate is clay and silt. In addition to the Phragmites beds there are beds of Triglochin, and scattered Polygonum, Juncus and other grasses. The riparian zone has a good mix of trees, shrubs and understory with a majority of native trees and shrubs. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 90 out of 140.


Site 7: Sediment cores

5.8. Site 8- Barwon River @ Colac- Lorne Road


Site 8: upstream


Site 8: downstream

The Barwon River at Colac- Lorne Road has large deep pools with a shallow areas at the sides and willow trees growing in the channel and some substrate exposed. The average stream width at this site is eight meters with a predominantly clay and silt substrate mixed with some sand. There are beds of Triglochin and Phragmites in addition to trailing grasses and large willows. The riparian zone consists of willow trees, pasture grasses and blackberries and allows stock access. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 69 out of 140.


Site 8: Sediment cores

5.9. Site 9- Barwon River @ Birregurra


Site 9: upstream


Site 9: downstream

The Barwon River at Birregurra consists of a large deep slow flowing pool. The average stream width at this site is five meters with steep clay banks. The substrate is clay and silt with willow roots, some snags and Triglochin beds scattered along the edges of the channel. There have been recent willow removal works and replanting of the riparian zone in amongst the pasture grass and blackberry groundcover. Rakali footprints were evident in the soft sediment edge. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 67 out of 140.


Site 9: Sediment cores

5.10. Site 10- Barwon River @ Conns Lane

	
Site 10: upstream	Site 10: downstream

The Barwon River at Conns Lane has large deep pools with some small deep backwaters and a narrow deep run at the top of the reach. The average stream width at this site is six meters. The substrate is clay and silt mixed with some sand and gravel. Phragmites beds line the channel and there are isolated patches of Triglochin in addition to Polygonum and trailing grasses along the waters edge. The riparian zone consists of relatively new and older native revegetation with pasture grass understory. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 98 out of 140.

Site 10: Sediment cores

5.11. Site 11- Barwon River@ Winchelsea- Deans Marsh Road


Site 11: upstream


Site 11: downstream

The Barwon River at Winchelsea- Deans Marsh Road has large deep pools with a shallow run at the top of the reach. The average stream width at this site is five meters and the substrate is clay and silt mixed with some sand and gravel. Triglochin is growing in the shallow areas of the channel and there are roots, large woody debris and trailing grasses. The riparian zone is predominately native trees and understory with a mix of grasses as groundcover. Rakali footprints were spotted at the waters edge. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 90 out of 140.


Site 11: Sediment cores

5.12. Site 12- Barwon River @ Winchelsea


Site 12: upstream


Site 12: downstream

The Barwon River at Winchelsea has large deep pools with a large shallow pool at the top of the reach. The average stream width at this site is twelve meters. The substrate is clay and silt mixed with sand and some gravel. In addition to the Phragmites beds at the top of the reach and along some edges there are also patches of Triglochin. Large woody debris, trailing grasses and emergent vegetation such as Polygonum are also present. Riparian vegetation is predominantly native with many established eucalypts and groundcover is pasture grass. A concurrent snapshot study by EnviroDNA (2019) found evidence of platypus at this site. Overall analysis of the health of the waterway using EPA habitat parameters for Low Gradient Streams gives this site a score of 88 out of 140.


Site 12: Sediment cores

Appendix 2

Macroinvertebrate list Spring

Site Code	Site Location	Taxa Code	Taxa Name	Number
1	East Barwon @ Kent Road	IB019999	Hydridae	1
1	East Barwon @ Kent Road	IF619999	Dugesiidae	10
1	East Barwon @ Kent Road	KG079999	Planorbidae	1
1	East Barwon @ Kent Road	KG089999	Physidae	30
1	East Barwon @ Kent Road	LO999999	Oligochaeta	1
1	East Barwon @ Kent Road	MM999999	Mites	1
1	East Barwon @ Kent Road	OP029999	Ceinidae	13
1	East Barwon @ Kent Road	OT019999	Atyidae	3
1	East Barwon @ Kent Road	QC099999	Dytiscidae	1
1	East Barwon @ Kent Road	QD109999	Simuliidae	2
1	East Barwon @ Kent Road	QDAF9999	Orthocladiinae	65
1	East Barwon @ Kent Road	QDAJ9999	Chironominae	5
1	East Barwon @ Kent Road	QE069999	Leptophlebiidae	1
1	East Barwon @ Kent Road	QH659999	Corixidae	12
1	East Barwon @ Kent Road	QH679999	Notonectidae	1
1	East Barwon @ Kent Road	QP039999	Gripopterygidae	31
1	East Barwon @ Kent Road	QT259999	Leptoceridae	2
2	East Barwon @ Dewings Bridge Road	IF619999	Dugesiidae	1
2	East Barwon @ Dewings Bridge Road	IH999999	Nematoda	1
2	East Barwon @ Dewings Bridge Road	KG059999	Lymnaeidae	1
2	East Barwon @ Dewings Bridge Road	KG079999	Planorbidae	1
2	East Barwon @ Dewings Bridge Road	KG089999	Physidae	28
2	East Barwon @ Dewings Bridge Road	KP039999	Sphaeriidae	2
2	East Barwon @ Dewings Bridge Road	LH019999	Glossiphoniidae	1
2	East Barwon @ Dewings Bridge Road	LO999999	Oligochaeta	11
2	East Barwon @ Dewings Bridge Road	MM999999	Mites	4
2	East Barwon @ Dewings Bridge Road	OP029999	Ceinidae	22
2	East Barwon @ Dewings Bridge Road	OP069999	Paramelitidae	3
2	East Barwon @ Dewings Bridge Road	QC099999	Dytiscidae	19
2	East Barwon @ Dewings Bridge Road	QC09999I	Dytiscidae (Larva)	2
2	East Barwon @ Dewings Bridge Road	QC10999I	Gyrinidae (Larva)	1
2	East Barwon @ Dewings Bridge Road	QC119999	Hydrophilidae	1
2	East Barwon @ Dewings Bridge Road	QCAO9999	Hydrochidae	4
2	East Barwon @ Dewings Bridge Road	QD099999	Ceratopogonidae	52
2	East Barwon @ Dewings Bridge Road	QDAE9999	Tanypodinae	10
2	East Barwon @ Dewings Bridge Road	QDAF9999	Orthocladiinae	21
2	East Barwon @ Dewings Bridge Road	QDAJ9999	Chironominae	12
2	East Barwon @ Dewings Bridge Road	QE029999	Baetidae	14
2	East Barwon @ Dewings Bridge Road	QE039999	Oniscigastridae	1
2	East Barwon @ Dewings Bridge Road	QE069999	Leptophlebiidae	45

Site Code	Site Location	Taxa Code	Taxa Name	Number
2	East Barwon @ Dewings Bridge Road	QH569999	Veliidae	9
2	East Barwon @ Dewings Bridge Road	QH659999	Corixidae	16
2	East Barwon @ Dewings Bridge Road	QH669999	Naucoridae	2
2	East Barwon @ Dewings Bridge Road	QH679999	Notonectidae	6
2	East Barwon @ Dewings Bridge Road	QH689999	Pleidae	1
2	East Barwon @ Dewings Bridge Road	QL019999	Crambidae	1
2	East Barwon @ Dewings Bridge Road	QO029999	Coenagrionidae	36
2	East Barwon @ Dewings Bridge Road	QO059999	Lestidae	2
2	East Barwon @ Dewings Bridge Road	QO179999	Libellulidae	1
2	East Barwon @ Dewings Bridge Road	QT259999	Leptoceridae	18
3	West Barwon @ Seven Bridges Road	IF619999	Dugesiidae	2
3	West Barwon @ Seven Bridges Road	KG079999	Planorbidae	17
3	West Barwon @ Seven Bridges Road	KG089999	Physidae	5
3	West Barwon @ Seven Bridges Road	LO999999	Oligochaeta	1
3	West Barwon @ Seven Bridges Road	MM999999	Mites	17
3	West Barwon @ Seven Bridges Road	OP069999	Paramelitidae	3
3	West Barwon @ Seven Bridges Road	OP089999	Perthiidae	1
3	West Barwon @ Seven Bridges Road	OR189999	Janiridae	1
3	West Barwon @ Seven Bridges Road	QC09999I	Dytiscidae (Larva)	1
3	West Barwon @ Seven Bridges Road	QC119999	Hydrophilidae	2
3	West Barwon @ Seven Bridges Road	QC209999	Scirtidae sp.	9
3	West Barwon @ Seven Bridges Road	QD099999	Ceratopogonidae	5
3	West Barwon @ Seven Bridges Road	QDAE9999	Tanypodinae	5
3	West Barwon @ Seven Bridges Road	QDAF9999	Orthocladiinae	6
3	West Barwon @ Seven Bridges Road	QDAJ9999	Chironominae	8
3	West Barwon @ Seven Bridges Road	QDAZ999I	Chironomidae (Pupa)	7
3	West Barwon @ Seven Bridges Road	QE069999	Leptophlebiidae	6
3	West Barwon @ Seven Bridges Road	QE089999	Caenidae	1
3	West Barwon @ Seven Bridges Road	QH569999	Veliidae	31
3	West Barwon @ Seven Bridges Road	QH659999	Corixidae	2
3	West Barwon @ Seven Bridges Road	QO029999	Coenagrionidae	2
3	West Barwon @ Seven Bridges Road	QO089999	Synlestidae	1
3	West Barwon @ Seven Bridges Road	QP039999	Gripopterygidae	4
3	West Barwon @ Seven Bridges Road	QT039999	Hydroptilidae	3
3	West Barwon @ Seven Bridges Road	QT159999	Conoesucidae	1
3	West Barwon @ Seven Bridges Road	QT259999	Leptoceridae	21
4	Barwon River @ u/s Boundary confluence	KG029999	Hydrobiidae	1
4	Barwon River @ u/s Boundary confluence	KG059999	Lymnaeidae	4
4	Barwon River @ u/s Boundary confluence	KG079999	Planorbidae	4
4	Barwon River @ u/s Boundary confluence	KG089999	Physidae	17
4	Barwon River @ u/s Boundary confluence	LO999999	Oligochaeta	5
4	Barwon River @ u/s Boundary confluence	MM999999	Mites	1

Site Code	Site Location	Taxa Code	Taxa Name	Number
4	Barwon River @ u/s Boundary confluence	OP029999	Ceinidae	5
4	Barwon River @ u/s Boundary confluence	OP069999	Paramelitidae	1
4	Barwon River @ u/s Boundary confluence	QC069999	Haliplidae	4
4	Barwon River @ u/s Boundary confluence	QC099999	Dytiscidae	6
4	Barwon River @ u/s Boundary confluence	QC09999I	Dytiscidae (Larva)	2
4	Barwon River @ u/s Boundary confluence	QCAN9999	Curculionidae	1
4	Barwon River @ u/s Boundary confluence	QD099999	Ceratopogonidae	14
4	Barwon River @ u/s Boundary confluence	QDAE9999	Tanypodinae	23
4	Barwon River @ u/s Boundary confluence	QDAF9999	Orthocladiinae	29
4	Barwon River @ u/s Boundary confluence	QDAJ9999	Chironominae	9
4	Barwon River @ u/s Boundary confluence	QDAZ999I	Chironomidae (Pupa)	1
4	Barwon River @ u/s Boundary confluence	QE029999	Baetidae	24
4	Barwon River @ u/s Boundary confluence	QE069999	Leptophlebiidae	7
4	Barwon River @ u/s Boundary confluence	QH659999	Corixidae	33
4	Barwon River @ u/s Boundary confluence	QH669999	Naucoridae	4
4	Barwon River @ u/s Boundary confluence	QL019999	Crambidae	1
4	Barwon River @ u/s Boundary confluence	QO029999	Coenagrionidae	22
4	Barwon River @ u/s Boundary confluence	QT259999	Leptoceridae	15
5	Boundary Ck @ Colac- Forrest Road	IF619999	Dugesiidae	1
5	Boundary Ck @ Colac- Forrest Road	OR189999	Janiridae	11
5	Boundary Ck @ Colac- Forrest Road	QC099999	Dytiscidae	2
5	Boundary Ck @ Colac- Forrest Road	QC09999I	Dytiscidae (Larva)	1
5	Boundary Ck @ Colac- Forrest Road	QC209999	Scirtidae sp.	20
5	Boundary Ck @ Colac- Forrest Road	QD079999	Culicidae	2
5	Boundary Ck @ Colac- Forrest Road	QD07999I	Culicidae (Pupa)	1
5	Boundary Ck @ Colac- Forrest Road	QDAE9999	Tanypodinae	1
5	Boundary Ck @ Colac- Forrest Road	QDAF9999	Orthocladiinae	1
5	Boundary Ck @ Colac- Forrest Road	QDAJ9999	Chironominae	30
5	Boundary Ck @ Colac- Forrest Road	QH659999	Corixidae	1
5	Boundary Ck @ Colac- Forrest Road	QH679999	Notonectidae	1
6	Barwon River @ d/s Boundary Ck confluence	LH019999	Glossiphoniidae	3
6	Barwon River @ d/s Boundary Ck confluence	LO999999	Oligochaeta	1
6	Barwon River @ d/s Boundary Ck confluence	MM999999	Mites	2
6	Barwon River @ d/s Boundary Ck confluence	OP029999	Ceinidae	3
6	Barwon River @ d/s Boundary Ck confluence	OP069999	Paramelitidae	56
6	Barwon River @ d/s Boundary Ck confluence	OV019999	Parastacidae	1
6	Barwon River @ d/s Boundary Ck confluence	QC099999	Dytiscidae	4
6	Barwon River @ d/s Boundary Ck confluence	QC119999	Hydrophilidae	1
6	Barwon River @ d/s Boundary Ck confluence	QCAO9999	Hydrochidae	1
6	Barwon River @ d/s Boundary Ck confluence	QD099999	Ceratopogonidae	6
6	Barwon River @ d/s Boundary Ck confluence	QD109999	Simuliidae	2
6	Barwon River @ d/s Boundary Ck confluence	QDAE9999	Tanypodinae	2

Site Code	Site Location	Taxa Code	Taxa Name	Number
6	Barwon River @ d/s Boundary Ck confluence	QDAF9999	Orthocladiinae	33
6	Barwon River @ d/s Boundary Ck confluence	QDAJ9999	Chironominae	1
6	Barwon River @ d/s Boundary Ck confluence	QDAZ999I	Chironomidae (Pupa)	1
6	Barwon River @ d/s Boundary Ck confluence	QE029999	Baetidae	7
6	Barwon River @ d/s Boundary Ck confluence	QE069999	Leptophlebiidae	1
6	Barwon River @ d/s Boundary Ck confluence	QE089999	Caenidae	1
6	Barwon River @ d/s Boundary Ck confluence	QH569999	Veliidae	2
6	Barwon River @ d/s Boundary Ck confluence	QH659999	Corixidae	1
6	Barwon River @ d/s Boundary Ck confluence	QO029999	Coenagrionidae	1
6	Barwon River @ d/s Boundary Ck confluence	QP039999	Gripopterygidae	44
6	Barwon River @ d/s Boundary Ck confluence	QT019999	Hydrobiosidae	1
6	Barwon River @ d/s Boundary Ck confluence	QT039999	Hydroptilidae	26
6	Barwon River @ d/s Boundary Ck confluence	QT259999	Leptoceridae	3
7	Barwon River @ u/s BAR016	IF619999	Dugesiidae	10
7	Barwon River @ u/s BAR016	KG079999	Planorbidae	1
7	Barwon River @ u/s BAR016	KG089999	Physidae	6
7	Barwon River @ u/s BAR016	LO999999	Oligochaeta	4
7	Barwon River @ u/s BAR016	MM999999	Mites	3
7	Barwon River @ u/s BAR016	OP029999	Ceinidae	6
7	Barwon River @ u/s BAR016	OP069999	Paramelitidae	16
7	Barwon River @ u/s BAR016	OP089999	Perthiidae	1
7	Barwon River @ u/s BAR016	OR189999	Janiridae	1
7	Barwon River @ u/s BAR016	OT019999	Atyidae	3
7	Barwon River @ u/s BAR016	QC099999	Dytiscidae	6
7	Barwon River @ u/s BAR016	QC10999I	Gyrinidae (Larva)	1
7	Barwon River @ u/s BAR016	QC119999	Hydrophilidae	2
7	Barwon River @ u/s BAR016	QC139999	Hydraenidae	1
7	Barwon River @ u/s BAR016	QC209999	Scirtidae sp.	1
7	Barwon River @ u/s BAR016	QD099999	Ceratopogonidae	6
7	Barwon River @ u/s BAR016	QDAE9999	Tanypodinae	8
7	Barwon River @ u/s BAR016	QDAF9999	Orthocladiinae	1
7	Barwon River @ u/s BAR016	QDAJ9999	Chironominae	4
7	Barwon River @ u/s BAR016	QDAZ999I	Chironomidae (Pupa)	2
7	Barwon River @ u/s BAR016	QE029999	Baetidae	3
7	Barwon River @ u/s BAR016	QH569999	Veliidae	8
7	Barwon River @ u/s BAR016	QH659999	Corixidae	9
7	Barwon River @ u/s BAR016	QH669999	Naucoridae	1
7	Barwon River @ u/s BAR016	QH679999	Notonectidae	16
7	Barwon River @ u/s BAR016	QO029999	Coenagrionidae	25
7	Barwon River @ u/s BAR016	QO059999	Lestidae	1
7	Barwon River @ u/s BAR016	QO129999	Aeshnidae	2
7	Barwon River @ u/s BAR016	QO169999	Corduliidae	4

Site Code	Site Location	Taxa Code	Taxa Name	Number
7	Barwon River @ u/s BAR016	QP039999	Gripopterygidae	1
7	Barwon River @ u/s BAR016	QT039999	Hydroptilidae	1
7	Barwon River @ u/s BAR016	QT209999	Kokiriidae	1
7	Barwon River @ u/s BAR016	QT259999	Leptoceridae	7
8	Barwon River @ Colac- Lorne Road	IF619999	Dugesiidae	2
8	Barwon River @ Colac- Lorne Road	KG089999	Physidae	14
8	Barwon River @ Colac- Lorne Road	LO999999	Oligochaeta	4
8	Barwon River @ Colac- Lorne Road	MM999999	Mites	1
8	Barwon River @ Colac- Lorne Road	OP029999	Ceinidae	2
8	Barwon River @ Colac- Lorne Road	OP069999	Paramelitidae	8
8	Barwon River @ Colac- Lorne Road	QC099999	Dytiscidae	4
8	Barwon River @ Colac- Lorne Road	QC10999I	Gyrinidae (Larva)	1
8	Barwon River @ Colac- Lorne Road	QD099999	Ceratopogonidae	4
8	Barwon River @ Colac- Lorne Road	QD109999	Simuliidae	1
8	Barwon River @ Colac- Lorne Road	QDAE9999	Tanypodinae	4
8	Barwon River @ Colac- Lorne Road	QDAF9999	Orthocladiinae	16
8	Barwon River @ Colac- Lorne Road	QDAJ9999	Chironominae	19
8	Barwon River @ Colac- Lorne Road	QE029999	Baetidae	13
8	Barwon River @ Colac- Lorne Road	QE069999	Leptophlebiidae	13
8	Barwon River @ Colac- Lorne Road	QE089999	Caenidae	3
8	Barwon River @ Colac- Lorne Road	QH569999	Veliidae	9
8	Barwon River @ Colac- Lorne Road	QH619999	Nepidae	1
8	Barwon River @ Colac- Lorne Road	QH659999	Corixidae	15
8	Barwon River @ Colac- Lorne Road	QH679999	Notonectidae	2
8	Barwon River @ Colac- Lorne Road	QL019999	Crambidae	1
8	Barwon River @ Colac- Lorne Road	QO029999	Coenagrionidae	52
8	Barwon River @ Colac- Lorne Road	QO169999	Corduliidae	2
8	Barwon River @ Colac- Lorne Road	QP039999	Gripopterygidae	21
8	Barwon River @ Colac- Lorne Road	QT039999	Hydroptilidae	1
8	Barwon River @ Colac- Lorne Road	QT259999	Leptoceridae	47
9	Barwon River @ Birregurra	IF619999	Dugesiidae	5
9	Barwon River @ Birregurra	KG029999	Hydrobiidae	18
9	Barwon River @ Birregurra	KG059999	Lymnaeidae	1
9	Barwon River @ Birregurra	KG089999	Physidae	17
9	Barwon River @ Birregurra	LH019999	Glossiphoniidae	1
9	Barwon River @ Birregurra	LO999999	Oligochaeta	10
9	Barwon River @ Birregurra	MM999999	Mites	7
9	Barwon River @ Birregurra	OP029999	Ceinidae	29
9	Barwon River @ Birregurra	OP069999	Paramelitidae	35
9	Barwon River @ Birregurra	OR189999	Janiridae	17
9	Barwon River @ Birregurra	OT019999	Atyidae	1
9	Barwon River @ Birregurra	QC099999	Dytiscidae	1

Site Code	Site Location	Taxa Code	Taxa Name	Number
9	Barwon River @ Birregurra	QC09999I	Dytiscidae (Larva)	3
9	Barwon River @ Birregurra	QCAO9999	Hydrochidae	2
9	Barwon River @ Birregurra	QCAO9999	Hydrochidae	3
9	Barwon River @ Birregurra	QD019999	Tipulidae	1
9	Barwon River @ Birregurra	QD099999	Ceratopogonidae	3
9	Barwon River @ Birregurra	QDAE9999	Tanypodinae	4
9	Barwon River @ Birregurra	QDAF9999	Orthocladiinae	2
9	Barwon River @ Birregurra	QDAJ9999	Chironominae	53
9	Barwon River @ Birregurra	QDAZ999I	Chironomidae (Pupa)	2
9	Barwon River @ Birregurra	QE039999	Oniscigastridae	2
9	Barwon River @ Birregurra	QE069999	Leptophlebiidae	10
9	Barwon River @ Birregurra	QH569999	Veliidae	9
9	Barwon River @ Birregurra	QH659999	Corixidae	49
9	Barwon River @ Birregurra	QH669999	Naucoridae	1
9	Barwon River @ Birregurra	QL019999	Crambidae	2
9	Barwon River @ Birregurra	QO029999	Coenagrionidae	35
9	Barwon River @ Birregurra	QP039999	Gripopterygidae	28
9	Barwon River @ Birregurra	QT039999	Hydroptilidae	1
9	Barwon River @ Birregurra	QT209999	Kokiriidae	1
9	Barwon River @ Birregurra	QT249999	Calamoceratidae	2
9	Barwon River @ Birregurra	QT259999	Leptoceridae	4
10	Barwon River @ Conns Lane	IF619999	Dugesiidae	9
10	Barwon River @ Conns Lane	KG059999	Lymnaeidae	3
10	Barwon River @ Conns Lane	KG089999	Physidae	43
10	Barwon River @ Conns Lane	LO999999	Oligochaeta	3
10	Barwon River @ Conns Lane	MM999999	Mites	6
10	Barwon River @ Conns Lane	OP029999	Ceinidae	37
10	Barwon River @ Conns Lane	OP069999	Paramelitidae	3
10	Barwon River @ Conns Lane	OR189999	Janiridae	1
10	Barwon River @ Conns Lane	OT019999	Atyidae	19
10	Barwon River @ Conns Lane	QC109999	Gyrinidae	1
10	Barwon River @ Conns Lane	QC10999I	Gyrinidae (Larva)	4
10	Barwon River @ Conns Lane	QC209999	Scirtidae sp.	1
10	Barwon River @ Conns Lane	QD099999	Ceratopogonidae	6
10	Barwon River @ Conns Lane	QDAF9999	Orthocladiinae	12
10	Barwon River @ Conns Lane	QDAJ9999	Chironominae	53
10	Barwon River @ Conns Lane	QE029999	Baetidae	2
10	Barwon River @ Conns Lane	QE069999	Leptophlebiidae	6
10	Barwon River @ Conns Lane	QH569999	Veliidae	4
10	Barwon River @ Conns Lane	QH659999	Corixidae	1
10	Barwon River @ Conns Lane	QH679999	Notonectidae	2
10	Barwon River @ Conns Lane	QO029999	Coenagrionidae	36

Site Code	Site Location	Taxa Code	Taxa Name	Number
10	Barwon River @ Conns Lane	QT259999	Leptoceridae	2
11	Barwon River @ Deans Marsh- Winchelsea Road	IF619999	Dugesiidae	18
11	Barwon River @ Deans Marsh- Winchelsea Road	KG089999	Physidae	31
11	Barwon River @ Deans Marsh- Winchelsea Road	MM999999	Mites	2
11	Barwon River @ Deans Marsh- Winchelsea Road	OP029999	Ceinidae	22
11	Barwon River @ Deans Marsh- Winchelsea Road	OP069999	Paramelitidae	2
11	Barwon River @ Deans Marsh- Winchelsea Road	OR189999	Janiridae	31
11	Barwon River @ Deans Marsh- Winchelsea Road	OT019999	Atyidae	22
11	Barwon River @ Deans Marsh- Winchelsea Road	QC109999	Gyrinidae	8
11	Barwon River @ Deans Marsh- Winchelsea Road	QCAO9999	Hydrochidae	1
11	Barwon River @ Deans Marsh- Winchelsea Road	QD109999	Simuliidae	11
11	Barwon River @ Deans Marsh- Winchelsea Road	QD359999	Empididae	1
11	Barwon River @ Deans Marsh- Winchelsea Road	QDAF9999	Orthocladiinae	15
11	Barwon River @ Deans Marsh- Winchelsea Road	QDAJ9999	Chironominae	39
11	Barwon River @ Deans Marsh- Winchelsea Road	QDAZ999I	Chironomidae (Pupa)	1
11	Barwon River @ Deans Marsh- Winchelsea Road	QE029999	Baetidae	15
11	Barwon River @ Deans Marsh- Winchelsea Road	QE069999	Leptophlebiidae	2
11	Barwon River @ Deans Marsh- Winchelsea Road	QH569999	Veliidae	4
11	Barwon River @ Deans Marsh- Winchelsea Road	QH659999	Corixidae	18
11	Barwon River @ Deans Marsh- Winchelsea Road	QH679999	Notonectidae	1
11	Barwon River @ Deans Marsh- Winchelsea Road	QO029999	Coenagrionidae	17
11	Barwon River @ Deans Marsh- Winchelsea Road	QP039999	Gripopterygidae	34
11	Barwon River @ Deans Marsh- Winchelsea Road	QT259999	Leptoceridae	4
12	Barwon River @ Winchelsea	IF619999	Dugesiidae	8
12	Barwon River @ Winchelsea	KG089999	Physidae	29
12	Barwon River @ Winchelsea	LO999999	Oligochaeta	2
12	Barwon River @ Winchelsea	MM999999	Mites	12
12	Barwon River @ Winchelsea	OP029999	Ceinidae	37
12	Barwon River @ Winchelsea	OR189999	Janiridae	2
12	Barwon River @ Winchelsea	OT019999	Atyidae	13
12	Barwon River @ Winchelsea	QC099999	Dytiscidae	1
12	Barwon River @ Winchelsea	QC10999I	Gyrinidae (Larva)	6
12	Barwon River @ Winchelsea	QC209999	Scirtidae sp.	11
12	Barwon River @ Winchelsea	QC349999	Elmidae	1
12	Barwon River @ Winchelsea	QC34999I	Elmidae (Larva)	1
12	Barwon River @ Winchelsea	QD249999	Stratiomyidae	2
12	Barwon River @ Winchelsea	QDAE9999	Tanypodinae	11
12	Barwon River @ Winchelsea	QDAF9999	Orthocladiinae	10
12	Barwon River @ Winchelsea	QDAJ9999	Chironominae	36
12	Barwon River @ Winchelsea	QE029999	Baetidae	4
12	Barwon River @ Winchelsea	QE069999	Leptophlebiidae	6
12	Barwon River @ Winchelsea	QH569999	Veliidae	8

Site Code	Site Location	Taxa Code	Taxa Name	Number
12	Barwon River @ Winchelsea	QH659999	Corixidae	12
12	Barwon River @ Winchelsea	QH679999	Notonectidae	2
12	Barwon River @ Winchelsea	QO029999	Coenagrionidae	49
12	Barwon River @ Winchelsea	QO039999	Isostictidae	4
12	Barwon River @ Winchelsea	QO169999	Corduliidae	1
12	Barwon River @ Winchelsea	QP039999	Gripopterygidae	26
12	Barwon River @ Winchelsea	QT039999	Hydroptilidae	1
12	Barwon River @ Winchelsea	QT249999	Calamoceratidae	1
12	Barwon River @ Winchelsea	QT259999	Leptoceridae	15

Boundary Creek and Big Swamp Remediation and Environmental Protection Plan

Barwon Water

Soil sampling and well completion report

IS288600 | Final A

15 October 2019

Boundary Creek and Big Swamp Remediation and Environmental Protection Plan

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Contents

Executive Summary

In response to the reduction of baseflow to Boundary Creek associated with the operation of the Barwon Downs borefield, and the subsequent drying of acid sulfate soils in Yeodene (Big) Swamp, Barwon Water received a Section 78 Ministerial Notice pursuant to Section 78 of the Water Act (1989), directing the corporation to develop and implement a Remediation Plan for the Boundary Creek and Big Swamp environments.

This report presents the findings of a soil sampling and groundwater monitoring investigation, which is one of a number of assessments aimed at informing the remediation plan.

The program collected a total of 181 soil samples across 17 sites via a combination of push tube and rotary auger drilling. Lithological logs indicate the presence of silts, clays and discrete sands and in the upper 6 m of the soil profile throughout Yeodene Swamp. This is consistent with the occurrence of alluvial deposits. Logs also indicate a relatively high organic matter content within the soil profile.

A total of 16 wells were constructed and were fitted with Solinst groundwater level loggers along with one barometric pressure logger. Groundwater levels varied between 1.4 and -0.10 m bgl (above ground surface) throughout the swamp and tended to be closer to the surface (<0.5 m bgl) in the lower reaches of the swamp and deeper (~1 m bgl) in the upstream reaches of the swamp.

Slug tests were undertaken at each of the 17 newly installed wells. Hydraulic conductivities ranged from 0.02 to 1.8 m/day, with an average conductivity of 0.50 m/day and a standard deviation of 0.62 m/day. This is broadly consistent with the range in hydraulic conductivities expected for unconsolidated silts (Domenico and Schwartz, 1990).

Organic carbon content was analysed and classified according to Huang et al., (2009). Accordingly, 26% of soil samples collected were classified as mineral soils, 24% as mineral soils with organics, 43% as organic soils and 8% as peat. This indicates that while the majority of soil samples are classified as organic soils or soils with organics, only a small proportion are technically classified as peat.

Sulfate concentrations in soils ranged from 0.9 mg/L to 5,100 mg/L with an average concentration of 284 mg/L. The average concentration of sulfate in soil samples (taken at 0.5 m depth intervals) increased from 165 mg/L at 0.5 m to 686 mg/L at 1.0 m depth. Concentrations below this subsequently declined to an average of between 130 and 160 mg/L to 6.0 m depth.

Of the 181 samples analysed, 180 exceed the 0.03 %S net acidity concentration limit for characterisation as acid sulfate soils. Acid neutralising capacity was below detection in all samples. This indicates that within the soils sampled, there is no capacity to neutralise any of the existing acid present, or any potential acidity that may be released upon further oxidation.

Concentrations of existing acidity tend to decline with depth. The average concentration throughout all cores was >0.5 %S in the upper 2.0 meters of the soil profile, 0.25 %S at 4.0 meters depth and 0.13 %S below 4.5 m depth. This is consistent with oxidation of sulfides and subsequent acidification during drying in the upper soil profile.

Significant concentrations of potential acidity (sulfide) exist in soils collected from the subsurface of the swamp. The average potential acidity increased from 0.12 %S in the top 0.5 m of the soil profile to 3.6 %S at 1.5 m depth. Average concentrations variably declined from 3.6 %S at 1.5 m depth to 1.3 %S below 4.5 m depth. The results indicate that significant stores of potential acidity remain throughout the lower soil profile of the swamp, and that future drying and oxidation of these soils may result in acid generation.

1. Introduction

1.1 Background

The Yeodene (Big) Swamp is located on Boundary Creek and contains acid sulfate soils (ASS) that have dried out, resulting in the release of acidic water to the lower reaches of Boundary Creek and ultimately, the Barwon River.

A report commissioned by Barwon Water titled “Barwon Downs Hydrogeological Studies 2016-17: numerical model calibration and historical impacts” (Jacobs, 2018a), found that the operation of the Barwon Downs borefield over the past 30 years is responsible for two thirds of the reduction of groundwater base flow into boundary Creek.

A subsequent study, titled the “Yeodene Swamp Study” (Jacobs, 2018b) concluded that baseflow reduction, combined with the inability to deliver supplementary flows to the swamp has led to the drying of ASS in Yeodene Swamp.

In response to the above, Barwon Water received a Section 78 Ministerial Notice pursuant to Section 78 of the Water Act 1989, directing the corporation to develop and implement a Remediation Plan for the Boundary Creek and Big Swamp environments.

Furthermore, Barwon Water are required to undertake appropriate hydrogeological, hydrological and geochemical assessments necessary to inform and support the development of the Remediation Plan. To refine this, a series of data gaps were assessed and prioritised by Rivers and Wetlands (Baldwin, 2018) in consultation with the Boundary Creek Remediation Working Group, Barwon Water, Jacobs and other independent experts including Professor Richard Bush and Dr Vanessa Wong.

This report presents the findings of a soil sampling and groundwater monitoring investigation, which represents one of a number of assessments aimed at informing the remediation plan and aims to close out the below questions which have been raised. Potential data gaps that could be informed by this study include:

Question 4: Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer?

Question 5: Are there preferential surface or subsurface flow paths in Big Swamp?

Question 6: How much actual and potential acidity is currently stored in Big Swamp?

Question 7: How much sulfate remains in the sediment profile in the swamp?

Question 8: How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?

Question 13: How extensive is fire damage to the peat in Big Swamp?

1.2 Scope of work

Jacobs were engaged by Barwon Water to design and undertake a field program.

The program includes:

- Technical advice during the borehole drilling and construction of up to 18 wells throughout Yeodene Swamp;
- Collection of soil samples for the purpose of hydrogeological and geochemical characterisation;
- Aquifer permeability testing (by slug testing) at the well locations for hydrogeological characterisation;
- Deployment of loggers for ongoing monitoring of groundwater levels; and
- Survey of new wells and existing features throughout the swamp.

This report summarises the outcomes of the field program. This report is intended to be essentially a factual report and does not provide extensive analysis and interpretation of the results. This is expected to be provided through later reports issued by Barwon Water, following further analysis.

2. Site investigation

2.1 Borehole drilling and soil sample collection

During the development of the soil sampling and well installation program, eighteen potential sites were proposed for investigation. Of these, 17 sites were safely accessible. BH13 could not be accessed safely due to the presence of dense vegetation and uneven surfaces. Investigations of the remaining sites took place between April and May 2019. Borehole drilling was undertaken by Go Dill Pty Ltd under supervision of a Jacobs hydrogeologist. Borehole logging, sample collection and handling was independently verified by a representative from Monash University. A brief summary of the drilling/sampling program is as follows:

2.1.1 Track mounted drilling

BH01, BH04, BH05, BH06, BH07, BH08, BH09, BH10, BH11, BH14, BH15, BH16 and BH17 were drilled using a Geoprobe track mounded drilling rig.

Collection of soil samples at these sites occurred via 60 mm diameter plastic lined push tubes to 4.5 m below ground level (m bgl) or until refusal. Holes were subsequently advanced to 6.0 m depth using 203 mm diameter hollow stem auger. The hollow stem augers increased the diameter of the borehole to 203 mm.

Using this method, undisturbed soil cores were returned to 4.5 m bgl and disturbed samples were returned between 4.5 and 6.0 m bgl.

2.1.2 Hand held sampling

BH02, BH03, BH12 and BH18 were sampled using a hand-held petrol driven 60 mm diameter push tube sampler due to access restrictions. These locations were sampled to 3.6 m bgl or refusal. The returned samples were undisturbed.

2.1.3 Sample handling

A total of 181 Soil samples were taken from a range of depths. Samples were described and handled according to Sullivan et. al (2018). These were sealed in ASS polyethylene zip lock bags provided by ALS laboratories and placed on ice in coolers in the field. Samples were transferred to a portable freezer upon return from the field on the day of collection. Samples were subsequently sent to Monash University for laboratory analysis and were received in a frozen condition.

A summary of the borehole drilling is shown below in Table 2-1, borehole locations are shown in Figure 2-1. Borehole lithology logs are shown in Appendix A.

Table 2-1 Summary of borehole drilling

Bore ID	Date Drilled	Drilling Method	Coordinates[1]		Surface elevation (m AHD)	Borehole diameter (mm)	Termination depth	
			Easting	Northing			m bgl[3]	m AHD[4]
BH01	17/04/2019	GeoProbe	735858.9	5743834.9	141.9	203	6	135.9
BH02	7/05/2019	Hand	735838.9	5743863.1	141.8	60	3.6	138.1
BH03	7/05/2019	Hand	735853.3	5743889.0	141.7	60	3.6	137.7
BH04	23/04/2019	GeoProbe	735682.3	5743890.3	143.4	203	6	137.4
BH05	18/04/2019	GeoProbe	735686.9	5743921.0	143.1	203	6	137.1
BH06	18/04/2019	GeoProbe	735712.2	5743922.107	142.9	203	6	136.9

Bore ID	Date Drilled	Drilling Method	Coordinates[1]		Surface elevation (m AHD)	Borehole diameter (mm)	Termination depth	
			Easting	Northing			m bgl[3]	m AHD[4]
BH07	17/04/2019	GeoProbe	735721.7	5743948.325	142.5	203	6	136.5
BH08	25/04/2019	GeoProbe	735607.0	5743908.6	144.6	203	6	138.6
BH09	24/04/2019	GeoProbe	735609.7	5743944.4	144.4	203	6	138.4
BH10	24/04/2019	GeoProbe	735622.3	5743966.9	144.3	203	6	138.3
BH11	8/05/2019	GeoProbe	735469.3	5743898.1	147.1	203	6	141.1
BH12	9/05/2019	Hand	735438.0	5743952.7	147.2	60	3.4	143.8
BH14	25/04/2019	GeoProbe	735360.8	5743853.1	147.7	203	6	141.7
BH15	26/04/2019	GeoProbe	735330.5	5743870.0	147.4	203	6	141.4
BH16	7/05/2019	GeoProbe	735300.1	5743903.5	148.0	203	6	142.0
BH17	6/05/2019	GeoProbe	735266.8	5743903.0	148.1	203	5.9	142.2
BH18[2] (YS05)	23/03/2019	Hand	735276	5743824	148.7	60	3.6	145.1

Note:

1. Datum MGA94 zone 54 - survey to an accuracy of ±0.030 m
2. BH18 coordinates were taken via handled GPS and to an accuracy of ±3.0 m
3. m bgl – metres below ground level
4. AHD – Australian Height Datum

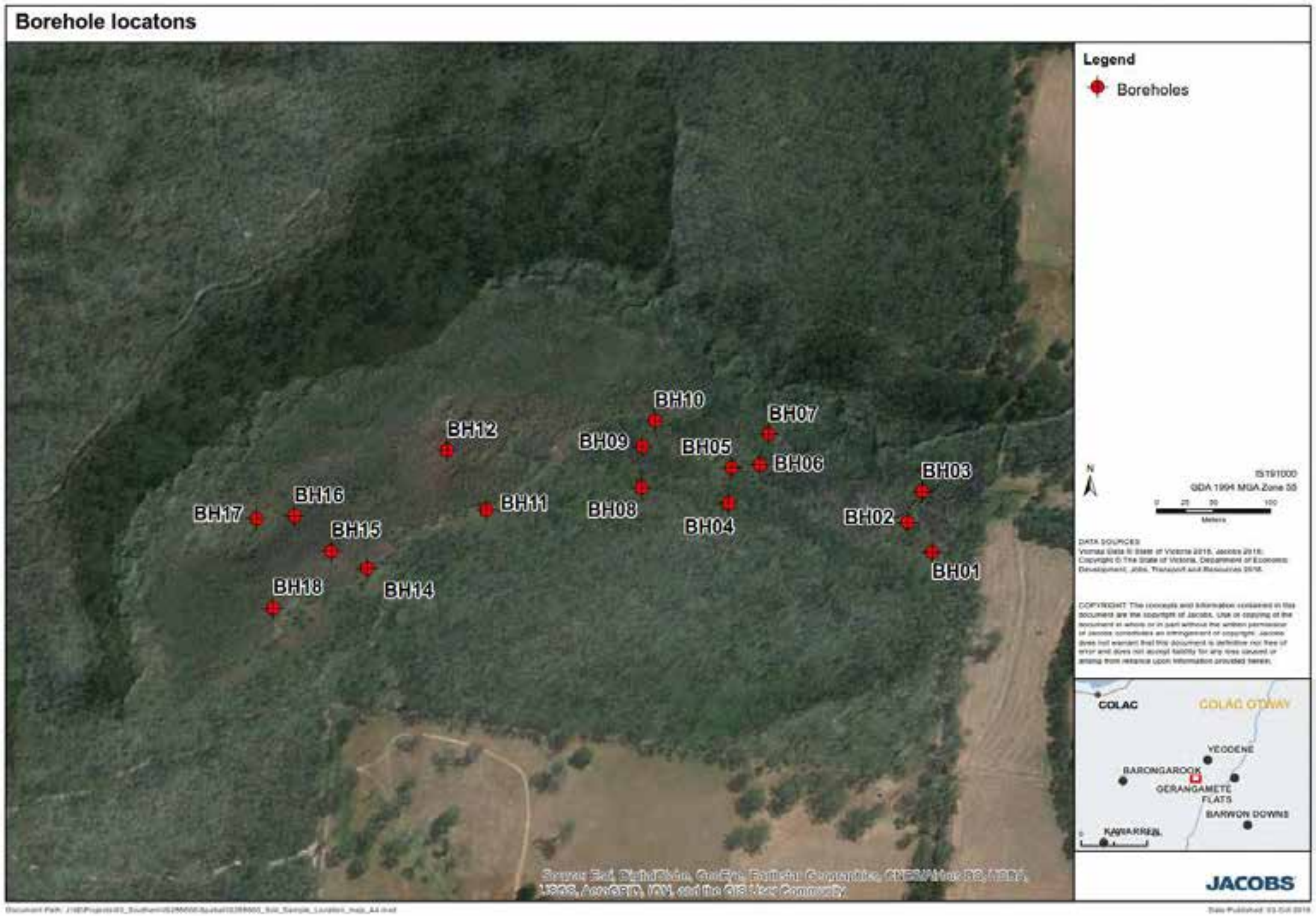

Figure 2-1 borehole location

2.2 Groundwater well construction

Table 2-2 below provides a summary of the construction details of the groundwater monitoring wells that were installed between April and May 2019 in the drilled boreholes. It is noted that a well was not installed at BH18 as a previously installed well (YS05) was already present at this location from earlier investigations (Jacobs, 2017).

Monitoring wells were constructed by sequentially joining threaded casing and screen lengths and lowering them down the drilled borehole to termination depth. Monitoring bores BH02, BH03 and BH12 were constructed with 26 mm class 18 uPVC casing with 1.5 m long screens slotted at a 0.3 mm aperture. A sump was not installed on these shallower wells to ensure the watertable was intersected.

The remaining wells were constructed using 50 mm diameter class 18 uPVC casing. Screens were 3.0 m long and slotted at a 0.4 mm aperture. All 50 mm diameter wells had 1.0 m sumps installed below the screen interval in case of sediment build up.

Gravel pack (8/16 Sibelco gravel) was free poured into the annulus between the well casing and drilled borehole to provide a filter pack around the screened section. Bentonite chips were subsequently free poured on top of the gravel pack to form a seal to the surface and to prevent grout or cement from seeping into the gravel pack.

During construction of BH02 and BH03, well screens were pushed past the bottom of the drilled borehole and into the underlaying sediments. Therefore, the bottom of the screened interval for both these wells does not have filter pack around it and is surrounded by natural formation. This represents the bottom 0.1 m of BH02 and the bottom 0.4 m of BH03. At BH06, BH08 and BH14, slight hole collapse occurred between drilling and construction. This occurred around the bottom of the sump and did not prevent any gravel pack from encasing the screen interval of these wells.

Constructed well casings were finished approximately 0.70 m above ground level and encased in yellow steel monument cover that were finished approximately 0.80 above ground level. BH02 and BH03 were installed with a 1.1 m high casing and 1.25 m high monument cover due to increased risk of surface water inundation at these locations. Due to the height of some well casings, the installed monument casing could not close entirely at some wells. All wells were named on the inside cap of the monument using a permanent marker.

A summary of well construction details are shown below in Table 2-2 and correspond to the borehole locations listed in Table 2-1. Further well construction details are summarised in the following appendices:

- Well construction and lithology logs are shown in Appendix A
- Push tube photographs are shown in Appendix B
- Well completion photographs are shown in Appendix C
- Well completion reports are detailed in Appendix D
- Well construction licenses are listed in Appendix E

Table 2-2 monitoring well installation details

Well ID	BCL	Stickup (m)	Constructed bore diameter (mm)	Total construction depth (m bgl)	Screen from (m bgl)	Screen to (m bgl)
BH01	WRK112869	0.60	50	6	2.0	5.0
BH02	WRK112870	1.16	26	3.7	2.2	3.7
BH03	WRK112871	1.20	26	4	2.5	4.0
BH04	WRK112872	0.82	50	6	2.0	5.0

Well ID	BCL	Stickup (m)	Constructed bore diameter (mm)	Total construction depth (m bgl)	Screen from (m bgl)	Screen to (m bgl)
BH05	WRK112873	0.79	50	6	2.0	5.0
BH06	WRK112874	0.68	50	6	1.9	4.9
BH07	WRK112875	0.55	50	6	2.0	5.0
BH08	WRK112876	0.67	50	6	1.9	4.9
BH09	WRK112877	0.68	50	6	2.0	5.0
BH10	WRK112878	0.69	50	6	2.0	5.0
BH11	WRK112879	0.63	50	6	2.0	5.0
BH12	WRK112880	0.71	26	3.4	1.9	3.4
BH14	WRK112882	0.64	50	6	2.0	5.0
BH15	WRK112883	0.66	50	6	2.0	5.0
BH16	WRK112884	0.81	50	6	2.0	5.0
BH17	WRK112885	0.66	50	5.9	1.9	4.9
YS05	N/A	0.82	50	3.00	1.50	3.00

2.3 Well development

Groundwater wells were developed between the 23rd and 24th May 2019 via surging and purging of the screened interval using both airlift and bail methods. Wells were developed in order to remove introduced products, improve near well permeability, reduce entry loss, reduce entry of suspended solids and increase well efficiency. Accordingly, all wells were developed according to the minimum construction reequipments for water bores in Australia (NUDLC, 2012).

All wells were developed by removing standing water from the casing via airlift purging and/or bailing. During airlifting, polyethylene tubing was gradually lowered down-hole with a continuous flow of air supplied by a compressor and standing water in the well was displaced by air and brought to the surface. Water was then allowed to flow through high pressure polyethylene piping secured to top of the well and was collected to monitor water quality. The tubing was continuously lowered down the well until the bottom was reached and the well was purged of water. If yields from the well were adequate, the tubing was left in the well to provide a continues flow of water from the aquifer to the surface for periods of time ranging from 30 minutes to 1 hour. If yields were low, wells were allowed to recover for a period before development continued. Go Dill Pty Ltd undertook the development, supervised on site by a Jacobs hydrogeologist.

Field water quality was recorded during development using a calibrated YSI water quality probe. Development was undertaken until a minimum of ten well volumes of water had been removed or until insufficient water was being produced. Wells with 50 mm casing diameter were developed via airlift on 23rd May. The remaining wells developed were developed by bailer due to wet conditions limiting access by vehicle and air compressor on 24th of May. All 26 mm diameter wells were bail purged. Table 2-3 summarises the development of the wells.

Table 2-3 Details of well development

Well ID	Date	Time	Cumulative volume (L)	Electrical conductivity (uS/cm	pH	Temperature (deg C)	Reduction Oxidation Potential (mV)	Dissolved Oxygen (mg/L)	Purge method
BH01	23/05/2019	10:00	25	574	6.18	19.8	72.4	1.65	Airlift
		10:02	40	602	5.95	13.7	65.8	3.99	
		10:06	60	594	5.88	13.2	75.9	1.63	
		10:07	80	607	5.84	12.7	78.9	6.42	
		10:15	90	600	5.75	12.3	89.7	10.3	
		10:20	100	821	5.53	11.7	99.4	9.16	
		10:25	125	930	4.9	11.4	135.1	9.34	
		10:30	150	979	4.51	11.7	154	9.61	
		10:35	175	1007	4.37	11.5	168	9.41	
BH02	24/05/2019	2:20	1	682	6.01	14	71	5.8	Bail
		2:30	2	658	6.18	14.1	40	2.07	
		2:40	3	627	6.27	14.3	47.8	1.55	
		2:50	4	580	6.26	14.6	68	2.59	
		3:00	5	602	6.32	14.2	71	4.09	
BH03	24/05/2019	1:30	1	636	5.18	12.7	164	3.56	Bail
		1:35	2	556	5.68	12.8	91	2.41	
		1:41	3	536	5.85	13.5	83	0.2	
		1:50	4	538	5.94	13.4	69	1.02	
		1:55	5	538	6.01	13.5	71	2.31	
		2:00	6	544	6.06	13.7	64	3	
		2:10	7	545	6.1	13.8	54	3.4	
BH04	23/05/2019	11:21	25	2960	4.02	14.7	198	9.44	Airlift
		11:25	50	2922	4.03	14.6	198	8.7	
		11:30	75	2965	4.02	14.2	200	8.74	
		11:35	100	3021	4.01	13.6	202	9.57	
		11:40	125	3013	4.01	13.6	203	8.33	
		11:50	150	3059	4.01	13.4	205	8.9	
BH05	23/05/2019	14:10	25	536	5.97	13.4	77.4	9.09	Airlift
		14:15	50	506	5.88	13.3	88.2	8.47	
		14:35	75	515	5.61	11.7	111	8.5	
BH06	23/05/2019	12:10	25	791	4.89	13.6	170	6.64	Airlift
		12:30	50	790	5.11	13.2	154	6.01	
		12:50	75	808	5.16	11.5	38	8.44	
BH07	23/05/2019	13:10	20	620	5.46	13.8	138	3.5	Airlift
		13:21	45	565	6.18	12.4	100	9.98	
		13:50	75	538	6.22	10.4	92	9.54	
BH08	23/05/2019	4:30	25	5500	3.73	15.4	207	7.73	Airlift
		4:45	27	6184	3.6	12.2	228	9.5	
BH08	24/05/2019	7:42	40	6782	3.57	15.3	219	5.42	Bail
		8:00	55	6711	3.54	15.1	247	3.19	
		8:10	60	6621	3.53	14.9	207	9.11	
BH09	23/05/2019	3:10	25	3581	4.14	14.7	187	8.56	Airlift
		3:50	50	3787	3.83	13.7	217	8.3	
BH10	23/05/2019	3:55	25	944	4.74	13.6	184	6.27	Airlift
		4:20	50	797	5.24	12.8	142.5	6.44	
BH11	24/05/2019	8:20	12	3332	2.6	14	410	3.92	Airlift
		8:30	25	3247	2.59	14.6	415	3.48	
		8:40	40	3300	2.71	14.6	396	0.03	
		8:45	50	3248	2.68	14.8	399	0	

		9:00	65	3372	2.67	14.6	398	3.71	
BH12	24/05/2019	9:10	1	1846	2.78	13.2	367	4.1	Airlift
		9:20	2	1833	2.83	13.1	357	5.02	
		9:30	4	1861	2.82	12.9	347	5.49	
		9:45	6	1887	2.77	13	359	6.06	
BH14	24/05/2019	12:35	25	5125	3.02	16.2	317	2.33	Bail
		12:40	30	4547	3.52	16.7	366	2.01	
		12:50	50	4356	3.6	16.6	259	1.51	
		13:00	60	4387	3.61	16.5	250	1.77	
		13:10	75	4437	3.6	16.5	247	1.95	
BH15	24/05/2019	12:00	25	1530	3.43	14.4	304	1.06	Bail
		12:10	40	1583	3.38	14.5	395	3.07	
		12:15	50	1560	3.31	14.4	293	1.44	
		12:30	75	1582	3.46	14.5	291	2.81	

2.4 Groundwater levels and logger installation

A total of 17 groundwater level loggers and one barometric logger was installed throughout the newly constructed wells and YS05.

Groundwater levels were recorded using an electronic water level tape before a Solinst level logger was deployed into the monitoring well on a stainless steel cable. All loggers were set to hang approximately 1 m above the bottom of the well, with 2 to 5 metres of water column above. One barometric logger was installed in BH01. All loggers were set to one hour recording intervals to measure short term fluctuations in water level. The loggers have a maximum of 40,000 memory points equating to 4.5 years of continues logging without downloading and or resetting. It is recommended that the logging frequency is revised following the first 12 months of monitoring to preserve logger batter and memory.

Table 2-4 below summarises the logger installation including measured water levels at time of deployment.

Table 2-4 level logger installation summary

Well ID	Date	Time	Logger serial number	Groundwater level at deployment	
				m bgl	m AHD
BH01	12/06/2019	7:53	0022105721	0.17	141.69
BH01 (Barro)	12/06/2019	8:00	0012104949	-	-
BH02	12/06/2019	7:55	0022105724	-0.08	141.83
BH03	12/06/2019	7:58	0022105709	-0.10	141.84
BH04	12/06/2019	9:13	0022105726	0.33	143.03
BH05	12/06/2019	9:15	0022105727	0.69	142.40
BH06	12/06/2019	9:18	0022105725	0.86	142.04
BH07	12/06/2019	9:20	0022105706	0.05	142.45
BH08	12/06/2019	10:08	0022105698	0.86	143.76
BH09	12/06/2019	10:10	0022105718	1.22	143.14
BH10	12/06/2019	10:13	0022105711	1.13	143.18
BH11	12/06/2019	10:15	0022105716	1.23	145.86

Well ID	Date	Time	Logger serial number	Groundwater level at deployment	
				m bgl	m AHD
BH12	12/06/2019	10:17	0022105699	1.22	145.98
BH14	12/06/2019	11:09	0022105689	1.40	146.26
BH15	12/06/2019	11:11	0022105722	0.31	147.11
BH16	12/06/2019	11:13	0022105732	0.63	147.36
BH17	12/06/2019	11:15	0022105691	1.17	146.94
YS05	06/08/2019	11:00	TBC	0.44	148.28

Note:

1. BH02 and BH03 groundwater level was measured to be above ground level and is denoted by a negative sign.

2.5 Survey

Elevation, and co-ordinates were recorded at the installed groundwater monitoring wells. In addition, to better characterise the location of key features within the swamp, elevation and co-ordinates were collected from 13 locations within the fire trench, and 10 locations along downstream drainage paths of the swamp. This was undertaken by a Jacobs surveyor on the 10th and 12th June 2019. All surveyed points were cross referenced to control Elliminyt PM78 and recorded to an accuracy of ±0.030m. Each survey point for the fire trench and tributary is shown in Table 2-5 and Table 2-6 respectively. Points are also shown spatially in Figure 2-2.

Table 2-5 Survey point locations along fire trench

Point ID	Easting	Northing	Elevation (m AHD)
999	735091.2	5743688.6	150.7
1000	735123.0	5743696.5	150.3
1001	735178.3	5743711.8	149.2
1002	735218.0	5743721.1	149.9
1003	735292.6	5743756.7	150.6
1004	735349.3	5743791.5	148.8
1012	735464.3	5743835.3	148.6
1020	735605.3	5743884.4	145.7
1021	735664.3	5743875.3	144.6
1022	735683.4	5743864.6	144.5
1029	735733.8	5743849.6	143.1
1030	735805.8	5743802.6	142.0
1032	735875.5	5743805.2	141.6

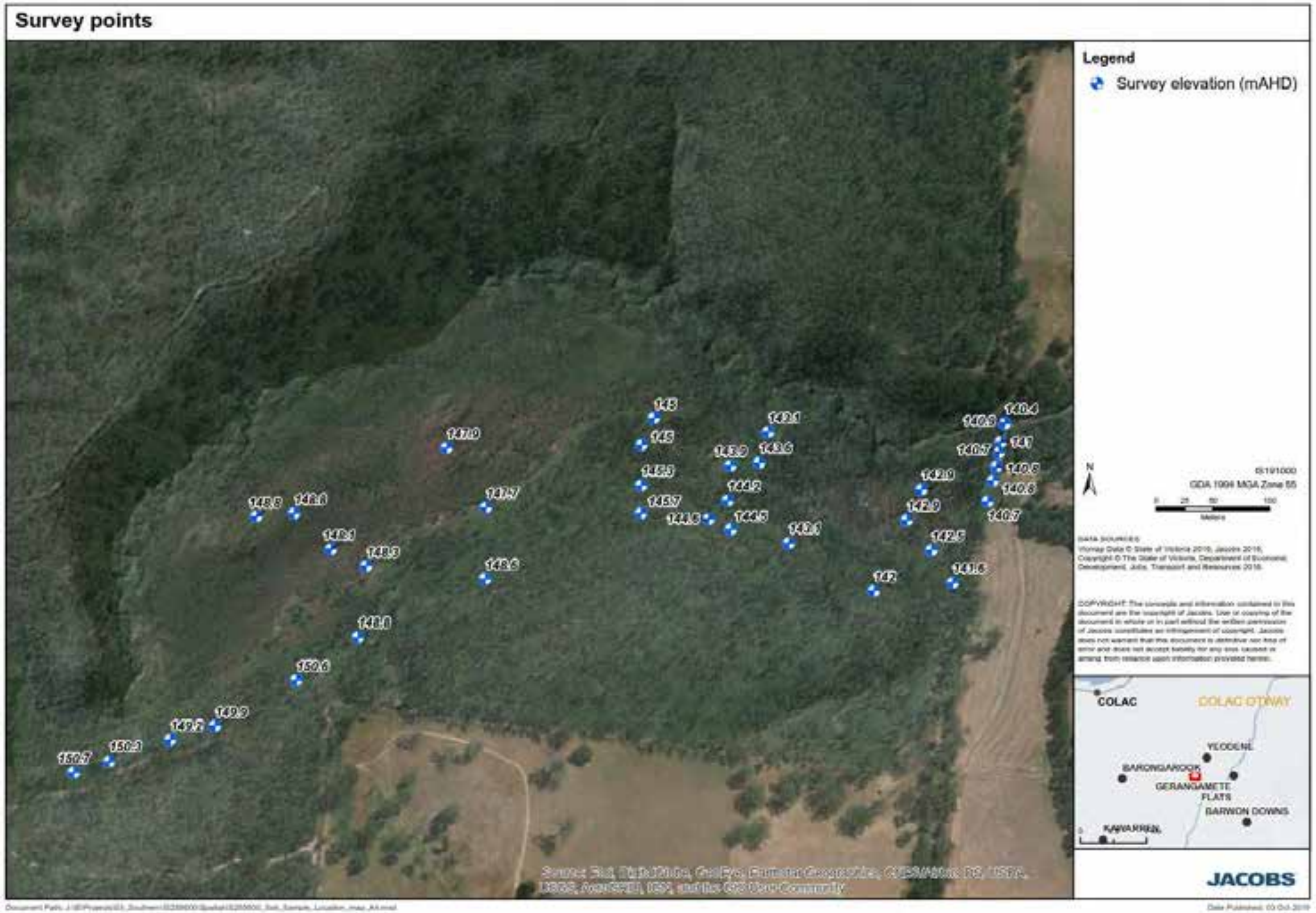

Figure 2-2 Location of survey points at wells installed, fire trench and drainage line

Table 2-6 Survey point locations along outflow tributary

Point ID	Easting	Northing	Elevation (m AHD)
2000	735930.6	5743942.4	140.4
2001	735930.3	5743941.7	140.9
2002	735926.0	5743926.3	141.0
2003	735923.521	5743916.736	140.7
2005	735920.6	5743904.8	140.8
2006	735917.0	5743893.0	140.8
2007	735911.0	5743874.9	140.7
2008	735913.1	5743875.7	141.4
2009	735922.6	5743908.0	141.2
2010	735930.3	5743941.4	141.0
2011	735930.7	5743942.5	140.8

2.6 Spoil management

During the investigation, excavated ASS waste material was exposed to the atmosphere, presumably resulting in some oxidation. As such, the exposed waste material was deposited in accordance with an environmental management plan to a depth of >0.5 m below the ground surface and buried under topsoil.

To limit oxidation, soil material excavated from depth was managed in the following way:

- The duration of waste material exposure at the surface prior to disposal to the subsurface was limited
- Clay dominated material was placed on top of coarser grained material as a natural oxygen barrier

While is it presumed that some oxidation did occur, there was no notable discoloration or iron hydroxide staining noticed on exposed material, suggesting this was limited. Figure 2-3 below illustrates the disposal.

Figure 2-3 Spoil management procedure

3. Results of investigation

3.1 Lithological logs

The location of boreholes is shown in Figure 2-1 and lithological logs in Appendix A.

Lithological logs indicate that clays and silts are the dominant lithology's throughout the swamp, although small discrete intervals of sands do occur. Small intervals of burnt peat were identified in the upper 0.5 m of some soil cores, most dominantly at BH17 and BH18 (see question 13 section 1.1).

Figure 3-1 below shows the lithology at boreholes both spatially and vertically using Leapfrog geological modelling software. A vertical exaggeration of 10x has been applied. This illustrates that boreholes located towards the upper reaches of the swamp (BH11, BH14, BH15 and BH16) tend to be clay dominated, while boreholes at the lower reaches of the swamp at (BH1, BH2, BH3 and BH7) tend to be silt dominated. Small lenses of coarse sand are evident at BH04, BH08, BH11, BH12, BH14, BH16 and BH17.

These results are consistent with the dominance of quaternary alluvial sediments in the upper 6 m of the stratigraphic profile in the swamp. The dominance of clay and limited presence of sand through the cores may limit connection between the LTA and the swamp (see question 4 in 1.1), however this is somewhat speculative and likely to be better resolved thorough water balance assessments that will be undertaken in subsequent studies.

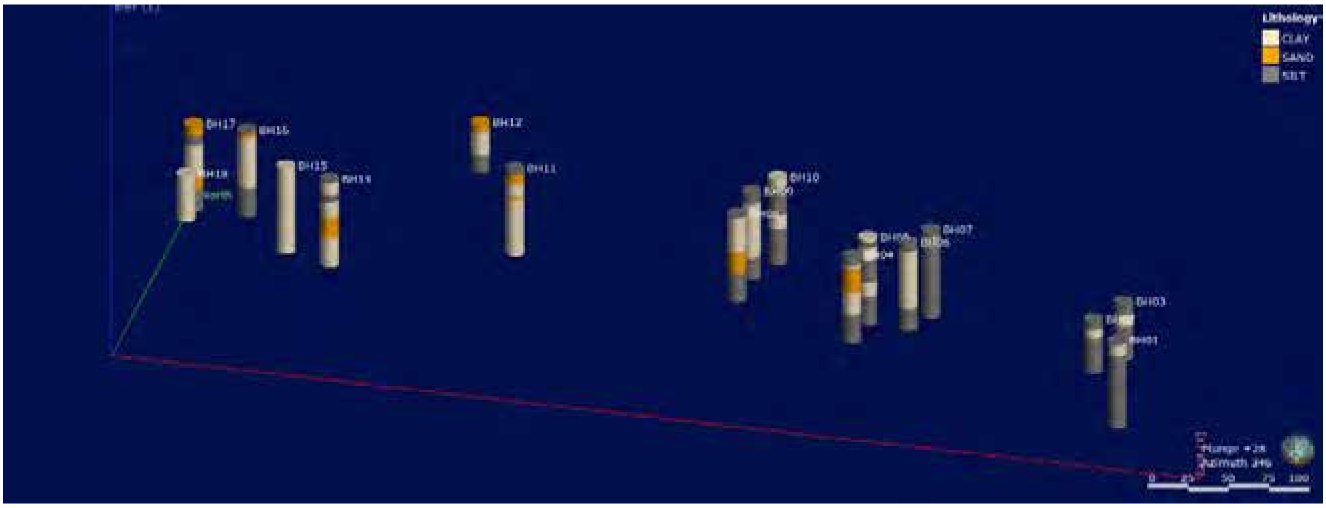

Figure 3-1 Leapfrog geological model showing the primary constituents of SILT (grey), CLAY (light yellow) and SAND (orange) throughout the bore logs

3.2 Aquifer Permeability testing

Slug testing of groundwater monitoring was completed between 11th and 13th June 2019. Testing was undertaken using a solid PVC slug to displace water in the well and a groundwater level logger was deployed in each well to record the change in groundwater head in real time and viewed on a laptop. Viewing the change in water column height in the well in real time allowed for visualisation that the test was complete before a subsequent test was undertaken. A minimum of one test was undertaken at each well with multiple tests occurring at wells which recovered faster.

Change in water level data recorded during the tests was processed using the Aqtesolv software package to estimate hydraulic conductivity (K) for the screened section of the aquifer at each well. The determination of a K value for each test was undertaken using a visual match on a log-log displacement/time curve using the Bouwer and Rice (1976) analytical solution for unconfined aquifers method. A hydraulic conductivity anisotropy ratio ($K_{vertical}/K_{horizontal}$) of 0.2 was assumed as is consistent for alluvium (Todd, 1980). While lower values may be appropriate for clay dominated sediments, analysis was not sensitive to this parameter with a K_v/K_h value of

0.01 yielding an average increase in the overall K value of only 9%. An aquifer thickness of 10 m was used in all analysis. Where multiple tests occurred, an average of the resulting estimates of K was used to give an overall estimate of hydraulic conductivity for the tested intervals. The curve fitting undertaken as part of this analysis is included in Appendix F and a summary of the results presented in Table 3-1.

Hydraulic conductivities ranged from 0.02 to 1.8 m/day, with an average conductivity of 0.50 m/day and a standard deviation of 0.62 m/day. This is broadly consistent with the range in hydraulic conductivities expected for unconsolidated silts (Domenico and Schwartz, 1990).

A broad range in hydraulic conductivities is observed through the swamp. Elevated hydraulic conductivities were observed at BH06, BH09, BH10, BH11, BH12 and BH16. These are predominantly located through the centre of the swamp. This may suggest greater groundwater flow rates at these locations. However, neither lithological logs nor slug tests suggest the occurrence of a pervasive unit of elevated permeability that promotes subsurface flow (see question 5 in section 1.1). Additionally, there does not appear to be a consistent trend between the dominant lithology at each given well and the hydraulic conductivity (Table 3-1), which makes the inference of such trends difficult to assert.

Further to the above, the dominance of clays and silts suggest that groundwater flow will be dominantly horizontal. As discussed above, an anisotropy ratio of 0.2 has been assumed for the below analysis, as is consistent with the range of 0.1 – 0.5 assumed for alluvium by Todd (1980), however this could be as low as 0.01 in clays, which reinforces that subsurface flow through the swamp will be dominantly horizontal.

Table 3-1 Results of slug testing of groundwater wells

Bore ID	Effective Screened Interval (m bgl)[1]	Dominant lithology in Sreen	Slug test type (Falling /Rising head)	Estimated hydraulic conductivity (k) (m/day)	
				Test Result	Final estimate for well
BH01	1.5 – 6.0	Silty CLAY	Falling head	0.27	0.22
			Rising head	0.22	
			Falling head	0.16	
			Rising head	0.22	
BH02	1.9 – 3.5	Silty CLAY	Falling head	0.03	0.11
			Falling head	0.18	
BH03	1.5 – 3.6	Silty CLAY	Falling head	0.03	0.03
			Falling head	0.03	
BH04	1.6 – 6.0	Silty CLAY	Falling head	0.09	0.09
			Rising head	0.09	
BH05	1.5 – 6.0	Silty CLAY	Falling head	0.05	0.06
			Rising head	0.06	
			Rising head	0.06	
BH06	1.5 – 5.9	Silty CLAY	Falling head	1.35	1.51
			Rising head	1.12	
			Falling head	1.18	
			Rising head	2.41	
BH07	1.5 – 6.0	Silty CLAY	Falling head	0.02	0.02
			Rising head	0.01	
BH08	1.5 – 5.9	Silty CLAY / Silty SAND	Rising head	0.10	0.10
BH09	1.5 – 6.0	Silty CLAY	Falling head	1.34	1.31
			Rising head	1.26	
			Falling head	1.34	
			Rising head	1.30	
BH10	1.6 – 6.0	Silty CLAY / Clayey SILT	Rising head	0.83	1.30
			Rising head	1.60	
			Falling head	1.14	
			Rising head	1.64	

Bore ID	Effective Screened Interval (m bgl)[1]	Dominant lithology in Sreen	Slug test type (Falling /Rising head)	Estimated hydraulic conductivity (k) (m/day)	
				Test Result	Final estimate for well
BH11	1.5 – 6.0	CLAY	Falling head	0.35	0.35
			Rising head	0.35	
BH12	0.7 – 3.5[1]	Sandy CLAY	Rising head	0.82	0.82
BH14	1.5 – 5.5	Clayey SILT, CLAY, SAND	Rising head	0.14	0.13
			Rising head	0.13	
BH15	1.5 – 6.0	Silty CLAY	Falling head	0.12	0.16
			Rising head	0.20	
BH16	1.3 – 6.0	Sandy CLAY	Rising head	1.72	1.79
			Rising head	1.85	
BH17	1.4 – 5.9	Sandy CLAY	Falling head	0.06	0.05
			Falling head	0.04	

Notes:

1. Effective screen is length of gravel pack of well.
2. Well screen was unsaturated

3.3 Groundwater levels

Depth to groundwater was measured in all 16 newly installed wells in June 2019. YS05 in was measured in July 2019.

The groundwater levels recorded as part of investigations have been summarised in Table 3-2 below. Groundwater levels varied between 1.4 and -0.10 m bgl. Groundwater levels labelled with a negative m bgl value indicate artesian conditions. These were recorded at BH02 and BH03 in the lower reaches of the swamp.

These data have been used in conjunction with a digital terrain model to generate a potentiometric groundwater surface and depth to groundwater map for the monitoring period (Figure 3-2). This illustrates a steep hydraulic gradient towards the swamp from the north and a gentler hydraulic gradient towards the swamp from the south. The hydraulic gradient through the swamp trends to the east in a broadly similar direction to the flow path of Boundary Creek.

Depth to watertable mapping indicates groundwater levels near to the surface (<0.5 m bgl) in the lower reaches of the swamp near (BH02) and through the north west portion of the swamp.

Table 3-2 Summary of groundwater levels (m bgl) and groundwater elevation (m AHD) recorded

Well ID	Date	Groundwater level	
		m bgl	m AHD
BH01	12/06/2019	0.17	141.69
BH02	12/06/2019	-0.08	141.83
BH03	12/06/2019	-0.10	141.84
BH04	12/06/2019	0.33	143.03
BH05	12/06/2019	0.69	142.40
BH06	12/06/2019	0.86	142.04
BH07	12/06/2019	0.05	142.45
BH08	12/06/2019	0.86	143.76

Well ID	Date	Groundwater level	
		m bgl	m AHD
BH09	12/06/2019	1.22	143.14
BH10	12/06/2019	1.13	143.18
BH11	12/06/2019	1.23	145.86
BH12	12/06/2019	1.22	145.98
BH14	12/06/2019	1.40	146.26
BH15	12/06/2019	0.31	147.11
BH16	12/06/2019	0.63	147.36
BH17	12/06/2019	1.17	146.94

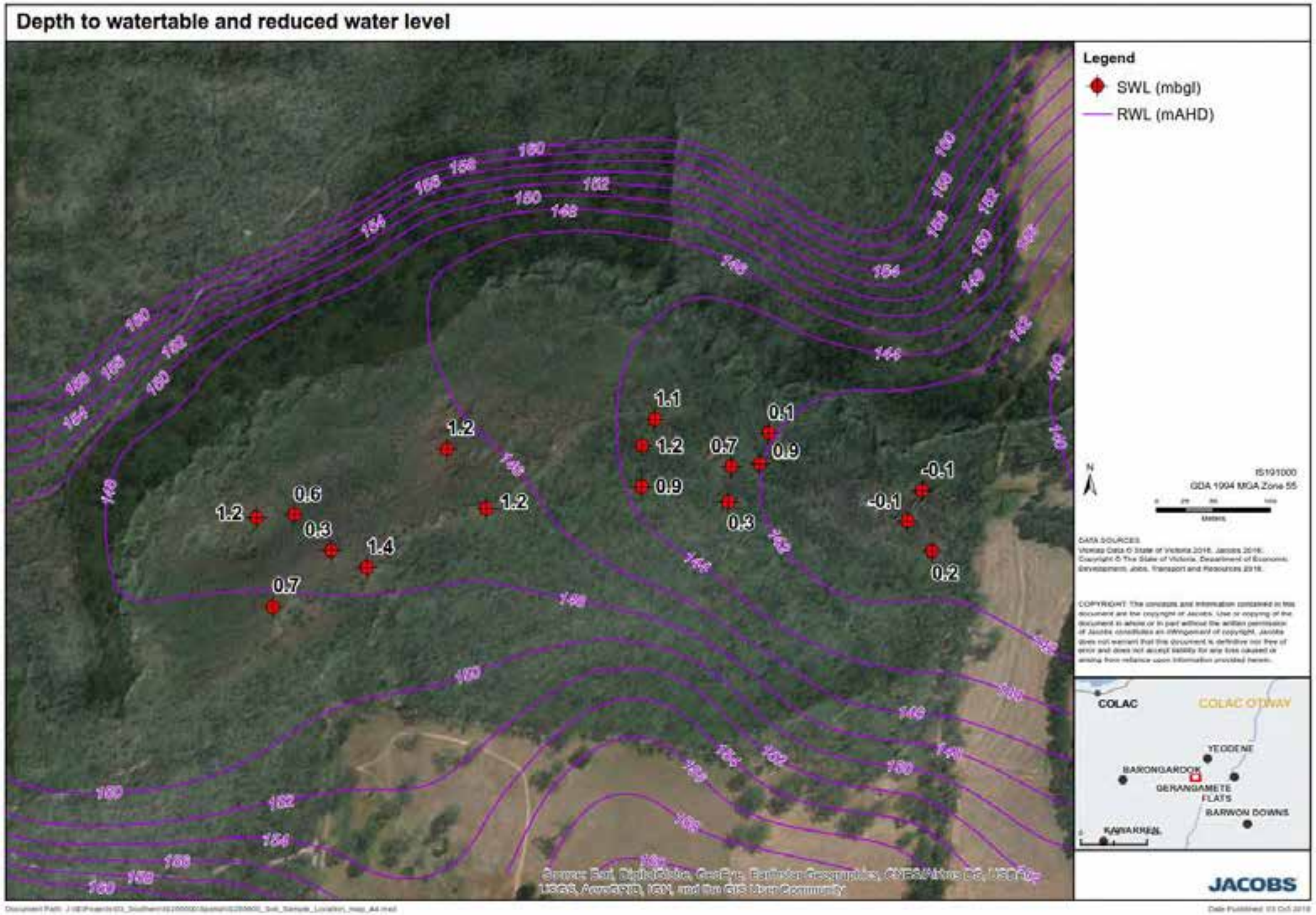

Figure 3-2 Depth to water table and groundwater elevation at wells and as interpreted throughout Big Swamp from the well data– June 2019

3.4 Static geochemical test work

Soil samples were collected at various depths at all boreholes across Big Swamp. The soils were analysed for a number of geochemical properties. This section provides a preliminary assessment of the general trends in geochemistry observed both spatially and with depth through the swamp. A detailed geochemical assessment is in preparation by Monash University. The general parameters discussed here include organic carbon, sulfate and acidity (in its various forms). These results have been detailed in Appendix G.

3.4.1 Organic carbon content

Analysis of the organic matter (OM) and organic carbon (OC) content of soils was undertaken by Monash University Laboratories via the loss on ignition (LOI) method. A total of 181 samples were analysed via this method with the results summarised in Table 3-3 below.

These results indicate that the soils throughout the swamp are predominated by those with a high organic carbon content. This is consistent with core logs (Appendix A) which indicate the presence of organic material, organic odour and peat layers throughout the soil profile.

While there are a number of guidelines available which classify organic soils according to their organic carbon content, mineral fraction, clay content and texture, we have adopted a limit of >30% OC for the classification of peat in accordance with Huang et al., (2009). This limit is based on a combination of experimental work, literature review and evaluation of currently existing classification systems (e.g. Inisheva, 2006; Isbell, 2002).

Accordingly, 26% of soil samples collected are classified as mineral soils, 24% as mineral soils with organics, 43% as organic soils and 8% as peat. To summarise, while the majority of soil samples are classified as organic soils or soils with organics, only a small proportion are technically consistent with peat.

These results provide a starting point to answering research question 8 (see section 1.1), in that the soils throughout the swamp contain significant concentrations of organic carbon. However, the bio-availability of this carbon and its capacity to promote processes such as sulfate reduction remain unquantified. This is likely to be further resolved in parallel studies being undertaken by Monash University.

Table 3-3 Summary of organic C content of soils via LOI analysis

Organic Carbon (%)	No. of samples	% of samples	Classification
<3	46	26%	Mineral soils
3 - 15	43	24%	Mineral soils with organics
15 - 30	77	43%	Organic soils
>30	15	8%	Peat

3.4.2 Sulfate

Sulfate was extracted from each of the 181 sediment samples using a 20 ml milli-Q water extraction at Monash University Laboratories. The concentration of sulfate in the resulting extracts ranged from 0.9 mg/L to 5,100 mg/L with an average concentration of 284 mg/L.

Trends in sulfate concentrations with depth are illustrated in Figure 3-3. The average concentration increases from 165 mg/L at 0.5 m to 686 mg/L at 1.0 m depth before gradually declining to an average of 160 mg/L at 3.0 m. Average concentrations below 3.0 m depth vary between 160 and 130 mg/L.

Given the nature of the site and the presence of acid sulfate soils, these results are consistent with oxidation of sulfides in the upper soil profile and the subsequent release of sulfuric acid. Similar trends in existing acidity would be expected throughout the soil profile if this is the case and are discussed in further detail below.

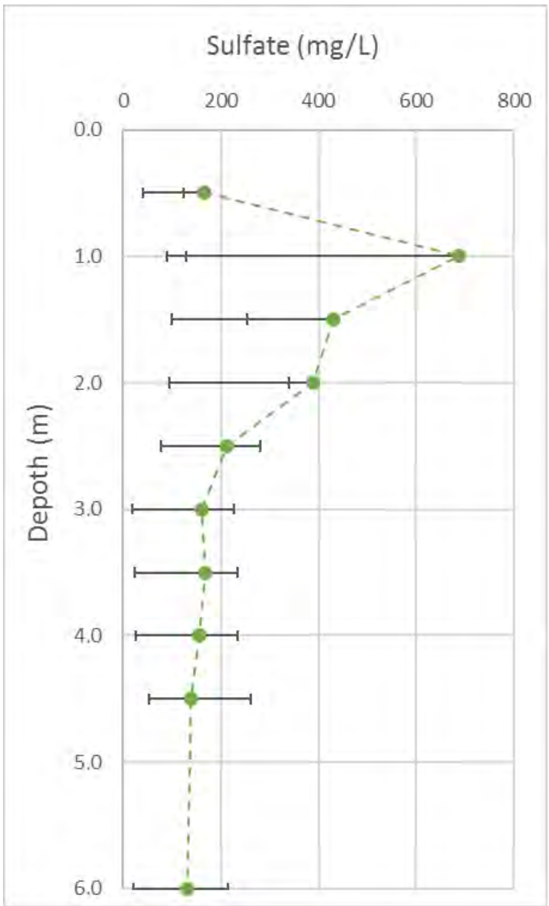

Figure 3-3 Average, 25th and 75th percentile (shown as error bars) of sulfate with depth (aggregate from 0.5 m intervals)

3.4.3 Acidity

A summary of the potential and existing acidity within each soil core has been prepared in Appendix G. General trends in potential and existing acidity with depth have been summarised in Figure 3-4. A full report and laboratory certificates regarding static chemistry results is in preparation by Monash University. For the purpose of this report, the results are briefly summarised below and the key findings are as follows:

- Acid neutralising capacity (ANC) was below detection in all samples analysed. This indicates that within the soils samples, there is no capacity to neutralise any of the existing acid present, or any potential acidity that may be released upon further oxidation.
- High concentrations of net acidity are present throughout the majority of samples collected from the swamp. Of the 181 samples collected, 180 exceed the criteria of 0.03 %S for classification as acid sulfate soils (EPA, 2009).
- Concentrations of existing acidity tends to decline with depth. Figure 3-4 shows a decline in the average concentration of acidity from >0.5 %S in the upper 2.0 meters of the soil profile, to 0.25 %S at 4.0 meters depth and 0.13 %S below 4.5 m depth. These trends are consistent sulfate concentrations and provide further support for the occurrence of sulfide oxidation in the upper portion of the soil profile.
- Significant concentrations of potential acidity (sulfide) exist in soils collected from the subsurface of the swamp. Figure 3-4 shows an increase in the average potential acidity from 0.12 %S in the top 0.5 m of the soil profile to 3.6 %S at 1.5 m depth. Average concentrations variably decline from 3.6 %S at 1.5 m depth to 1.3 %S below 4.5 m depth. The results indicate that significant stores of potential acidity remain throughout the soil profile of the swamp, and that future drying and oxidation of these soils may result in acid generation.

- Average sulfide concentrations peaked between 1.5-2.0 m below the ground surface. This could be related to the formation contemporary sulfides as a result of the infiltration of ferrous, sulfate rich leachate from the upper profile as it is subject to reducing conditions below the water table. However, there is significant variability in the concentration of sulfides at depth and as such, this could be an artefact of heterogeneity at the site.

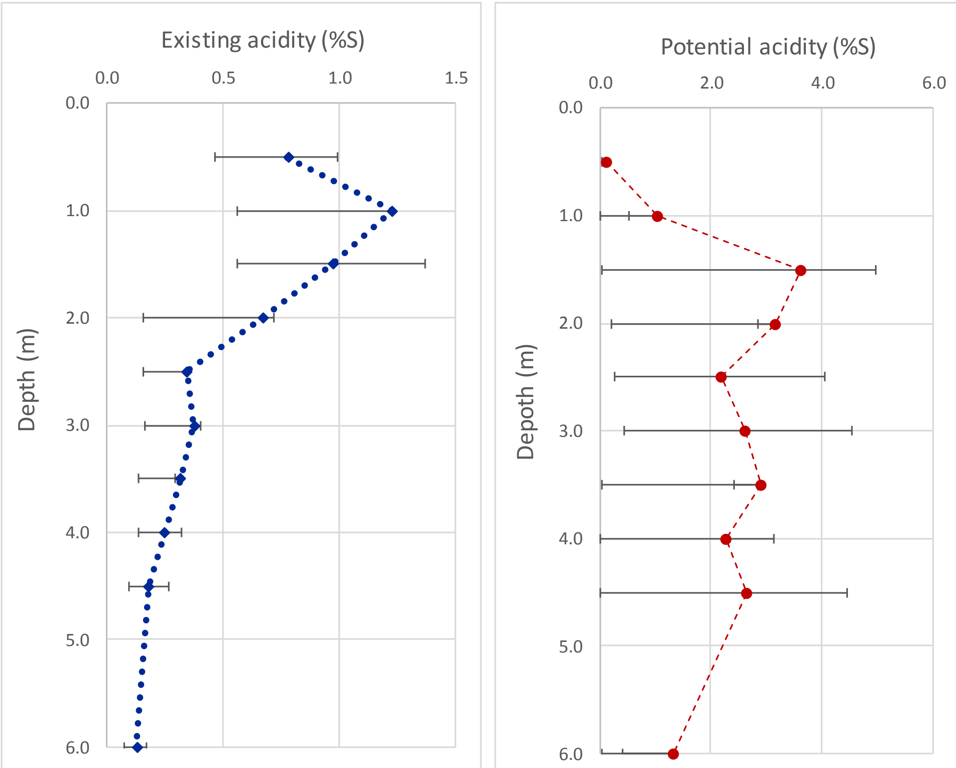

Figure 3-4 Average, 25th and 75th percentile (show as error bars) of existing and potential acidity with depth (aggregate from 0.5 m intervals)

In addition to trends throughout soil profiles discussed above, spatial trends were also assessed using subsurface 3D geological modelling software Leapfrog Works (Leapfrog). This has been used to show the 3D spatial distribution of the boreholes with respect to existing and potential acidity in Yeodene Swamp. A radial basis function linear interpolation was applied to the numerical borehole data to create two 3D numerical heat map models showing the 3D spatial distribution of potential and existing acidity within the swamp.

The models were bound by the topography and a horizontal elevation of 135.8 m AHD (the lowest elevation of coring at BH01). Ellipsoid ratios of 9, 9 and 1 were applied for the maximum, intermediate and minimum directions of the model (x, y and z) respectively. This yields a greater emphasis on the horizontal plane of the models rather than the vertical plain for both models. This was undertaken to allow for the numerical value at a specific borehole and depth to have a greater effect horizontally where no data was available. The purpose of these models is to allow discussion of spatial trends in acidity to be discussed and not the full quantification of acid stores.

Figure 3-5 and Figure 3-6 show a horizontal slice with a slight dip at approximate depths at 0 – 2 m bgl for existing acidity and 2 – 6 m bgl for potential acidity. Figure 3-5 illustrates that the highest concentrations of existing acidity tend to occur throughout the upstream areas of the swamp at BH18, BH14, BH12 and BH11. In these boreholes, concentrations of existing acidity exceed 2.0 %S in the upper 2.0 m of the soil profile (approximately double the average concentration for this interval through the swamp).

Similarly, concentrations of potential acidity tend to be higher in the same general area, with concentrations exceeding 10 %S at BH18, BH15 and BH14. However, similar concentrations were also observed through the through the downstream portion of the swamp at discrete intervals in BH4, BH5, BH6, BH8, BH9 and BH10.

Conversely, throughout the central area of the swamp (at BH11 and BH12), only one sample was collected with a concentration of potential acidity exceeding 1 %S. The average concentration across samples from BH11 and BH12 was 0.58 %S, compared to the average concentration of potential acidity of 6.2 %S at BH18. While this illustrates the reduction in potential acidity that are observed through the central portion of the swamp, it should be noted that such concentrations are still ~20 times greater than the net acidity limit for classification of ASS.

Given this, it can be concluded that regardless of specific location within the swamp, significant stores of potential acidity are likely to exist that should be taken into account when considering management strategies.

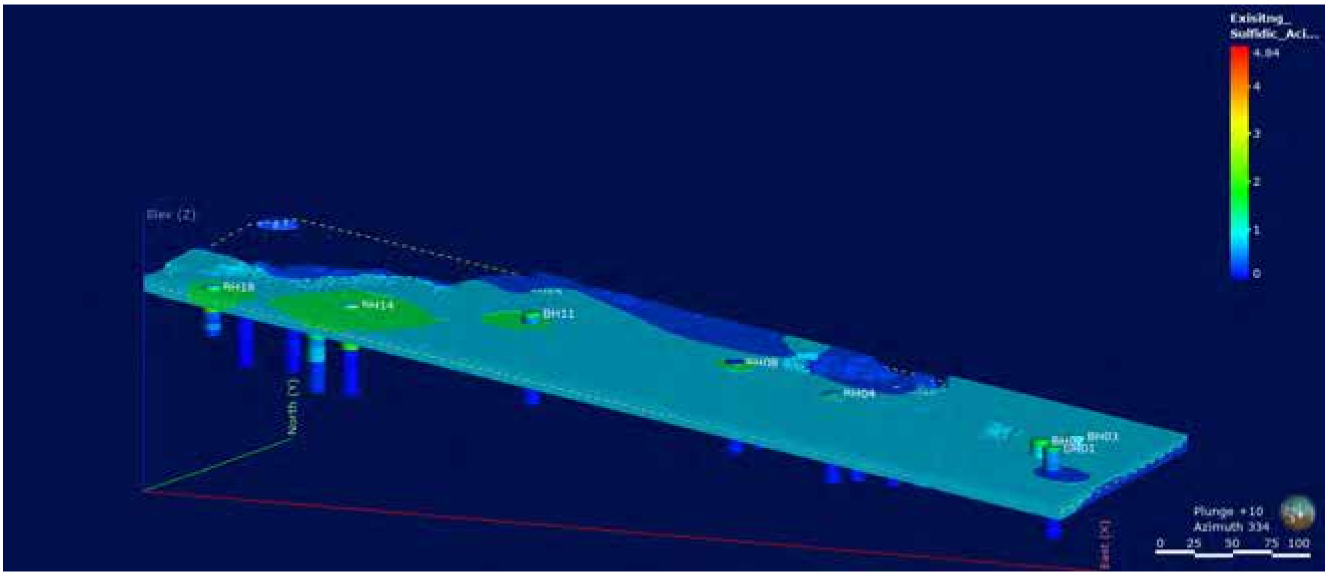

Figure 3-5 Existing acidity heat map sliced at 0 – 2 m depth

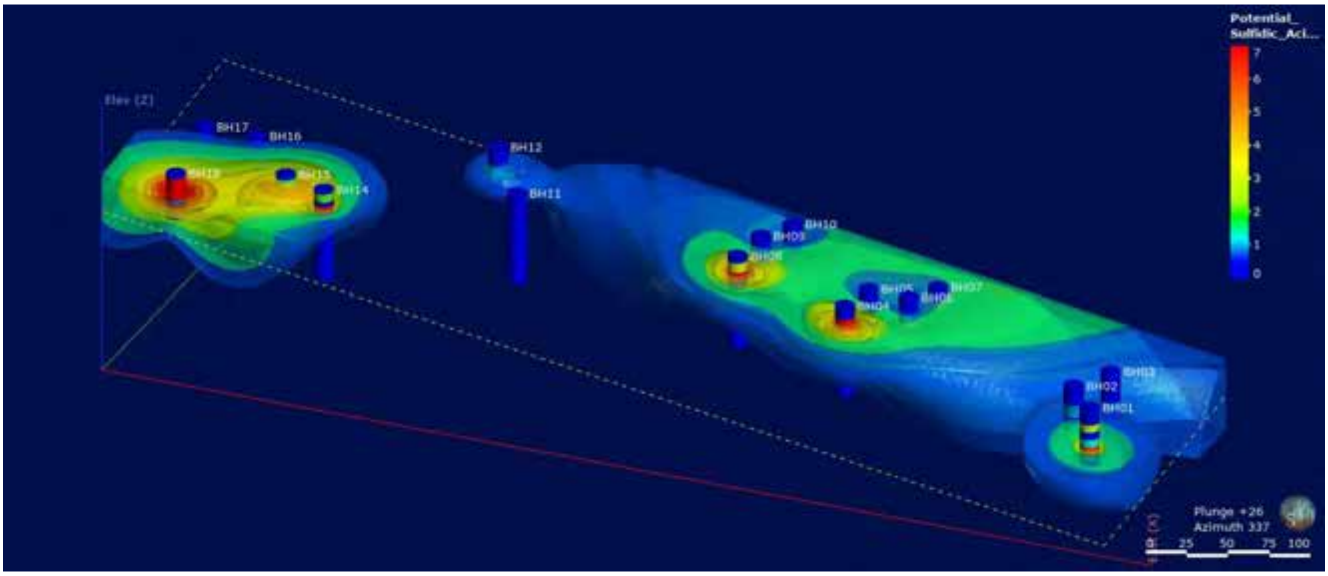

Figure 3-6 Potential acidity heat map sliced at 2 – 6 m depth

4. Summary and conclusions

4.1 Summary

This report details the outcomes of a field program involving soil sample collection at 17 sites for subsequent static geochemical analysis of acid suflate soils, the construction of 17 well at these sites, the deployment of groundwater level loggers in each well, aquifer permeability testing at each site and groundwater level monitoring. The outcomes of the field program can be summarised as follows.

4.1.1 Lithological logs and soil sample collection

A total of 181 soil samples were collected across 17 sites via a combination of push tube and rotary auger drilling. Each core was logged, photographed and samples were collected and handled in accordance with Sullivan et al. (2018) during transfer to Monash University for static geochemical analysis.

Lithological logs indicate the presence of silts, clays and discrete sands and in the upper 6 m of the soil profile throughout Yeodene Swamp. This is consistent with the occurrence of alluvial deposits. Logs also indicate a relatively high organic matter content within the soil profile.

4.1.2 Well construction and logger installation

A total of 16 wells were constructed. Of these, 13 were constructed to a depth of ~6 m bgl with 50 mm uPVC using a drilling rig. An additional 3 wells were constructed by hand to depths of 3 to 4 m bgl with 26 mm uPVC. Wells were finished with a stick up of ~0.70 m and a steel lockable standpipe.

Solinst groundwater level loggers were deployed in each well to a depth approximately 1 m above the well's total depth. Loggers were set to record levels at a 1 hr frequency. A total of 17 groundwater loggers were deployed including 16 at the newly installed wells and one in a previously installed well (BH18 previously termed YS05 in the Yeodene Swamp Study – Jacobs, 2018b). One Barometric level logger was also installed at BH01.

4.1.3 Aquifer permeability testing

Slug tests were undertaken at each of the 17 newly installed wells. Hydraulic conductivities ranged from 0.02 to 1.8 m/day, with an average conductivity of 0.50 m/day and a standard deviation of 0.62 m/day. This is broadly consistent with the range in hydraulic conductivities expected for unconsolidated silts (Domenico and Schwartz, 1990).

4.1.4 Groundwater levels

Groundwater levels varied between 1.4 and -0.10 m bgl (negative sign denotes groundwater levels above ground surface – artesian conditions). Depth to watertable mapping indicates groundwater levels near to the surface (<0.5 m bgl) in the lower reaches of the swamp (near BH02) and through the north west portion of the swamp.

4.1.5 Static geochemical test work

181 samples were analysed for organic carbon content and classified according to Huang et al., (2009). Accordingly, 26% of soil samples collected were classified as mineral soils, 24% as mineral soils with organics, 43% as organic soils and 8% as peat. In summary, while most soil samples are classified as organic soils or soils with organics, only a small proportion are technically classified as peat.

Sulfate concentrations ranged from 0.9 mg/L to 5,100 mg/L with an average concentration of 284 mg/L. The average concentration of sulfate in soil samples at 0.5 m intervals increased from 165 mg/L at 0.5 m to 686 mg/L at 1.0 m depth. Concentrations below this subsequently declined to an average of between 130 and 160 mg/L to 6.0 m depth.

Of the 181 samples analysed, 180 exceed the 0.03 %S net acidity concentration limit for characterisation as acid sulfate soils. Acid neutralising capacity was below detection in all samples. This indicates that within the soils sampled, there is no capacity to neutralise any of the existing acid present, or any potential acidity that may be released upon further oxidation.

Concentrations of existing acidity tend to decline with depth. The average concentration of throughout all cores was >0.5 %S in the upper 2.0 meters of the soil profile, 0.25 %S at 4.0 meters depth and 0.13 %S below 4.5 m depth.

Significant concentrations of potential acidity (sulfide) exist in soils collected from the subsurface of the swamp. The average potential acidity increased from 0.12 %S in the top 0.5 m of the soil profile to 3.6 %S at 1.5 m depth. Average concentrations variably declined from 3.6 %S at 1.5 m depth to 1.3 %S below 4.5 m depth. The results indicate that significant stores of potential acidity remain throughout the soil profile of the swamp, and that future drying and oxidation of these soils may result in acid generation.

4.2 Conclusions

Within the context of the Boundary Creek and Big Swamp Remediation and Environmental Protection Plan, a number of conclusions can be drawdown from the above investigations which have the capacity to answer or inform research questions that have remained unresolved to date. The conclusions and relevant research questions have been listed below:

4.2.1 Question 4: Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer?

The dominance of clays and silts and limited occurrence of sand through the cores suggests that connection between the LTA and the swamp may be limited. Further, the shallow groundwater levels are not indicative of significant drawdown at the swamp. However, the results presented here are not conclusive and are likely to be better resolved through water balance assessments that will be undertaken in other studies.

4.2.2 Question 5: Are there preferential surface or subsurface flow paths in Big Swamp?

Elevated hydraulic conductivities were observed at BH06, BH09, BH10, BH11, BH12 and BH16. These are predominantly located through the centre of the swamp and may suggest higher groundwater flow rates through these areas. However, neither lithological logs nor slug tests suggest the occurrence of a pervasive unit of elevated permeability that promotes subsurface flow. Given the alluvial nature of sediments through the swamp and the dominance of clay and silt, it is likely that groundwater flow will be dominantly horizontal.

4.2.3 Question 6: How much actual and potential acidity is currently stored in Big Swamp?

The static geochemical test work presented within this report provides sufficient data to quantify the amount of existing and potential acidity within the swamp. While full quantification is beyond the scope of this report, further interrogation of the data and refinement of the models in section 3.4.2 could be used for this purpose.

4.2.4 Question 7: How much sulfate remains in the sediment profile in the swamp?

Results indicate average sulfate concentrations of >400 mg/L in the upper 2 m of the soil profile throughout the swamp. Trends in sulfate concentrations with depth are similar to those given by existing acidity vs depth. This suggests that the products of sulfide oxidation (including sulfate) have been retained in the soil profile to some degree. The capacity for these to react and generate alkalinity under different conditions is being assessed separately by Monash University.

4.2.5 Question 8: How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?

The static geochemical results presented within this report provide an indication of the organic carbon content, which was found to be >15% in greater than half of all samples collected. The bioavailability of this carbon has not been assessed as part of this study.

4.2.6 Question 13: How extensive is fire damage to the peat in Big Swamp?

Charring and the occurrence of burnt material within soil profiles was limited to the upper 0.5 m of the soil profiles in cores taken towards the western portion of the swamp. However as discussed in section 3.4, peat layers did not dominate the soil profile.

5. References

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Appendix A. Borehole logs and groundwater monitoring well construction details

JACOBS Piezometer Installation Details

BH01

Project:	Yeodene Swamp ASS field investigation	**Page:**	1 of 1
Client:	Barwon Water	**Location:**	Yedodene Swamp
		Project No:	IS288600

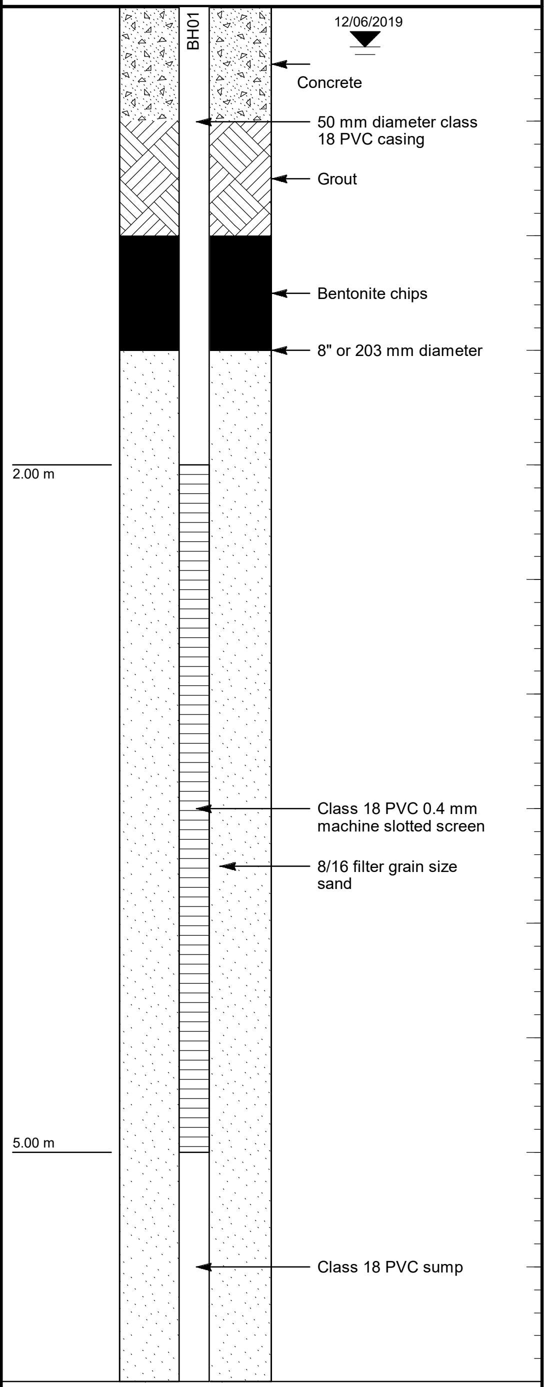
Contractor:	GoDrill	**Easting:**	735858.9	**Elevation:**	141.86	**Started:**	17/05/0219
Plant:	Geoprobe	**Northing:**	5743834.9	**Datum:**		**Finished:**	17/05/0219
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Description of Strata
PT	12/06/2019 (water level)		0.00	Clayey SILT with some sand: brown black with orange and red staining, dry to moist, loose poor cohesion, many roots and rootlets
PT				Clayey SILT: low plasticity, dark brown-dark grey, moist, loose with some cohesion
PT		141		Silty CLAY: low to moderate plasticity, medium to dark brown with bright orange mottles, moist, soft, cohesive, some hard fibres 5mm incisions (peat)
PT		140, 139, 138	1, 2, 3, 4	Silty CLAY with trace gravels: low plasticity, dark brown to black, wet, soft, angular gravels, high organic content (rootlets and decaying material)
AD/T		137, 136	5	Clayey SILT with some sand: low plasticity, dark grey to medium grey, wet, soft poor cohesion, fine sand, limited organic materials
			6	Hole Terminated at 6.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH01	Standpipe	0.60 m 142.5 m	6.00 m 135.86 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH02

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

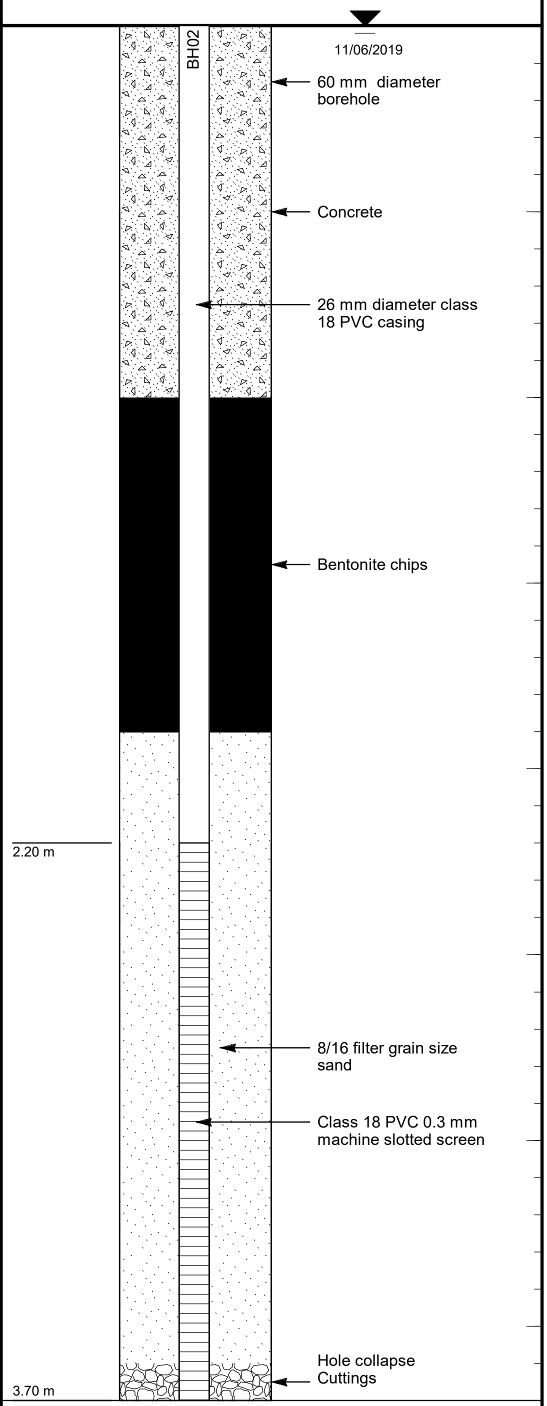
Contractor:	GoDrill	**Easting:**	735838.9	**Elevation:**	141.75	**Started:**	07/05/2019
Plant:	Petrol driven and sampler	**Northing:**	5743863.1	**Datum:**		**Finished:**	07/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

Method & Support	Water	RL (m)	Depth (m)	Graphic Log	Description of Strata
PT	11/06/2019		0.0–0.6		Clayey SILT: orange-brown, wet, soft loose granular texture and dispersible grains
PT		141	0.6–1.2		Clayey SILT: dark brown to black brown with orange mottles, wet, soft loose, dispersible angular texture, poor cohesion
PT		140, 139	1.2–3.70		Silty CLAY: low to moderate plasticity, dark grey, wet, soft, cohesive, decaying organic material
					Hole Terminated at 3.70 m

Depth marks: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5

ID	Type	Stick Up & RL	Tip Depth & RL
BH02	Standpipe	1.16 m 142.9 m	3.70 m 138.05 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH03

Project: Yeodene Swamp ASS field investigation		**Page:**	1 of 1
Client: Barwon Water	**Location:** Yedodene Swamp	**Project No:**	IS288600

Contractor:	GoDrill	**Easting:**	735853.3	**Elevation:**	141.74	**Started:**	07/05/2019
Plant:	Petrol driven and sampler	**Northing:**	5743889.0	**Datum:**		**Finished:**	07/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Graphic Log	Description of Strata
PT	11/06/2019	141.5, 141.0	0.5		Clayey SILT: orange-red with dark brown mottles, wet, loose granular texture that disaggregates, some rootles and organic matter
PT		140.5	1.0, 1.5		Clayey SILT: dark brown with orange and red mottles, wet, loose poor cohesion, angular texture, few rootlets present
PT		140.0, 139.5, 139.0, 138.5, 138.0	2.0, 2.5, 3.0, 3.5		Silty CLAY: low plasticity, brown to grey, wet, soft cohesive buttery texture with some rootlets and decaying organic material
			4.0		Hole Terminated at 4.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH03	Standpipe	1.20 m 142.94 m	4.00 m 137.74 m

Water level: 11/06/2019

- Concrete
- Bentonite chips
- 26 mm diameter class 18 PVC casing
- 60 mm diameter borehole
- 2.50 m — 8/16 filter grain size sand
- Class 18 PVC 0.3 mm machine slotted screen
- Cuttings
- 4.00 m

DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static)   ▽ = Water level (during drilling)

JACOBS Piezometer Installation Details

BH04

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

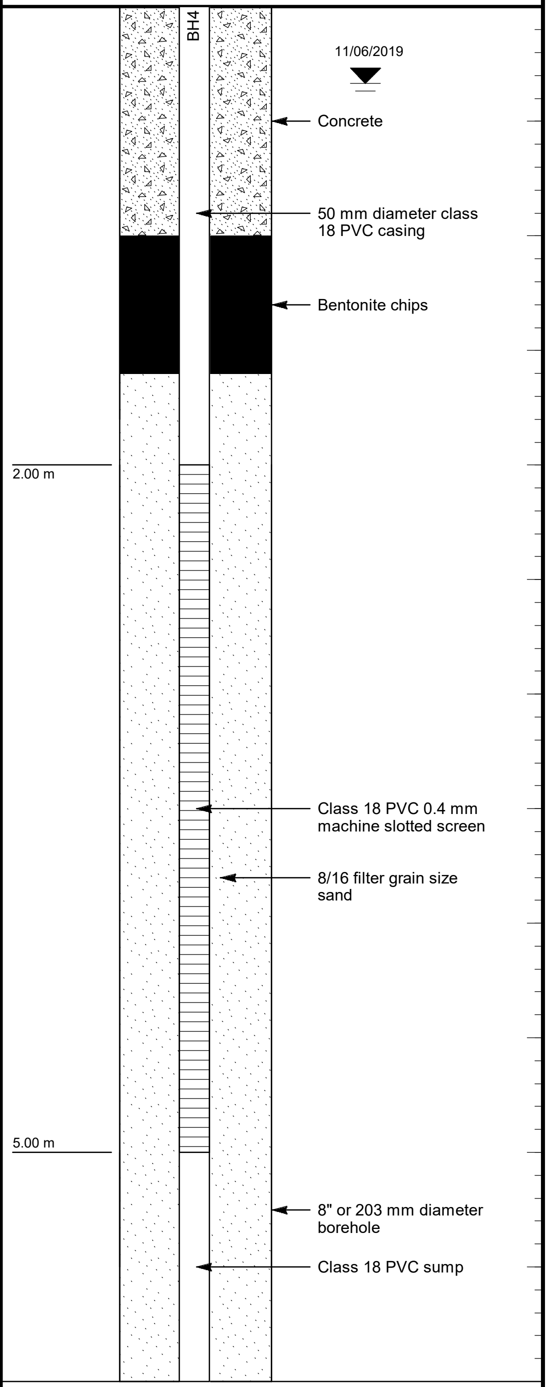
Contractor:	GoDrill	**Easting:**	735682.3	**Elevation:**	143.37	**Started:**	24/04/2019
Plant:	Geoprobe	**Northing:**	5743890.3	**Datum:**		**Finished:**	24/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Description of Strata
PT	11/06/2019 (water level)	143	0	Clayey SILT: red with white mottles, dry, firm to hard grains, no cohesion, dark abundant roots/rootlets and decaying organic matter
PT				Clayey SILT: dark brown to black with some yellow brown mottles, moist, loose poor cohesion, crumbly, some roots
PT		142	1	Silty CLAY: moderate to low plasticity, dark brown to black, moist, soft, cohesive, abundant decaying organic material
PT		141	2	Clayey SAND with some silt: low plasticity, wet, soft, cohesive, medium size sand, no organic matter
PT		140	3	Silty CLAY with trace sand: moderate to low plasticity, medium grey, wet, soft, no organic matter
PT / AD/T		139	4	CLAY with a trace sand: moderate to high plasticity, dark grey, most, stiff to very stiff, fine to medium grained sand
		138	5–6	Hole Terminated at 6.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH4	Standpipe	0.82 m 144.19 m	6.00 m 137.37 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static)
▽ = Water level (during drilling)

Piezometer Installation Details

BH05

Project:	Yeodene Swamp ASS field investigation		**Page:**	1 of 1
Client:	Barwon Water	**Location:** Yedodene Swamp	**Project No:**	IS288600

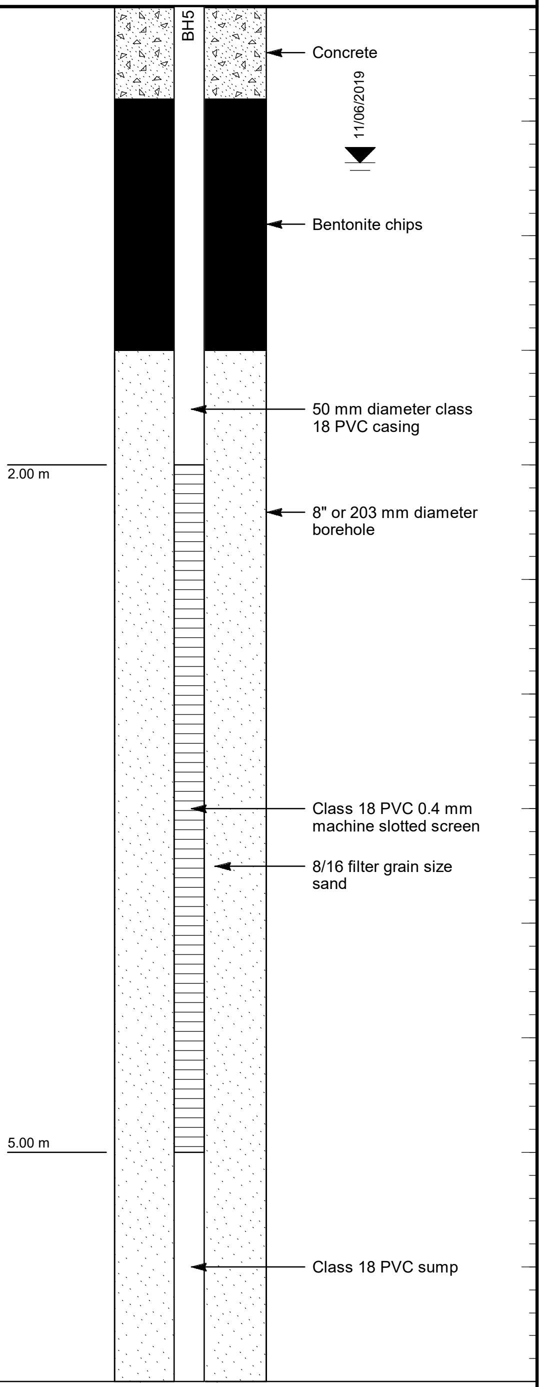
Contractor:	GoDrill	**Easting:**	735686.9	**Elevation:**	143.08	**Started:**	18/04/2019
Plant:	Geoprobe	**Northing:**	5743921.0	**Datum:**		**Finished:**	18/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Graphic Log	Description of Strata
PT	11/06/2019 (water level, static)	143	0.0	Silt	Sandy SILT with some clay: orange red to yellow brown, dry, loose hard granular sand texture, rootlets abundant
PT				Clay	Silty CLAY: low to moderate plasticity, dark brown with red mottles, moist, soft to firm, some organic matter
PT		142	1	Clay	Clayey SILT: low plasticity, dark brown, wet, soft, cohesive, some fibrous inclusions (peat)
PT		141	2	Clay	Silty CLAY with trance of sand: low to moderate plasticity, dark brown, moist, soft to firm, some organic material, find sand
PT		140	3	Silt	Clayey SILT with trace of sand: low plasticity, dark brown, wet, soft, cohesive, find sand
PT / AD/T		139 / 138	4 / 5	Clay	Silty CLAY: low plasticity, dark grey with some yellow brown mottles, wet, soft, cohesive
			6		Hole Terminated at 6.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH5	Standpipe	0.80 m 143.88 m	6.00 m 137.08 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH06

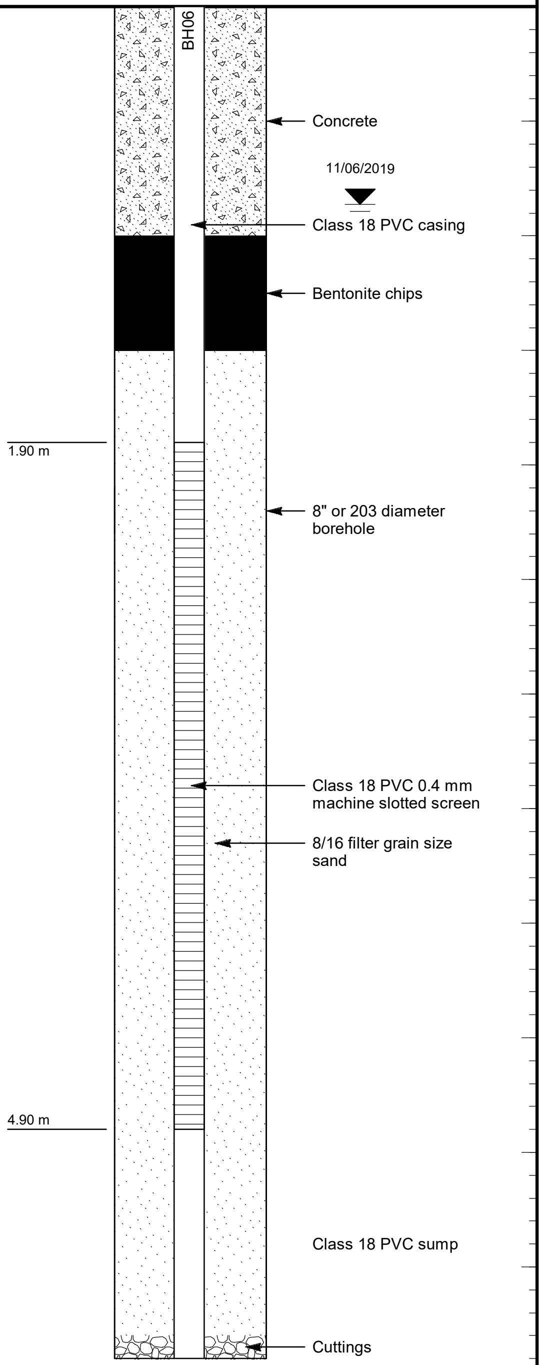
Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

Contractor:	GoDrill	**Easting:**	735712.2	**Elevation:**	142.90	**Started:**	18/04/2019
Plant:	Geoprobe	**Northing:**	5743922.1	**Datum:**		**Finished:**	18/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

Method & Support	Water	RL (m)	Depth (m)	Description of Strata (ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type))
PT			0	Clayey SILT with some sand: dark brown to red brown, dry, very loose, poor cohesion, granular texture, rootlets abundant, fine sands
				Clayey SILT: dark brown/black with dark red rootles, moist, firm fibrous texture (peat), some rootles
				SILT with some sand: yellow brown, dry, loose, poor cohesion, fine sand
	11/06/2019	142	1	Clayey SILT with trace sand: low plasticity, dark brown, moist, soft, fibrous texture (peat), find sand, organic material abundant
		141	2	Silty CLAY: low to moderate plasticity, dark brown, wet, soft, abundant organics
		140	3	Silty CLAY: low to moderate plasticity, dark brown, wet, soft, abundant organics
AD/T		139	4	Silty CLAY: low to moderate plasticity, dark brown, wet, very soft, abundant organics
		138	5	
		137	6	Hole Terminated at 6.00 m

ID	Type	Stick Up & RL	Tip Depth & RL
BH06	Standpipe	0.68 m 143.58 m	5.90 m 137.00 m



DRILLING
PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS
= Water level (static)
= Water level (during drilling)

JACOBS Piezometer Installation Details

BH07

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

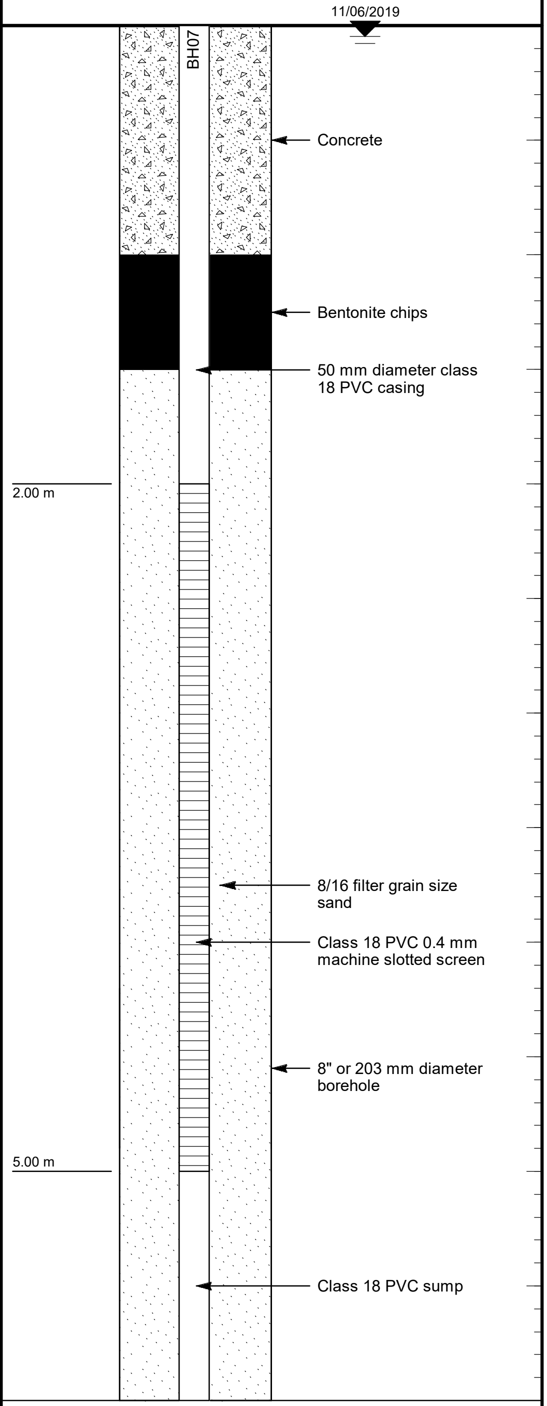
Contractor:	GoDrill	**Easting:**	735721.7	**Elevation:**	142.50	**Started:**	17/04/2019
Plant:	Geoprobe	**Northing:**	5743948.3	**Datum:**		**Finished:**	17/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Graphic Log	Description of Strata (ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type))
PT (0.00–4.50 m)	11/06/2019 (water level at surface)	142.50–142.10	0.00–0.40		Clayey SILT: dark brown to black with orange/red grains, moist, loose, granular texture, rootlets abundant
PT			0.40–0.60		Clayey SILT with trace gravel: low plasticity, dark brown to back, moist, soft, cohesive, trace rootles, decaying organic material
PT (to 4.50 m); AD/T (4.50–6.00 m)		141.90–136.50	0.60–6.00		Silty CLAY: low plasticity, dark grey to dark brown, wet, soft, cohesive, high concentration of decaying organic material.
		136.50	6.00		Hole Terminated at 6.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH07	Standpipe	0.56 m 143.05 m	6.00 m 136.50 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH08

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

Contractor:	GoDrill	**Easting:**	735607.0	**Elevation:**	144.62	**Started:**	25/04/2019
Plant:	Geoprobe	**Northing:**	5743908.6	**Datum:**		**Finished:**	25/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH08	Standpipe	0.67 m 145.29 m	5.90 m 138.72 m

Method & Support: PT (0.0–4.5 m); AD/V (4.5–6.0 m)

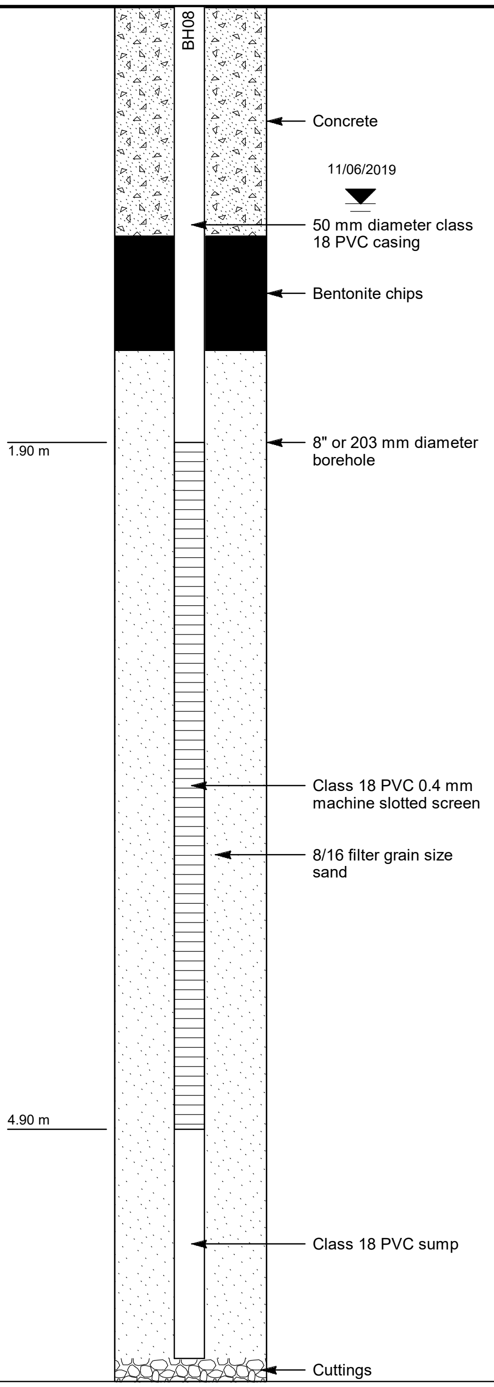
Water: 11/06/2019 (static water level ≈ 0.85 m)

Description of Strata

ROCK TYPE : Colour, Grain size, Structure
(texture, fabric, mineral composition, hardness
alteration, cementation, major defect type)

Depth (m)	Description of Strata
0.00 – 0.15	Sandy SILT: red with white mottles, dry, poor cohesion, hard grains in loose material, few rootlets
0.15 – 0.35	Clayey SILT: low plasticity, dark brown, moist, soft, cohesive, some rootlets
0.35 – 1.50	Silty CLAY with trace sand: moderate plasticity, dark grey to brown grey, moist, firm, fine sand, many rootlets
1.50 – 2.50	Sandy CLAY: low plasticity, grey with light grey mottles, moist, soft, cohesive, fine to medium sand, no rootlets
2.50 – 4.00	Silty CLAY with some sand: moderate to high plasticity, grey, moist, firm to stiff, fine to medium sand, trace organics
4.00 – 6.00	Silty SAND: light grey with some black mottles, wet, loose, medium grained sand
6.00	Hole Terminated at 6.00 m

RL (m): 144, 143, 142, 141, 140, 139
Depth (m): 1, 2, 3, 4, 5, 6



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static)   ▽ = Water level (during drilling)

Piezometer Installation Details

BH09

Project:	Yeodene Swamp ASS field investigation	**Page:**	1 of 1
Client:	Barwon Water	**Location:**	Yedodene Swamp
		Project No:	IS288600

Contractor:	GoDrill	**Easting:**	735609.7	**Elevation:**	144.36	**Started:**	24/04/2019
Plant:	Geoprobe	**Northing:**	5743944.4	**Datum:**		**Finished:**	24/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

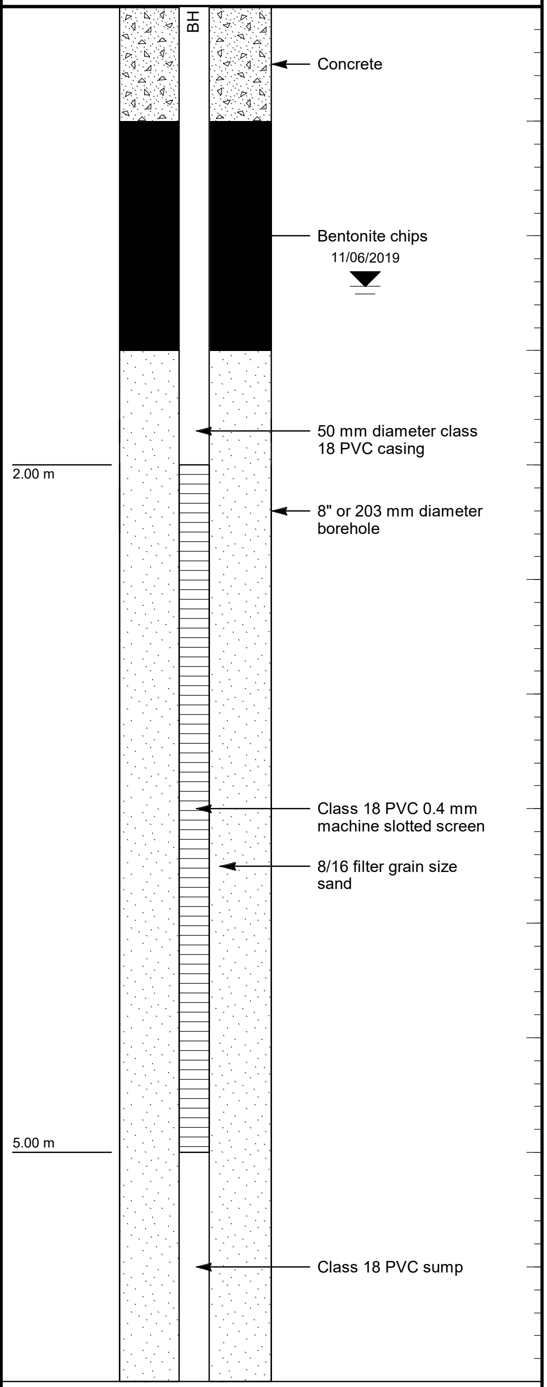
DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

Description of Strata

ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)

ID	Type	Stick Up & RL	Tip Depth & RL
BH	Standpipe	0.68 m 145.04 m	6.00 m 138.36 m

Method & Support	Water	RL (m)	Depth (m)	Description of Strata
PT		144	0.00	SILT with trace sand: red to red brown, dry, loose, poor cohesion, find sand, decaying organic material
PT	11/06/2019 (water level)	143	1	Clayey SILT with trace sand: dark brown, moist, loose, poor cohesion, friable
PT		142	2	Silty CLAY: moderate to low plasticity, medium brown to grey, moist, firm, abundant organics
PT				Silty CLAY: moderate to low plasticity, medium brown to grey, moist, firm to stiff, abundant organics
PT		141	3	Silty CLAY: low to moderate plasticity, medium brown to grey, wet, soft to firm, increasing concentration of organics but variable
PT		140	4	CLAY with some sand: high plasticity, medium grey with yellow brown mottles, moist, very stiff
AD/T		139	5	Sandy CLAY: moderate plasticity, medium grey to yellow mottles, wet, firm
			6	Hole Terminated at 6.00 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH10

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

Contractor:	GoDrill	**Easting:**	735622.3	**Elevation:**	144.31	**Started:**	24/04/2019
Plant:	Geoprobe	**Northing:**	5743966.9	**Datum:**		**Finished:**	24/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

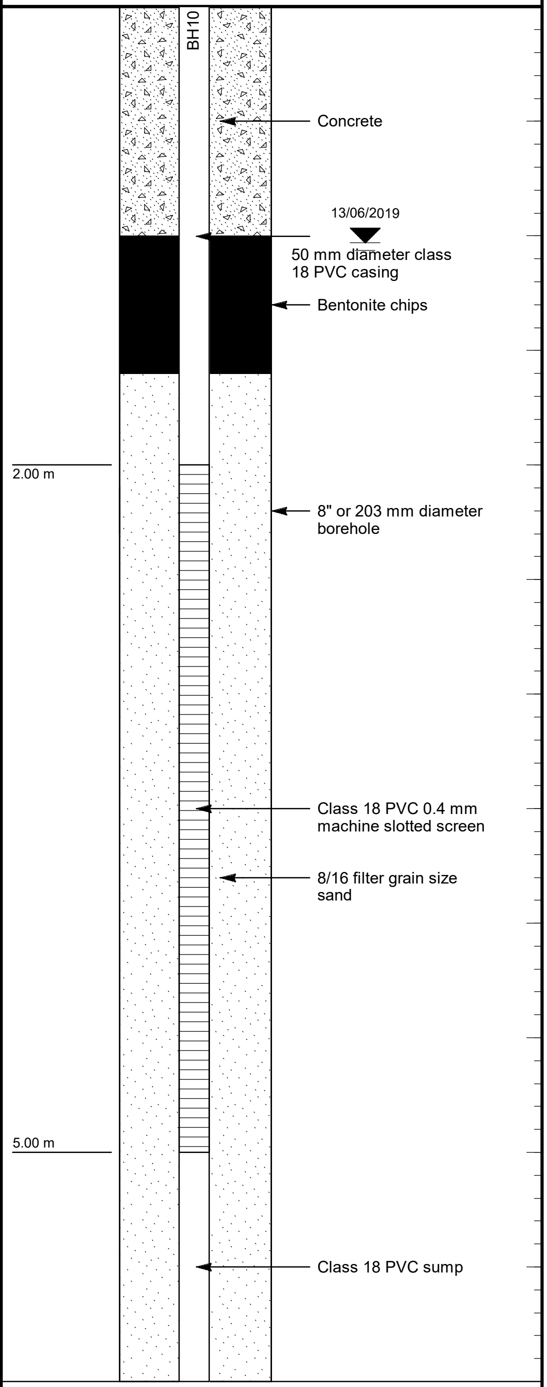
Method & Support: PT (0.00–4.50 m); AD/T (4.50–6.00 m)
Water: 13/06/2019 (water level at approx. 1.00 m)

RL (m)	Depth (m)	Description of Strata (ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type))
144.31 – 143.71	0.00 – 0.60	Clayey SILT: low plasticity, red to dark brown/black, cohesive, abundant leaf material at the surface, some rootlets
143.71 – 141.81	0.60 – 2.50	Silty CLAY: moderate to low plasticity, dark brown-black, wet, soft to firm, cohesive, some rootlets, some granular incisions (peat)
141.81 – 140.81	2.50 – 3.50	Clayey SILT: low plasticity, medium to dark brown, wet, very soft, abundant decaying organic material
140.81 – 138.31	3.50 – 6.00	Silty CLAY: moderate to low plasticity, dark brown-dark grey with some orange mottles, wet, firm, varying concentrations of organics in lenses
	6.00	Hole Terminated at 6.00 m

RL scale: 144, 143, 142, 141, 140, 139
Depth scale: 1, 2, 3, 4, 5, 6

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH10	Standpipe	0.68 m 145.0 m	6.00 m 138.31 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static)
▽ = Water level (during drilling)

Piezometer Installation Details

BH11

Project:	Yeodene Swamp ASS field investigation	**Page:**	1 of 1
Client:	Barwon Water	**Location:** Yedodene Swamp	**Project No:** IS288600

Contractor:	GoDrill	**Easting:**	735469.3	**Elevation:**	147.09	**Started:**	08/05/2019
Plant:	Geoprobe	**Northing:**	5743898.0	**Datum:**		**Finished:**	08/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Columns: Method & Support | Water | RL (m) | Depth (m) | Graphic Log | Description of Strata

Description of Strata

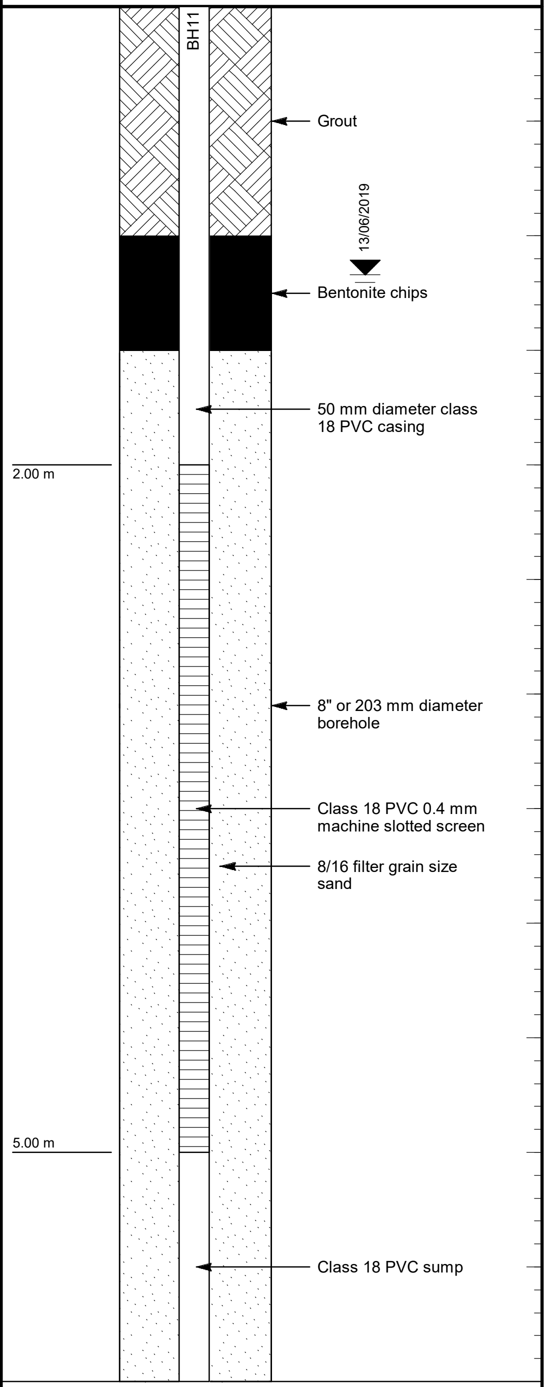
ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)

Description of Strata
Clayey SILT with some sand: black brown with orange red mottles, dry, loose, fine sand, abundant rootlets
SAND with some silt: orange with white mottles, medium grained, dry, loose, some roots/rootlets
Silty CLAY: moderate plasticity, black brown, moist, firm, cohesive, abundant rootlets and organic material
Clayey SAND: grey, medium grain size
CLAY with some sand: high plasticity, medium grey, moist, stiff, find sand, some organic rootlets
Hole Terminated at 6.00 m

Method & Support: PT (0 to ~4.5 m); AD/T (~4.5 to 6 m). Water: 13/06/2019 (static water level). RL (m): 147, 146, 145, 144, 143, 142. Depth (m): 1, 2, 3, 4, 5, 6.

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH11	Standpipe	0.63 m 147.72 m	6.00 m 141.09 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

JACOBS Piezometer Installation Details

BH12

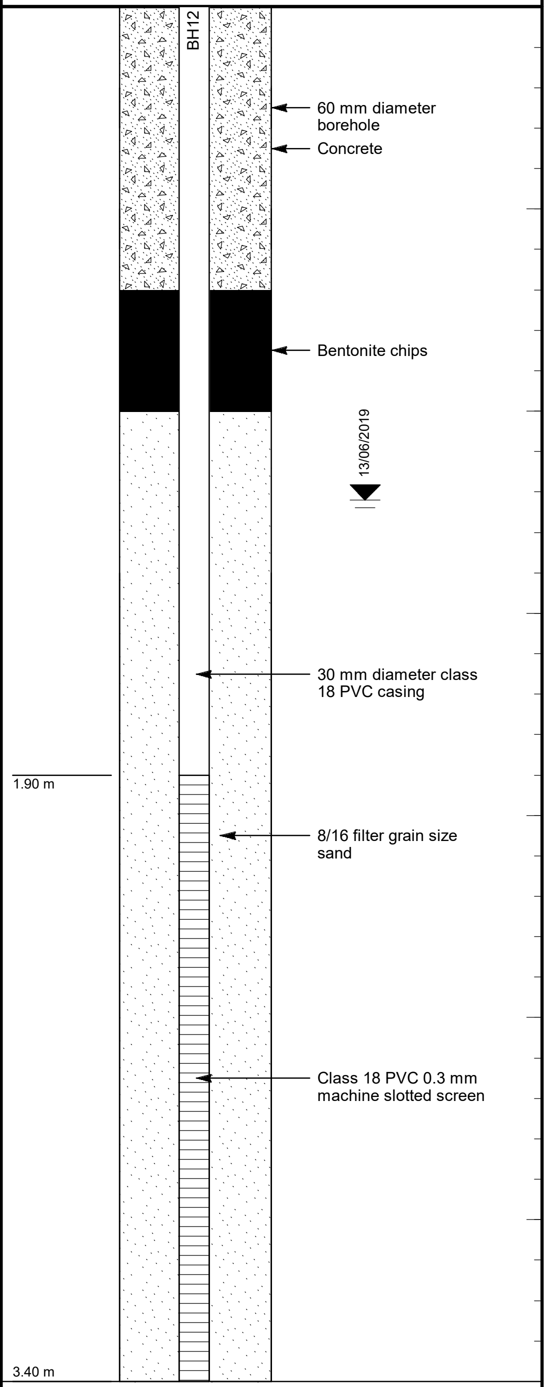
Project: Yeodene Swamp ASS field investigation | **Page:** 1 of 1
Client: Barwon Water | **Location:** Yedodene Swamp | **Project No:** IS288600

Contractor:	GoDrill	**Easting:**	735438.0	**Elevation:**	147.20	**Started:**	09/05/2019
Plant:	Hand auger	**Northing:**	5743952.7	**Datum:**		**Finished:**	09/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

Method & Support	Water	RL (m)	Depth (m)	Description of Strata (ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type))
PT		147.20–146.70	0.0–0.5	Clayey SAND: red brown, moist
PT	13/06/2019 (▼ at 146)	146.70–146.00	0.5–1.2	Clayey SAND: dark brown with organic matter, moist
PT		146.00–145.00	1.2–2.2	Silty CLAY with sand: dark grey becoming lighter, moist, find sand, organic matter
PT		145.00–143.80	2.2–3.4	Sandy CLAY with some silt: yellow brown
				Hole Terminated at 3.40 m

ID	Type	Stick Up & RL	Tip Depth & RL
BH12	Standpipe	0.71 m 147.91 m	3.40 m 143.80 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Piezometer Installation Details

BH14

Project:	Yeodene Swamp ASS field investigation			**Page:**	1 of 1
Client:	Barwon Water	**Location:**	Yedodene Swamp	**Project No:**	IS288600

Contractor:	GoDrill	**Easting:**	735360.8	**Elevation:**	147.67	**Started:**	25/04/2019
Plant:	Geoprobe	**Northing:**	5743853.1	**Datum:**		**Finished:**	25/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

Method & Support: PT (Push Tube); AD/T (Auger drilling with tc-bit)

Water: 13/06/2019

Description of Strata

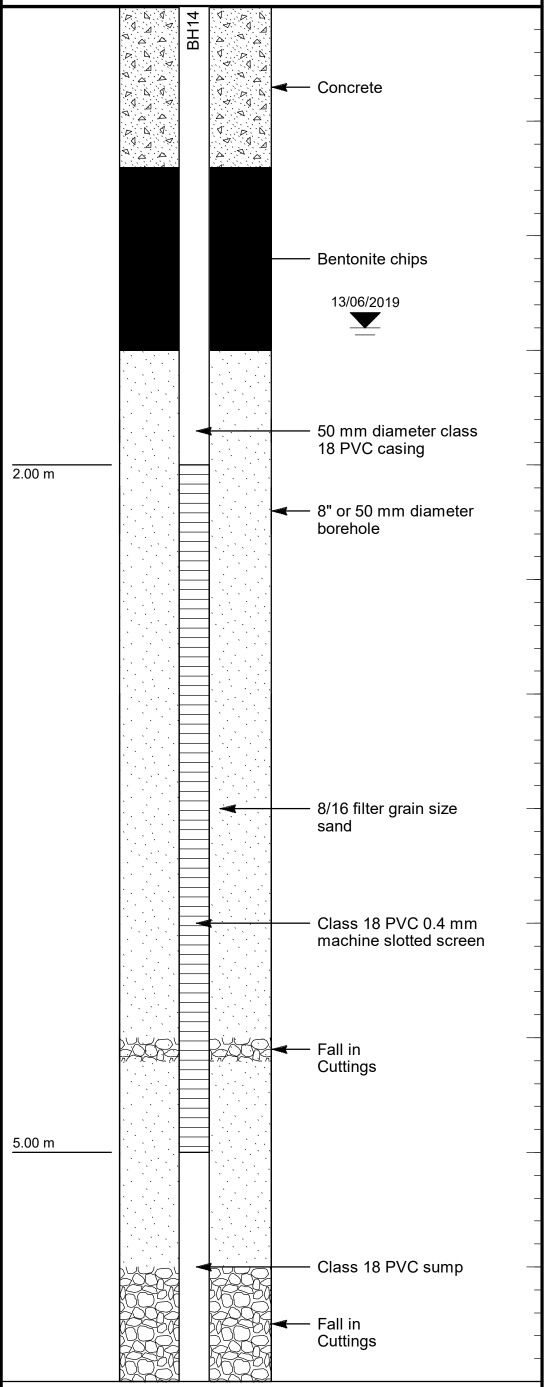
ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)

- Clayey SILT: low plasticity, dark brown with red mottles, moist, soft, cohesive
- Clayey SILT: low plasticity, dark brown to grey brown, moist, soft to firm, lenses of wet decaying wood
- Silty CLAY: low to moderate plasticity, dark grey/brown, moist, soft to firm, cohesive, some fibrous grains (peat), some decaying organic matter
- Clayey SILT with trace sand: light grey, wet, soft, find sand
- CLAY with some sand: light grey, moist, firm to stiff, fine grained sand
- Silty SAND with some clay: medium to fine grained, wet, loose, poor cohesion
- SAND with trace gravel: light grey, wet, coarse, loose, poor cohesion, subrounded up to 10mm silicate gravels
- Hole Terminated at 6.00 m

RL (m): 147, 146, 145, 144, 143, 142

Depth (m): 1, 2, 3, 4, 5, 6

ID	Type	Stick Up & RL	Tip Depth & RL
BH14	Standpipe	0.64 m 148.3 m	6.00 m 141.67 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

JACOBS Piezometer Installation Details

BH15

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

Contractor:	GoDrill	**Easting:**	735330.5	**Elevation:**	147.42	**Started:**	26/04/2019
Plant:	Geoprobe	**Northing:**	5743870.0	**Datum:**		**Finished:**	26/04/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

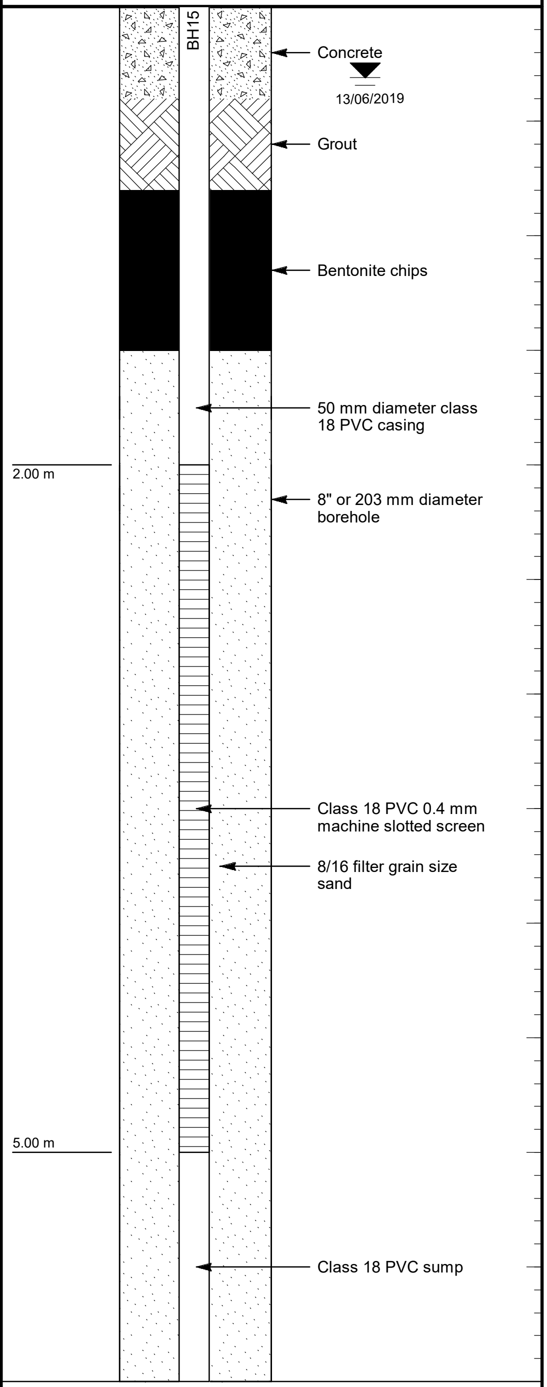
Description of Strata
ROCK TYPE : Colour, Grain size, Structure
(texture, fabric, mineral composition, hardness
alteration, cementation, major defect type)

Method & Support	Water	RL (m)	Depth (m)	Description of Strata
PT	3/06/2019 (static water level)	147.42	0.0	Silty CLAY with trace sand: low plasticity, red brown and black brown, moist, soft, cohesive, fine sand with some hard-cohesive grains
PT			0.2	Silty CLAY: low plasticity, grey brown with red mottles, moist, soft, lenses of decaying organics
PT			1.5	Silty CLAY: moderate plasticity, grey brown, moist, soft, some organics and rootlets
PT			2.0	Silty CLAY: moderate plasticity, dark brown with orange red mottles, wet, soft to stiff, abundant organics
PT			2.5	Silty CLAY with trace sand: low plasticity, brown grey, wet, soft to firm, fine sand, lenses of organics
PT / AD/T			4.0	Sandy CLAY with some silt: high plasticity, medium grey, wet, stiff, increased sand with depth
		141.42	6.00	Hole Terminated at 6.00 m

RL (m) scale: 147, 146, 145, 144, 143, 142. Depth (m) scale: 1, 2, 3, 4, 5, 6.

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH15	Standpipe	0.66 m 148.1 m	6.00 m 141.42 m



DRILLING
PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS
▼ = Water level (static)
▽ = Water level (during drilling)

Piezometer Installation Details

BH16

Project: Yeodene Swamp ASS field investigation **Page:** 1 of 1

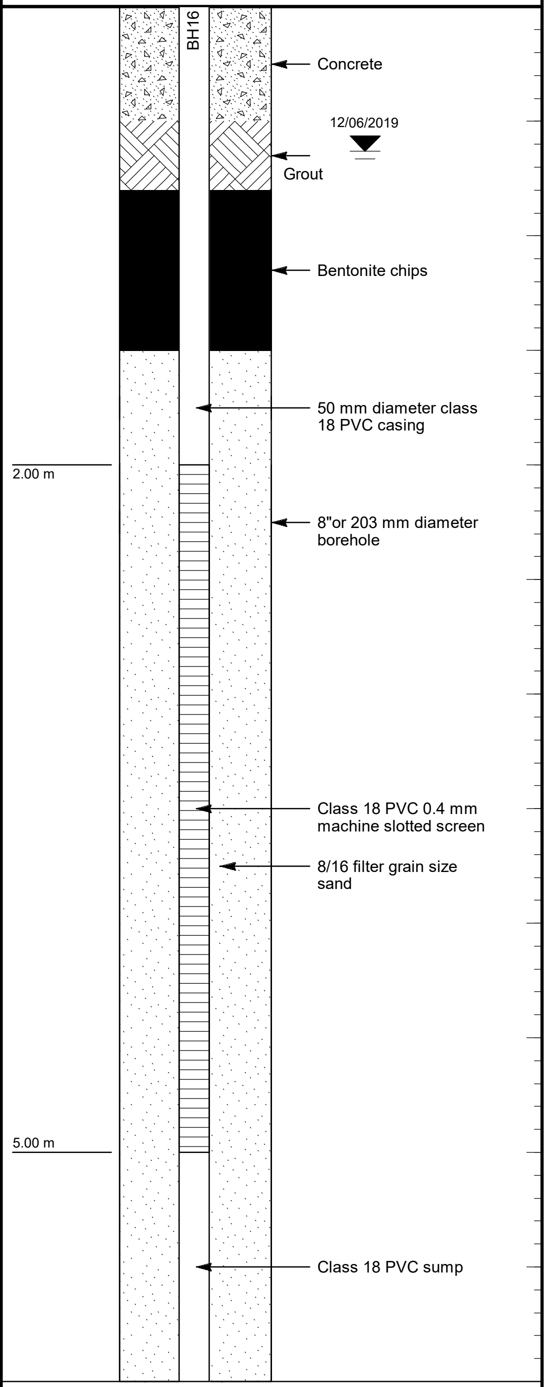
Client: Barwon Water **Location:** Yedodene Swamp **Project No:** IS288600

Contractor:	GoDrill	**Easting:**	735300.1	**Elevation:**	147.99	**Started:**	07/05/2019
Plant:	Geoprobe	**Northing:**	5743903.5	**Datum:**		**Finished:**	07/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING | MATERIAL SUBSTANCE | INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH16	Standpipe	0.82 m 148.08 m	6.00 m 141.99 m

Method & Support	Water	RL (m)	Depth (m)	Description of Strata ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)
PT	12/06/2019		0	Silty CLAY with char: low plasticity, orange to red, moist, stiff, cohesive, dark brown pieces of char
				Sandy SILT: black brown, dry, loose, poor cohesion, some rootlets
				Silty SAND: low plasticity, orange brown with some medium grey mottling, wet, loose, slightly cohesive, medium to fine grained sand becoming coarser with depth
		147	1	
		146	2	Sandy CLAY: low plasticity, medium grey with orange mottles, wet, soft
				CLAY with some sand: high plasticity, grey, wet, soft, fine sand
		145	3	
				Sandy CLAY: moderate to low plasticity, grey, wet, soft
		144	4	Sandy CLAY: orange with grey mottles, moist, soft to firm
AD/T		143	5	
		142	6	Hole Terminated at 6.00 m



DRILLING

PT - Push Tube
AD/T - Auguer drilling with tc-but

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

JACOBS Piezometer Installation Details

BH17

Project: Yeodene Swamp ASS field investigation
Page: 1 of 1
Client: Barwon Water
Location: Yedodene Swamp
Project No: IS288600

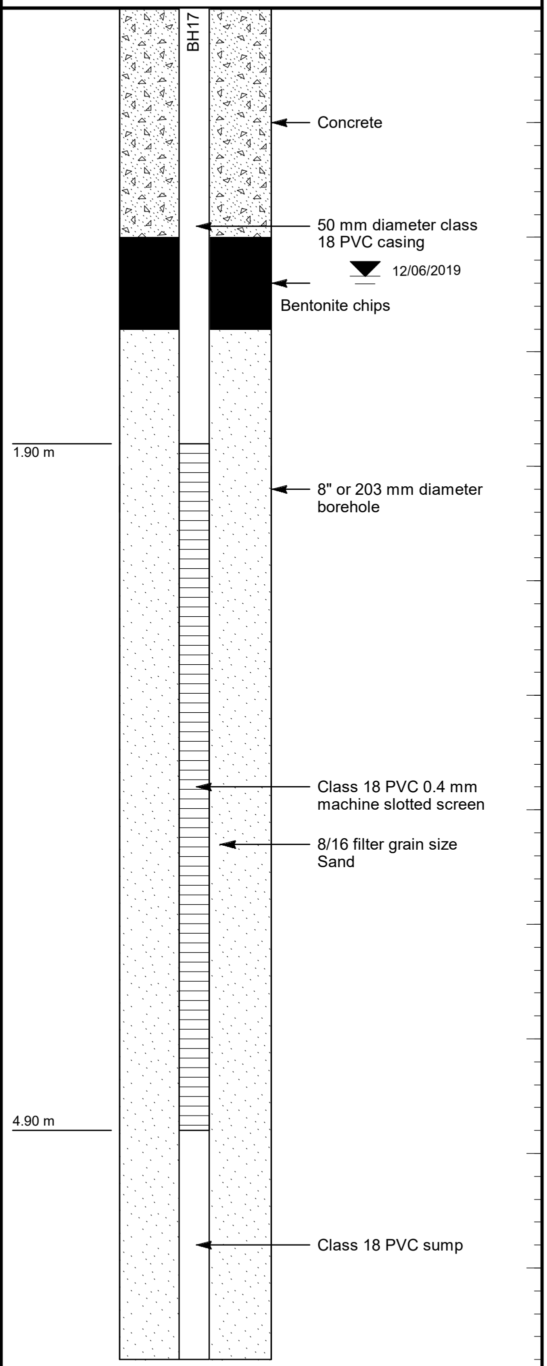
Contractor:	GoDrill	**Easting:**	735266.8	**Elevation:**	148.10	**Started:**	06/05/2019
Plant:	Geoprobe	**Northing:**	5743903.0	**Datum:**		**Finished:**	06/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING / MATERIAL SUBSTANCE

Method & Support	Water	RL (m)	Depth (m)	Description of Strata ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, major defect type)
PT	12/06/2019	148	0	Sandy SILT with some clay: low plasticity, orange to red, dry to moist, loose, poor cohesion, abundant rootlets
				Silty SAND: grey, fine to medium grained, dry, loose, poor cohesion, residual burnt peat
				SAND: yellow brown, medium grained, dry, loose, poor cohesion
		147	1	Sandy SILT: grey with yellow and brown mottles, moist, loose, poor cohesion
		146	2	Sandy CLAY: low to moderate plasticity, light grey, moist, firm, sand fine grained sand
		145	3	Sandy CLAY: low plasticity, light brown with dark grey mottles, wet, stiff
		144	4	Silty SAND: light grey with yellow brown mottles, wet, loose, poor cohesion, silicates present
				Clayey SAND: orange/brown, wet, loose, poor cohesion
		143	5	
		142	6	Hole Terminated at 6.00 m

INSTALLATION DETAILS

ID	Type	Stick Up & RL	Tip Depth & RL
BH17	Standpipe	0.66 m 148.77 m	5.90 m 142.20 m



DRILLING

NMLC	NMLC Coring	HQ	HQ Coring	TCR	% core run recovered
NQ	NQ Coring	PQ	PQ Coring	RQD	% core run > 100mm long (rock fraction only measured)

GROUNDWATER SYMBOLS

▼ = Water level (static) ▽ = Water level (during drilling)

Engineering Log - Borehole

BH18

Project:	Yeodene Swamp ASS field investigation			**Page:**	1 of 1
Client:	Barwon Water	**Location:**	Yedodene Swamp	**Project No:**	IS288600

Contractor:	GoDrill	**Easting:**	735276.0	**Elevation:**	148.72	**Started:**	08/05/2019
Plant:	Geoprobe	**Northing:**	5743824.0	**Datum:**		**Finished:**	08/05/2019
Logged by:	NU **Checked by:** GH	**Grid:**	MGA94 Zone 54	**Inclination:**	-90°	**Orientation:**	

DRILLING INFORMATION | MATERIAL SUBSTANCE

Method & Support	Penetration	Groundwater Levels	Samples & SPT Data	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description	Moisture	Consistency Relative Density	Field Test Data & Other Observations
PT (0.00–3.20)				148.72	0.00		SW-SC	Sandy SILT: orange-red with black brown mottles, dry, loose, some char, dominated by FeOH	D	L	ALLUVIUM 0.00: Within burnt area
							CH	Silty CLAY: low to moderate plasticity, black brown with some mottles, moist, soft, cohesive	M		0.20: Organic odour
		▶ (water inflow)					CH	Silty CLAY: low to moderate plasticity, black brown with some orange red mottles, wet, soft, some pieces of char			
							CH	Silty CLAY with trace sand: moderate to low plasticity dark grey, wet, soft, find sand	W	S	1.60: Organic odour
							CH	Sandy CLAY: moderate to high plasticity, grey, wet, soft, medium size sand			
					3.20			Hole Terminated at 3.20 m			

RL (m) scale: 148, 147, 146, 145, 144, 143, 142, 141, 140, 139
Depth (m) scale: 1, 2, 3, 4, 5, 6, 7, 8, 9

METHOD & SUPPORT
- HA Hand Auger
- AS Auger
- AD/V Auger - V-bit
- AD/T Auger - TC-bit
- WB Washbore
- RR Rock Roller
- AH Air Hammer
- C Casing

PENETRATION
No resistance ranging to refusal

GROUNDWATER
- = Water level (static)
- = Water level (during drilling)
- = Water inflow
- = Water outflow

SAMPLES & FIELD TESTS

D	Disturbed Sample	N	SPT blows per 300mm
B	Bulk Sample	HW	SPT penetration by hammer weight
SPT	SPT Sample	RW	SPT penetration by rod weight
U	Undisturbed Sample	HP	Hand Penetrometer
E	Enviro Sample	HV	Hand Vane Shear
W	Water Sample		(P: Peak Su R: Residual Su)

MOISTURE
- D = Dry
- M = Moist
- W = Wet
- Wp = Plastic Limit
- Wl = Liquid Limit

DENSITY (N-value)

VL	Very Loose	0 - 4
L	Loose	4 - 10
MD	Medium Dense	10 - 30
D	Dense	30 - 50
VD	Very Dense	50 - 100

CONSISTENCY (Su) {N-value}

VS	Very Soft	< 12 kPa {0-2}
S	Soft	12 - 25 {2-4}
F	Firm	25 - 50 {4-8}
St	Stiff	50 - 100 {8-15}
VSt	Very Stiff	100 - 200 {15-30}
H	Hard	> 200 kPa {>30}

Appendix B. Push tube photographs

Appendix B. Push tube photographs


BH01, 0 to 4.5 m


BH02, 0 to 3.6 m


BH03, 0 to 3.7 m


BH04, 0 to 4.5 m


BH05, 0 to 4.5 m


BH06, 0 to 4.5 m

BH07, 0 to 4.5 m

BH08, 0 to 4.5 m

BH09, 0 to 4.5 m


BH10, 0 to 4.5 m


BH11, 0 to 4.5 m


BH14, 0 to 4.5 m

BH15, 0 to 4.5 m

BH16, 0 to 4.5 m

BH17, 0 to 4.5 m


BH18, 0 to 3.4 m

Appendix C. Well completion photographs

Appendix C. Well completion photographs

BH01

BH02

BH03

BH04

BH05

BH06

BH07

BH08

BH09

BH10

BH11

BH12

BH14

BH15

BH16

BH17

Appendix D. Well completion reports

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY –
To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA .... ZONE ....

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method ....

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type CA SC SL OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS — Casing Shoe Y / N: ☐ Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C B S P G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify: ....

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature .... Date 05 / 06 / 2019

Name of Plant Operator ....

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

OFFICE USE ONLY	
BORE NUMBER	
BORE USES	
GMA	ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type CA SC SL OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
SL ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
CA ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS Casing Shoe Y / N Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C B S P G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)

Have water samples been taken? Yes ☑ No ☐ To 6 (m)

Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑

If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐

Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA .... ZONE ....

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL						CASING			SCREENS / SLOTS						OFFICE USE
CA	SC	SL	OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
☐	☐	☑	☐	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
☑	☐	☐	☐	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
☐	☐	☐	☐	2	+0.7	50	60	C18 uPVC							
☐	☐	☐	☐												
☐	☐	☐	☐												

WELL HEAD FITTINGS: Casing Shoe Y / N: Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

C	B	S	P	G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
☐	☐	☐	☐	☑	6	1.5					Gravity	1.2 - 2.4
☐	☑	☐	☐	☐	1.5	0.8			Medium Chips			
☑	☐	☐	☐	☐	0.8	0	4	40				
☐	☐	☐	☐	☐								

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify: ....

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature .... Date 05 / 06 / 2019

Name of Plant Operator ....

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type (CA SC SL OH)	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS: Casing Shoe Y / N: ☐ Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material (C B S P G)	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date: 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

WATER ACT 1989

BORE COMPLETION REPORT

Southern Rural Water
Managing Water. Serving Communities.

SRW COPY –
To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. WLE074097

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 735299 N 5743902

ZONE: 54 / ~~55~~ (delete as applicable) GDA 94/AD~~66~~ (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY	
BORE NUMBER	
BORE USES	
GMA	ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249(Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type (CA SC SL OH)	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS — Casing Shoe Y / N: ☐ Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material (C B S P G)	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date: 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. WLE074097

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 735299 N 5743902

ZONE: 54 / ~~55~~ (delete as applicable) GDA 94/AD~~66~~ (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA .... ZONE ....

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249(Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type (CA SC SL OH)	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS — Casing Shoe Y / N: — Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material (C B S P G)	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date: 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

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LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/ADG66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL						CASING			SCREENS / SLOTS						OFFICE USE
Type CA	SC	SL	OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
☑	☐	☐	☐	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
☐	☐	☑	☐	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
☑	☐	☐	☐	2	+0.7	50	60	C18 uPVC							
☐	☐	☐	☐												
☐	☐	☐	☐												

WELL HEAD FITTINGS Casing Shoe Y / N Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C	B	S	P	G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
☐	☐	☐	☐	☑	6	1.5					Gravity	1.2 - 2.4
☐	☑	☐	☐	☐	1.5	0.8			Medium Chips			
☑	☐	☐	☐	☐	0.8	0	4	40				
☐	☐	☐	☐	☐								

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

WATER ACT 1989

BORE COMPLETION REPORT

Southern Rural Water
Managing Water. Serving Communities.

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL						CASING			SCREENS / SLOTS						OFFICE USE
Type CA	SC	SL	OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
☑	☐	☐	☐	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
☐	☐	☑	☐	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
☑	☐	☐	☐	2	+0.7	50	60	C18 uPVC							
☐	☐	☐	☐												
☐	☐	☐	☐												

WELL HEAD FITTINGS Casing Shoe Y / N Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C	B	S	P	G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
☐	☐	☐	☐	☑	6	1.5					Gravity	1.2 - 2.4
☐	☑	☐	☐	☐	1.5	0.8			Medium Chips			
☑	☐	☐	☐	☐	0.8	0	4	40				
☐	☐	☐	☐	☐								

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY –
To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / ~~55~~ (delete as applicable) GDA 94/AD~~66~~ (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249(Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL						CASING			SCREENS / SLOTS						OFFICE USE
Type CA	SC	SL	OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
☑	☐	☐	☐	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
☐	☐	☑	☐	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
☑	☐	☐	☐	2	+0.7	50	60	C18 uPVC							
☐	☐	☐	☐												
☐	☐	☐	☐												

WELL HEAD FITTINGS Casing Shoe Y / N ☐ Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C	B	S	P	G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
☐	☐	☐	☐	☑	6	1.5					Gravity	1.2 - 2.4
☐	☑	☐	☐	☐	1.5	0.8			Medium Chips			
☑	☐	☐	☐	☐	0.8	0	4	40				
☐	☐	☐	☐	☐								

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / ~~55~~ (delete as applicable) GDA 94/~~AD66~~ (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY	
BORE NUMBER	
BORE USES	
GMA	ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249(Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type (CA SC SL OH)	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS — Casing Shoe Y / N: — Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material (C B S P G)	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY –
To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / ~~55~~ (delete as applicable) GDA 94/AD~~66~~ (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249(Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type CA SC SL OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS Casing Shoe Y / N: Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C B S P G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature Date: 05 / 06 / 2019

Name of Plant Operator

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

SRW COPY – To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type CA SC SL OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
SL ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
CA ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS Casing Shoe Y / N Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C B S P G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

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Managing Water. Serving Communities.

WATER ACT 1989

BORE COMPLETION REPORT

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LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL: Type	From (m)	To (m)	CASING: Inner diam (mm)	Outer diam (mm)	Material	SCREENS / SLOTS: Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	OFFICE USE: Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS: Casing Shoe Y / N: Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature Date: 05 / 06 / 2019

Name of Plant Operator

Print and Sign

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WATER ACT 1989

BORE COMPLETION REPORT

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LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type (CA SC SL OH)	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS: Casing Shoe Y / N: ☐ Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material (C B S P G)	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

WATER ACT 1989

BORE COMPLETION REPORT

Southern Rural Water
Managing Water. Serving Communities.

SRW COPY –
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LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner: Barwon Water

Site Address: 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced: 07 / 05 / 2019 Date Completed: 07 / 05 / 2019 Total Depth: 6 (m)

Was Bore Decommissioned? Y / N: N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL						CASING			SCREENS / SLOTS						OFFICE USE
Type CA	SC	SL	OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
☑	☐	☐	☐	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
☐	☐	☑	☐	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
☑	☐	☐	☐	2	+0.7	50	60	C18 uPVC							
☐	☐	☐	☐												
☐	☐	☐	☐												

WELL HEAD FITTINGS: Casing Shoe Y / N: ☐ Bullnose / Endcap Y / N: Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C	B	S	P	G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
☐	☐	☐	☐	☑	6	1.5					Gravity	1.2 - 2.4
☐	☑	☐	☐	☐	1.5	0.8			Medium Chips			
☑	☐	☐	☐	☐	0.8	0	4	40				
☐	☐	☐	☐	☐								

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name: Ben Oughton Driller's Licence No. 1049

Driller's Signature: Date: 05 / 06 / 2019

Name of Plant Operator:

Print and Sign

Southern Rural Water
Managing Water. Serving Communities.

WATER ACT 1989
BORE COMPLETION REPORT

SRW COPY –
To be sent to Southern Rural Water within 28 days of completion of bore.

LICENCE TO CONSTRUCT WORKS No. W L E 0 7 4 0 9 7

Report on site 1 ☑ 2 ☐ 3 ☐ 4 ☐ 5 ☐

GPS CO-ORDS: E 7 3 5 2 9 9 N 5 7 4 3 9 0 2

ZONE: 54 / 55 (delete as applicable) GDA 94/AGD66 (delete as applicable)

Drilled Bore ☑ Spearpoint ☐ Well or Shaft ☐ Dragline ☐

OFFICE USE ONLY
BORE NUMBER
BORE USES
GMA ZONE

Bore Owner Barwon Water

Site Address 25 POSSUM RIDGE ROAD, YEODENE, VIC 3249 (Boundary Creek - Big Swamp)

Date Commenced 07 / 05 / 2019 Date Completed 07 / 05 / 2019 Total Depth 6 (m)

Was Bore Decommissioned? Y / N N If Yes, State Method

1. DRILLING AND WATER INTERSECTION DETAILS

DRILLING TECHNIQUE				WATER INTERSECTIONS (while drilling, measurements taken from natural surface)									OFFICE USE
Method	From (m)	To (m)	Bit diam (mm)	From (m)	To (m)	Test Method	Static Level (m)	Est. yield l/sec	Draw down (m)	Casing at test (m)	Depth at test (m)	Ec at 25 C (µS/cm)	Lithology
Hollow Stem Auger	0	6	200										

2. CASINGS (CA) SCREENS (SC) SLOTS (SL) OPEN HOLE (OH)

GENERAL			CASING			SCREENS / SLOTS						OFFICE USE
Type CA SC SL OH	From (m)	To (m)	Inner diam (mm)	Outer diam (mm)	Material	Inner diam (mm)	Outer diam (mm)	Material	Aperture (mm)	Filter Y / N	Trade Name	Lithology
CA ☑	6	5	50	60	C18 uPVC	26	32	C18 uPVC	0.3	N		
SL ☑	5	2	26	32	C18 uPVC	50	60	C18 uPVC	0.4	N		
CA ☑	2	+0.7	50	60	C18 uPVC							

WELL HEAD FITTINGS Casing Shoe Y / N Bullnose / Endcap Y / N Y

3. CEMENT (C) BENTONITE (B) SEALS (S) PACKERS (P) GRAVEL (G)

Material C B S P G	From (m)	To (m)	Cement (bags)	Water (litres)	Seal / Packer type	Outer diam of seal (mm)	Artificial Gravel Packing Method of placement	Gravel size mesh passing (mm)
G ☑	6	1.5					Gravity	1.2 - 2.4
B ☑	1.5	0.8			Medium Chips			
C ☑	0.8	0	4	40				

4. FINAL BORE DEVELOPMENT

Method	Yield l/sec	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Final Static Level	Ec at 25 C (µS/cm)
Hand bailing	3 l/min		45		0.75	926

5. DRILLER'S PUMPING TEST

Method	Static Level (m)	Yield l/sec	Pumping Level (m)	Draw down (m)	Pumping Time (min)	Recovery Time (min)	Ec at 25 C (µS/cm)

6. IF NOT A DRILLED BORE

Type	Length (m)	Width (m)	Diam (m)	Lining Material	From (m)	To (m)

7. SAMPLES

Have material samples been taken? Yes ☑ No ☐ If Yes From 0 (m)
Have water samples been taken? Yes ☑ No ☐ To 6 (m)
Samples taken by: Bore Owner ☐ Driller ☐ Project Geologist ☑

8. DISINFECTION

Was the Bore Disinfected? Yes ☐ No ☑
If yes, state method of disinfection: Chlorine Washed ☐ Steam Cleaned ☐
Other, please specify:

9. DRILLER'S LOG

Material	From (m)	To (m)
Clay, silty, red/orange	0	0.1
Silt, sandy, black/brown	0.1	0.5
Sand, clayey with silt, orange/brown grey	0.5	2
Clay, sandy, grey	2	6
Clay, sand, Drk grey	4	6

Driller's Name Ben Oughton Driller's Licence No. 1049

Driller's Signature Date 05 / 06 / 2019

Name of Plant Operator

Print and Sign

Appendix E. Well construction Licence

COPY OF RECORD IN THE VICTORIAN WATER REGISTER

LICENCE TO CONSTRUCT WORKS

under Section 67 of the Water Act 1989

The information in this copy of record is as recorded at the time of printing. Current information should be obtained by a search of the register. The State of Victoria does not warrant the accuracy or completeness of this information and accepts no responsibility for any subsequent release, publication or reproduction of this information.

This licence does not remove the need to apply for any authorisation or permission necessary under any other Act of Parliament with respect to anything authorised by the works licence.

Water used under this licence is not fit for any use that may involve human consumption, directly or indirectly, without first being properly treated.

This licence is not to be interpreted as an endorsement of the design and/or construction of any works (including dams). The Authority does not accept any responsibility or liability for any suits or actions arising from injury, loss, damage or death to person or property which may arise from the maintenance, existence or use of the works.

Each person named as a licence holder is responsible for ensuring all the conditions of this licence are complied with.

This licence authorises its holders to construct the described works, subject to the conditions.

Licence Holder(s)

BARWON WATER of 44 LONSDALE STREET
SOUTH GEELONG VIC 3220

Licence Contact Details

BARWON WATER 44 LONSDALE STREET

SOUTH GEELONG VIC 3220

Licence Details

Expiry date	28 Mar 2020
Status	Active
Authority	Southern Rural Water
Name of waterway or aquifer	NA for construct/decommission
Water system	Unincorporated (GMU)

Summary of Licensed Works

The details in this section are a summary only. They are subject to the conditions specified in this licence.

Works ID	*Works type*	*Use of water*
WRK112869	Bore	Observation
WRK112870	Bore	Observation
WRK112871	Bore	Observation
WRK112872	Bore	Observation
WRK112873	Bore	Observation
WRK112874	Bore	Observation
WRK112875	Bore	Observation
WRK112876	Bore	Observation
WRK112877	Bore	Observation
WRK112878	Bore	Observation
WRK112879	Bore	Observation
WRK112880	Bore	Observation
WRK112881	Bore	Observation
WRK112882	Bore	Observation
WRK112883	Bore	Observation
WRK112884	Bore	Observation
WRK112885	Bore	Observation
WRK112886	Bore	Observation

Description of Licensed Works

WORKS ID WRK112869

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735802.078	5743839.275	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112870

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735842.659	5743828.521	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112871

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735740.577	5743898.978	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112872

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735830.248	5743889.117	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112873

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735725.600	5743876.597	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112874

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735761.978	5743931.093	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112875

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735618.190	5743916.251	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112876

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735634.810	5743953.576	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112877

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735432.908	5743914.204	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112878

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735427.588	5743953.473	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112879

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735426.652	5744001.564	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112880

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735372.904	5743845.708	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112881

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735333.053	5743873.448	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112882

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735302.808	5743891.766	Zone 54

Land description
Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address
25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112883

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735253.750	5743914.896	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112884

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735303.069	5743804.663	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112885

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735752.298	5743915.492	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Description of Licensed Works

WORKS ID WRK112886

Works type	Bore
Works subtype	Drilled bore
Proposed maximum depth	60.000 metres

Works location

Easting	*Northing*	*Zone MGA*
735643.222	5743986.250	Zone 54

Land description

Volume 4177 Folio 273
CA 115A Parish of Yeo

Property address

25 POSSUM RIDGE ROAD, YEODENE, VIC 3249

Related Instruments

Related entitlements	Nil
Related water-use entities	Nil

Application History

Reference	*Type*	*Status*	*Lodged date*	*Approved date*	*Recorded date*
WLI610021	Issue	Approved	28 Mar 2019	28 Mar 2019	

Conditions

Licence WLE074097 is subject to the following conditions:

Siting and construction

1 The bore(s) must be drilled at the location specified in the application approved by the Authority.

2 If after drilling the bore is considered unsatisfactory a replacement bore may be drilled on the land specified in the licence.

Preventing pollution

3 All earthworks must be carried out, and all drilling fluids and waters produced during construction and development must be disposed of, in ways that avoid contaminating native vegetation, waterways, aquifers, the riparian environment, the riverine environment or other people’s property.

4 Construction must stop immediately if the Authority reasonably believes that fuel, lubricant, drilling fluid, soil or water produced during construction and development is at risk of being spilled into native vegetation, waterways, aquifers, the riparian environment, the riverine environment or other people’s property.

5 The licence holder must construct and maintain bund walls, in accordance with the timeframe, specifications, guidelines or standards prescribed by the Authority, to prevent fuel, lubricant, drilling fluid, soil or water produced during construction and development from being spilled into native vegetation, waterways, aquifers, the riparian environment, the riverine environment or other people’s property.

Construction standards

6 The bore(s) must be constructed, and where relevant decommissioned, in accordance with the Minimum Construction Requirements for Water Bores in Australia, Edition 3 or its successor.

Drilling licence and supervision requirements

7 The bore(s) must be constructed by, or under the direct supervision of, a driller licensed under the Water Act 1989 and endorsed as a Class 1, 2, or 3 driller, with appropriate endorsements.

8 If artesian pressure is expected or encountered, then a driller licensed under the Water Act 1989, and endorsed as a class 3 driller, must install casing in the bore(s) to a suitable depth, and in a suitable manner, to prevent its outbreak. A suitable valve must also be fitted to the bore.

Bore completion report

9 A Bore Completion Report must be submitted to the Authority within 28 working days of the bore(s) being completed.

Protecting water resources

10 No more than 18 bore(s) may be brought to final development under this licence.

11 At the completion of drilling and before the drilling rig leaves the site, all but 18 bore(s) must be decommissioned so as to eliminate physical hazards, conserve aquifer yield, prevent groundwater contamination and prevent the intermingling of desirable and undesirable waters.

12 The bore(s) must be located at least 30 metres from any authority's channel, reserve or easement unless authorised by the Authority.

Protecting water quality

13 Drilling must not exceed the maximum depth.

14 The bore(s) must be constructed so as to prevent aquifer contamination caused by vertical flow outside the casing.

15 If two or more aquifers are encountered, the bore(s) must be constructed to ensure that an impervious seal is made and maintained between each aquifer to prevent aquifer connection through vertical flow outside the casing; under no circumstances are two or more aquifers to be screened within the one bore or in any other manner to allow connection between them.

16 Boreheads must be constructed, to ensure that no flood water, surface runoff or potential

subsurface contaminated soakage can enter the bore or bore annulus.

Protecting other water users

17 The diameter of the drill casing must not exceed 130 millimetres.

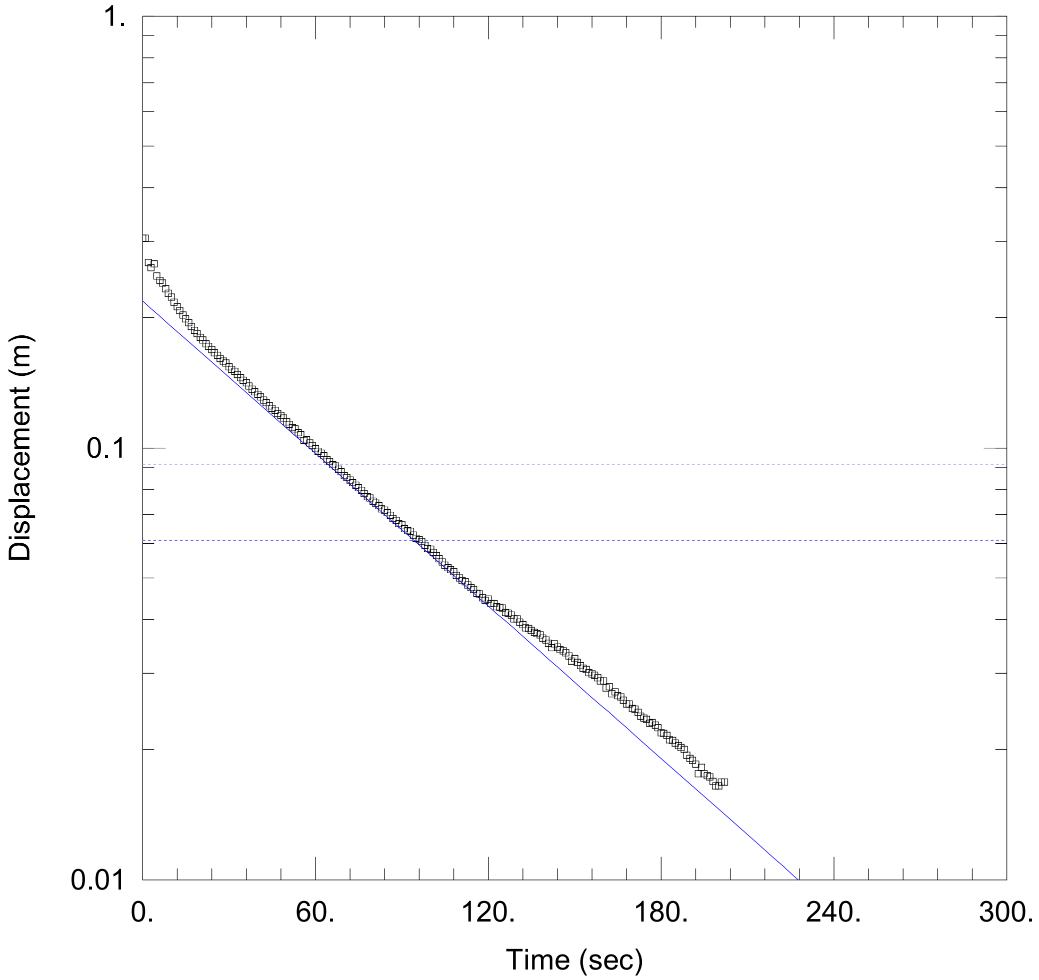
18 The bore(s) must be constructed so that water levels in the bore(s) can be measured by an airline, a piezometer or a method approved in writing by the Authority.

Fees and charges

19 The licence holder must, when requested by the Authority, pay all fees, costs and other charges under the Water Act 1989 in respect of this licence.

END OF COPY OF RECORD

Appendix F. Aquifer permeability test results



BH01 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH01.aqt
Date: 06/18/19 Time: 17:03:10

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH01
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

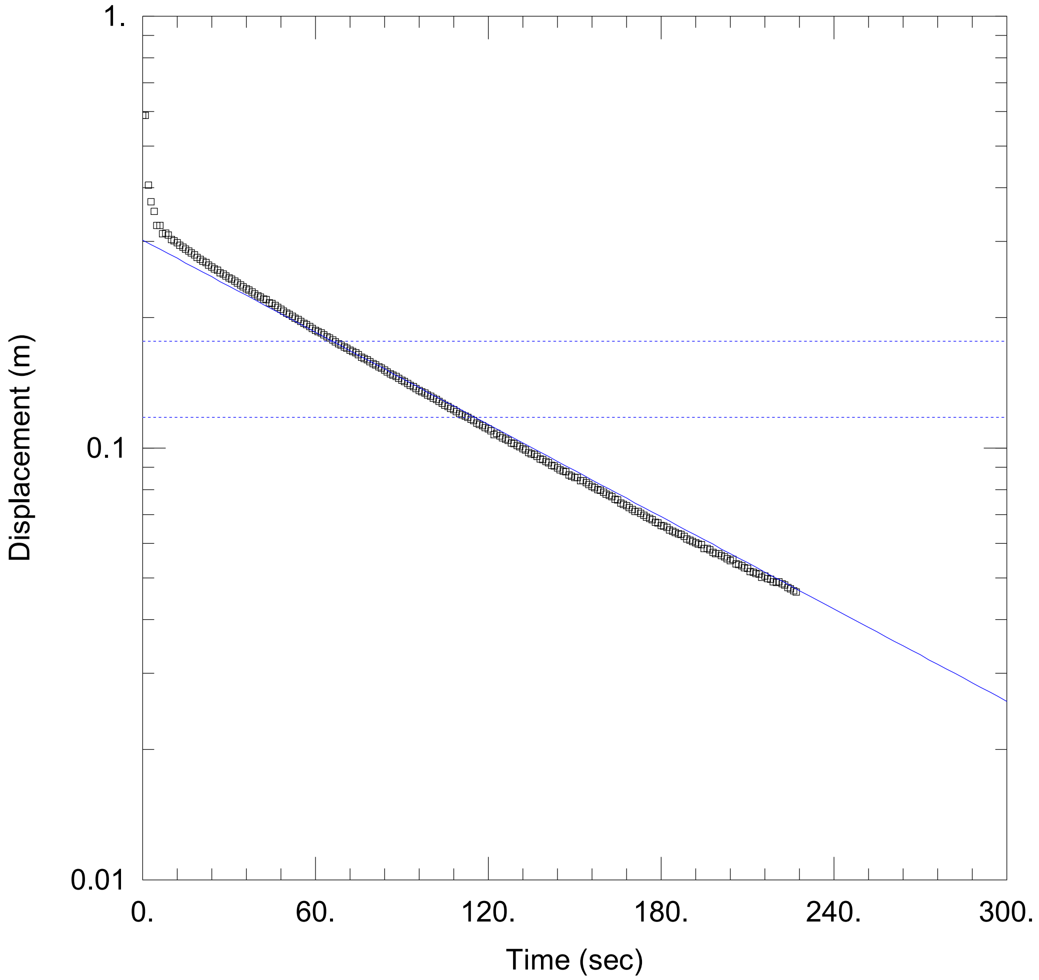
WELL DATA (BH01)

Initial Displacement: 0.3059 m
Static Water Column Height: 5.83 m
Total Well Penetration Depth: 5.83 m
Screen Length: 4.5 m
Casing Radius: 0.025 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.2676 m/day
y0 = 0.2187 m



BH01 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH01.aqt
Date: 06/18/19 Time: 17:07:11

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH01
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

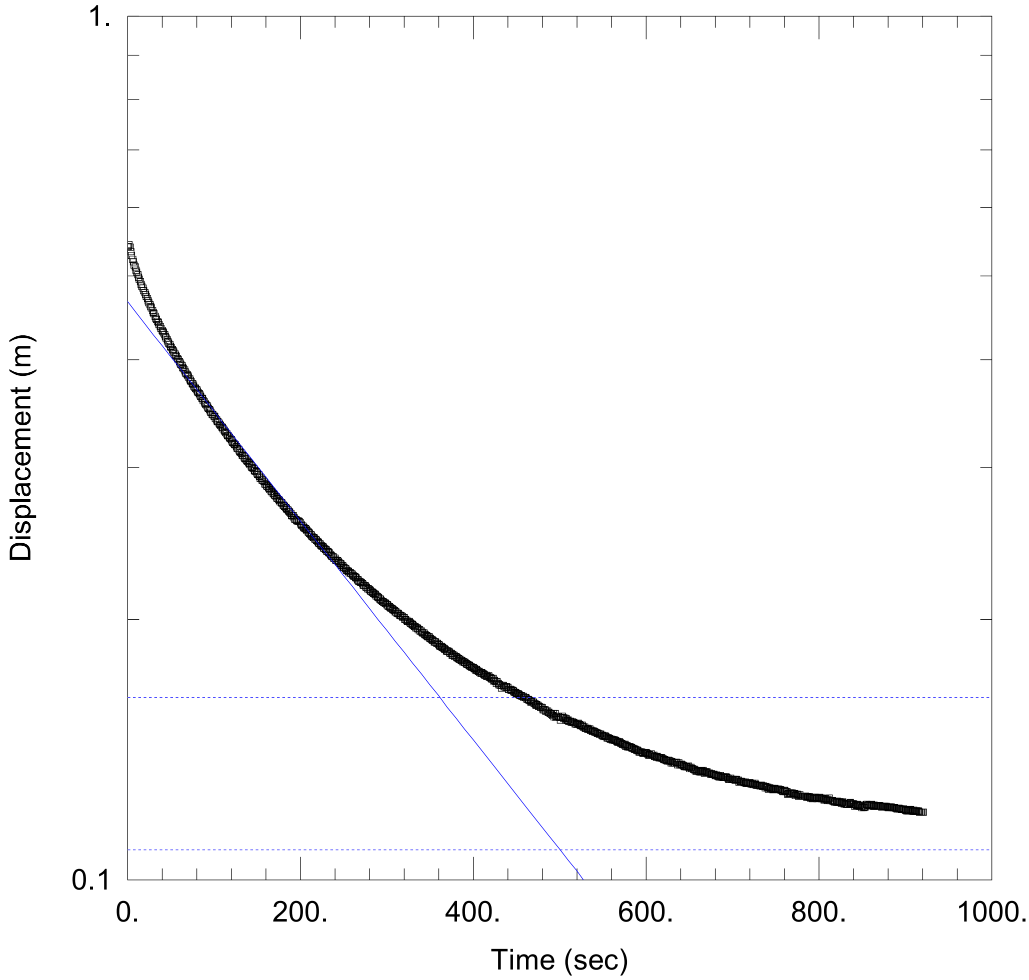
WELL DATA (BH01)

Initial Displacement: 0.5881 m
Total Well Penetration Depth: 5.83 m
Casing Radius: 0.025 m
Static Water Column Height: 5.83 m
Screen Length: 4.5 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.1619 m/day
y0 = 0.3029 m



BH05 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH05.aqt
Date: 06/18/19 Time: 17:29:25

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH05
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

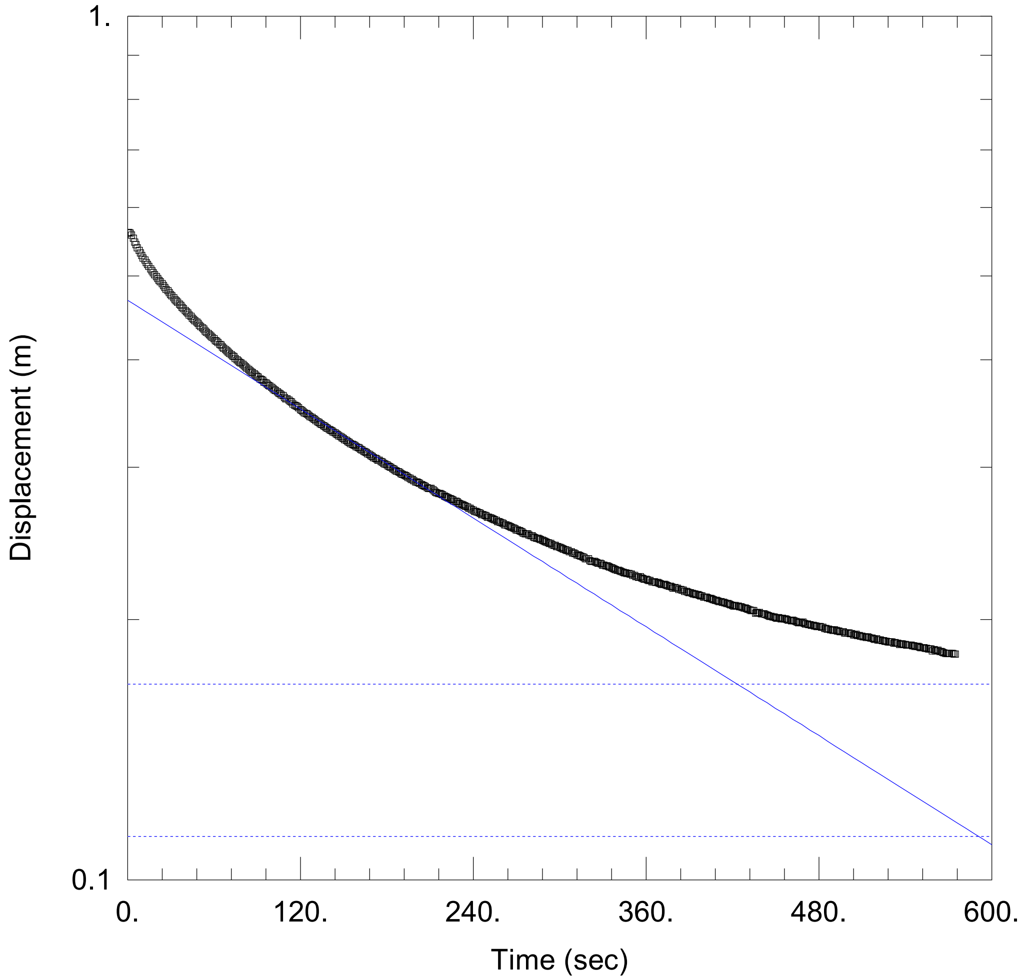
WELL DATA (New Well)

Initial Displacement: 0.5411 m
Total Well Penetration Depth: 5.31 m
Casing Radius: 0.025 m
Static Water Column Height: 5.314 m
Screen Length: 4.5 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.05668 m/day y0 = 0.4667 m



BH05 RH2

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Date: 06/18/19 Time: 17:31:13

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH05
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

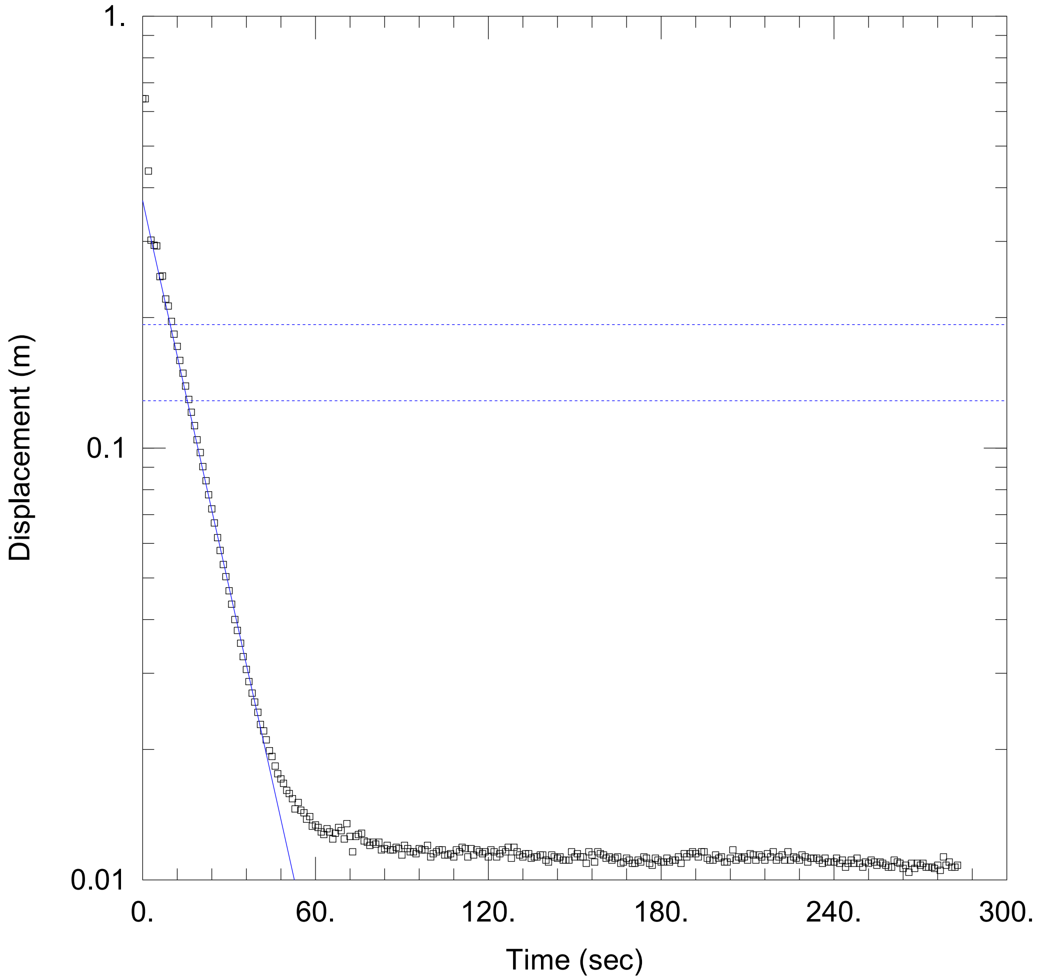
WELL DATA (New Well)

Initial Displacement: 0.5613 m Static Water Column Height: 5.314 m
Total Well Penetration Depth: 5.31 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.04697 m/day y0 = 0.4688 m



BH06 FH1

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Date: 06/19/19 Time: 06:56:53

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH06
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

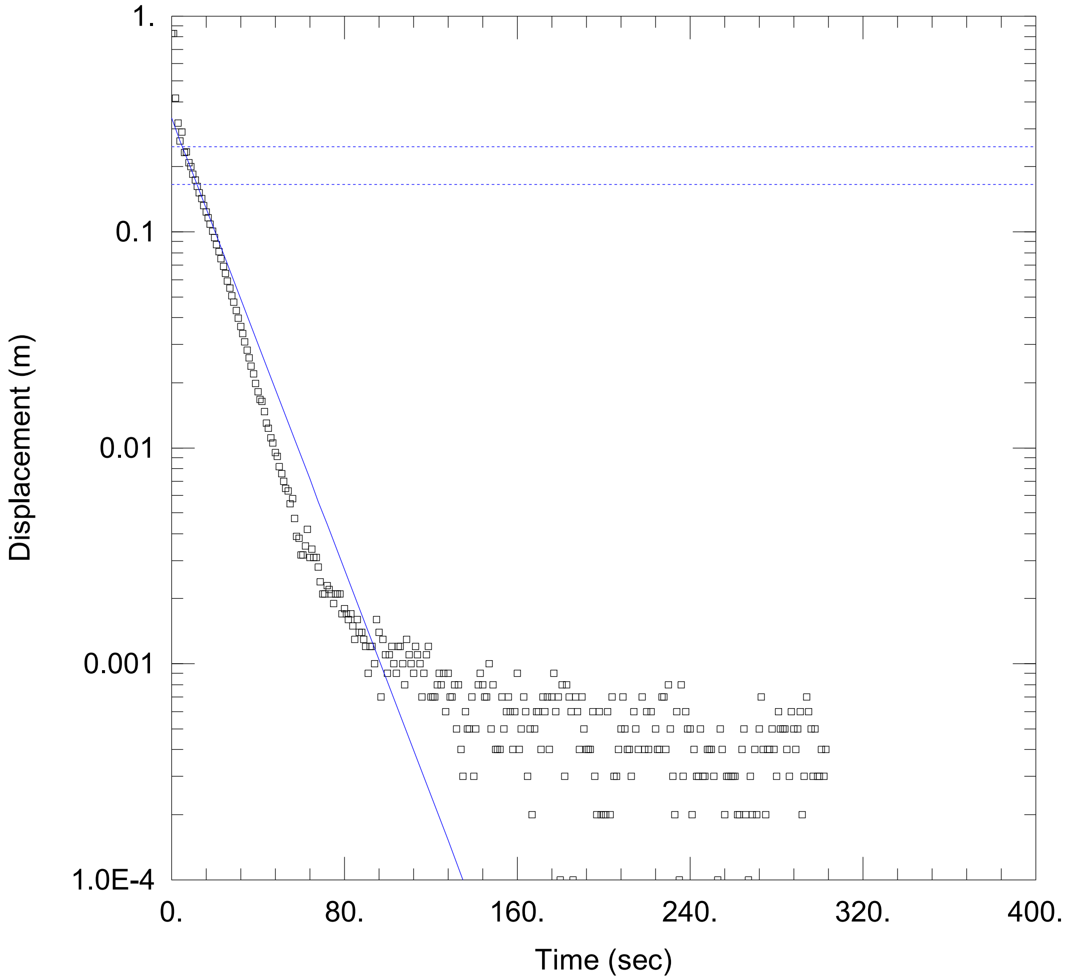
WELL DATA (New Well)

Initial Displacement: 0.6427 m Static Water Column Height: 5.039 m
Total Well Penetration Depth: 5.04 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.347 m/day y0 = 0.3736 m



BH06 FH2

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Date: 06/19/19 Time: 06:59:52

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH06
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

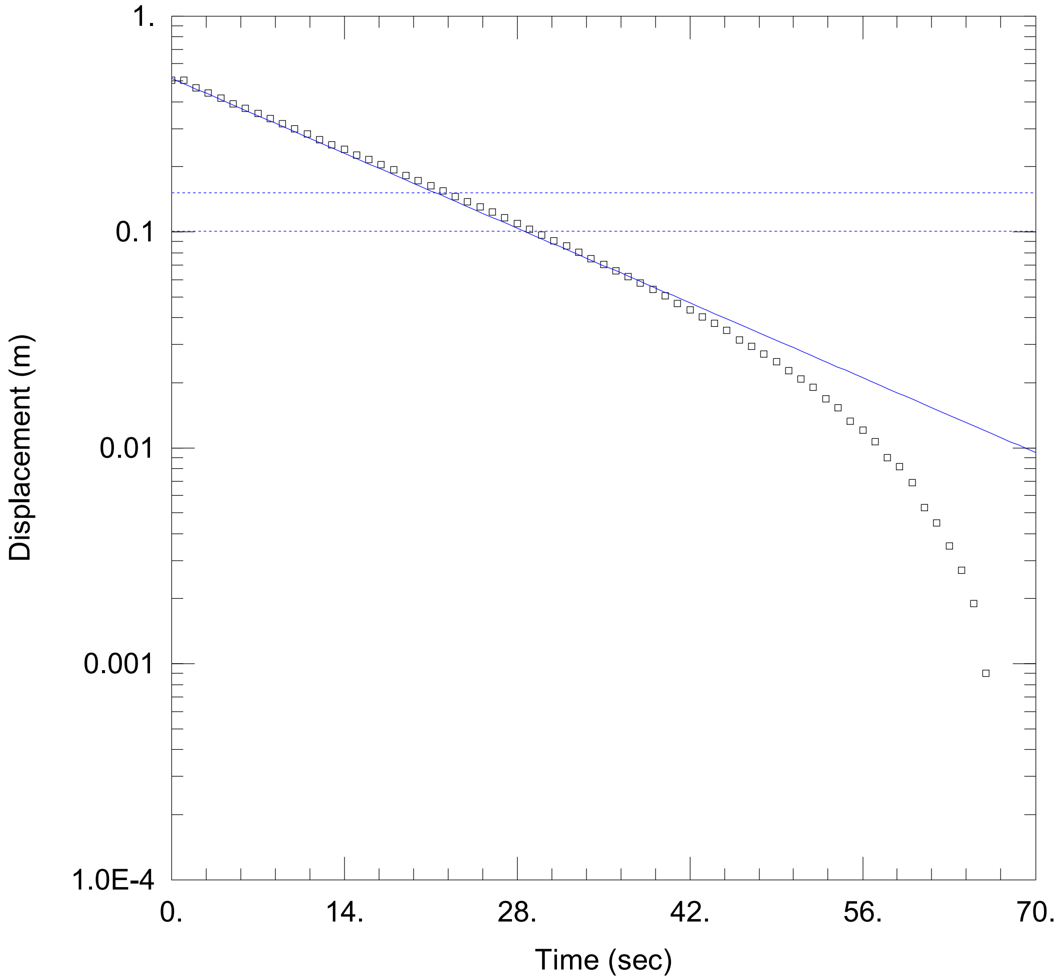
WELL DATA (New Well)

Initial Displacement: 0.8276 m Static Water Column Height: 5.039 m
Total Well Penetration Depth: 5.04 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.18 m/day y0 = 0.3361 m



BH06 RH1

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Date: 06/19/19 Time: 06:58:36

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH06
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

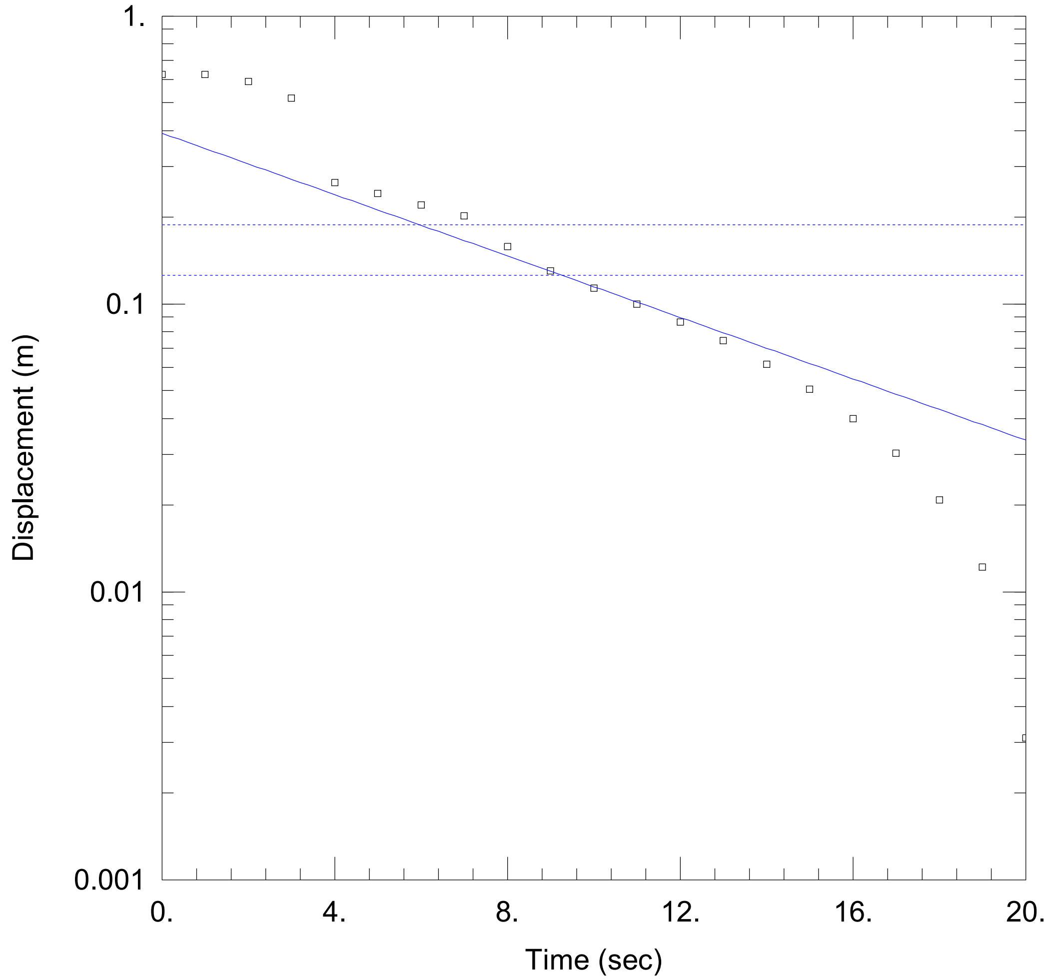
WELL DATA (New Well)

Initial Displacement: 0.5046 m Static Water Column Height: 5.039 m
Total Well Penetration Depth: 5.04 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.119 m/day y0 = 0.5139 m



BH06 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH06.aqt
Date: 06/19/19 Time: 07:01:56

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH06
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

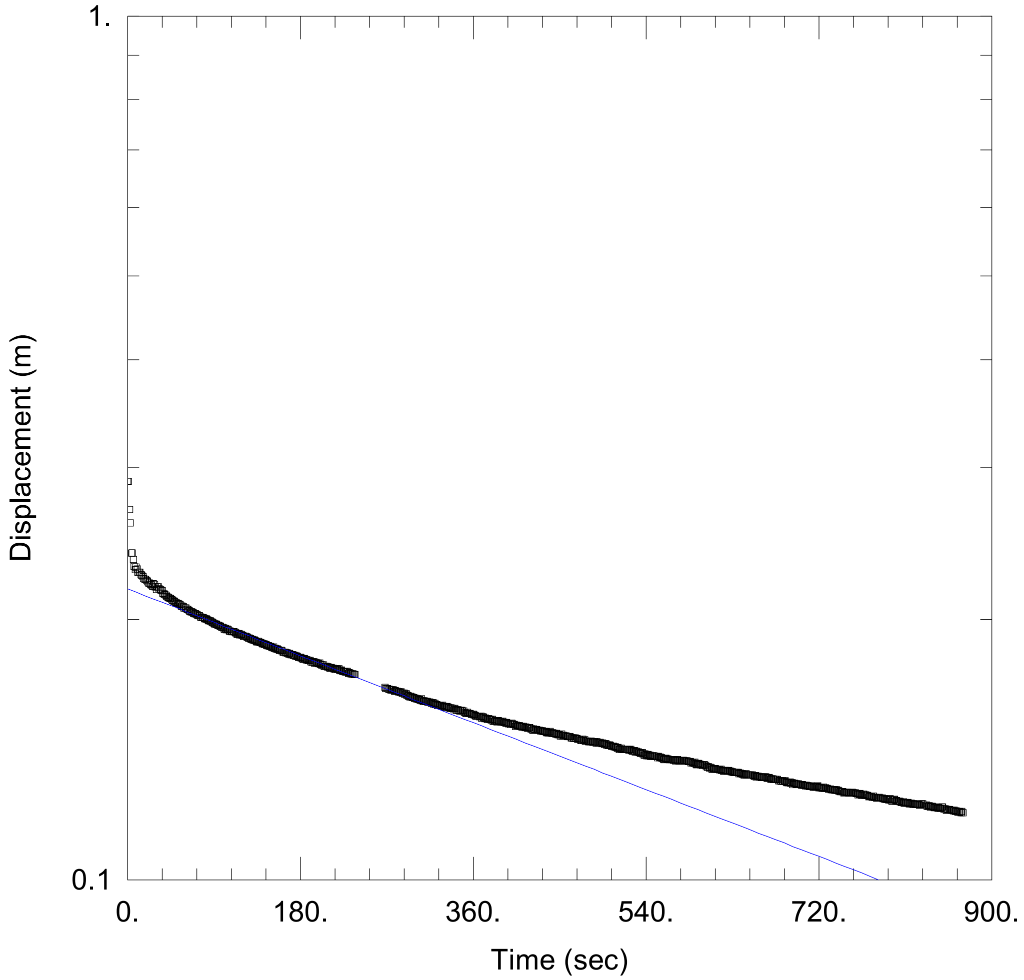
WELL DATA (New Well)

Initial Displacement: 0.6277 m Static Water Column Height: 5.039 m
Total Well Penetration Depth: 5.04 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 2.407 m/day y0 = 0.3914 m



BH07 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH07.aqt
Date: 06/19/19 Time: 07:03:14

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH07
Test Date: 11/06/2019

AQUIFER DATA

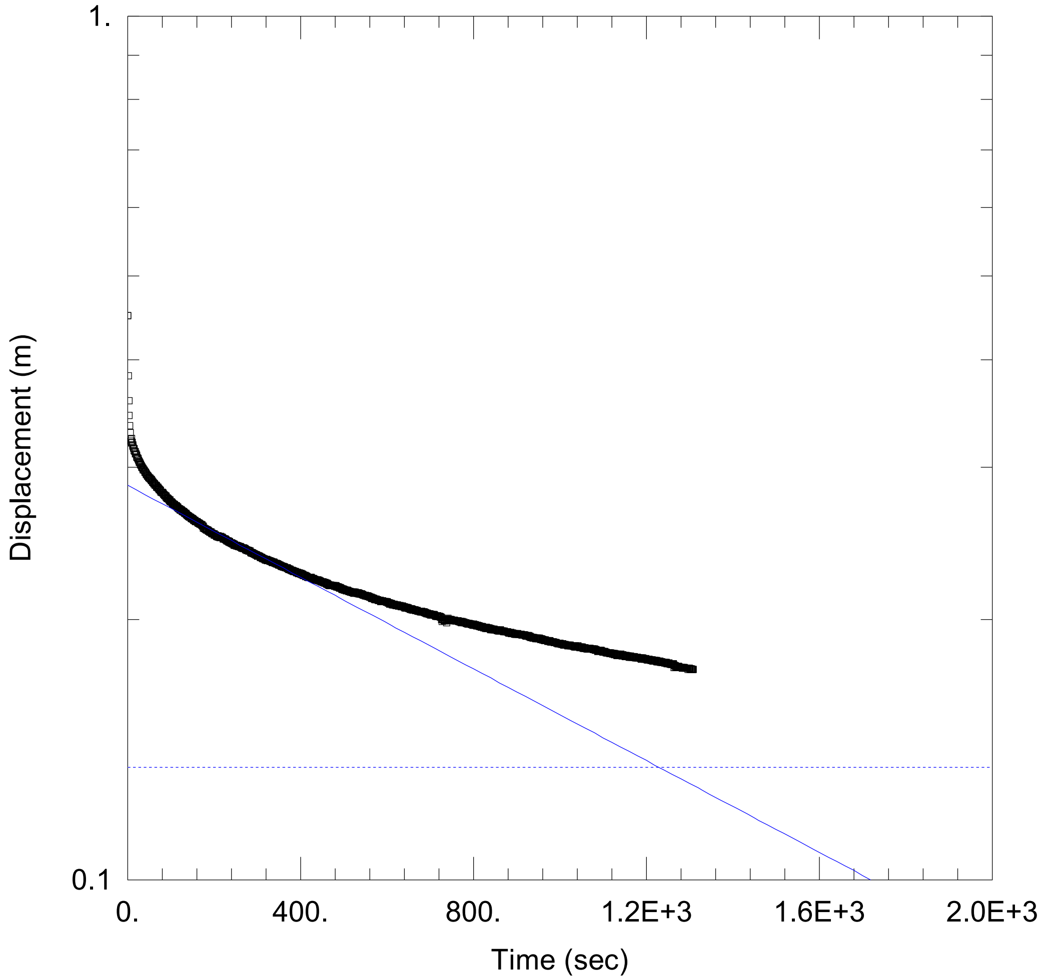
Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

WELL DATA (New Well)

Initial Displacement: 0.2889 m Static Water Column Height: 5.955 m
Total Well Penetration Depth: 5.96 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.01965 m/day y0 = 0.2171 m



BH07 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH07.aqt
Date: 06/19/19 Time: 07:04:44

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH07
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

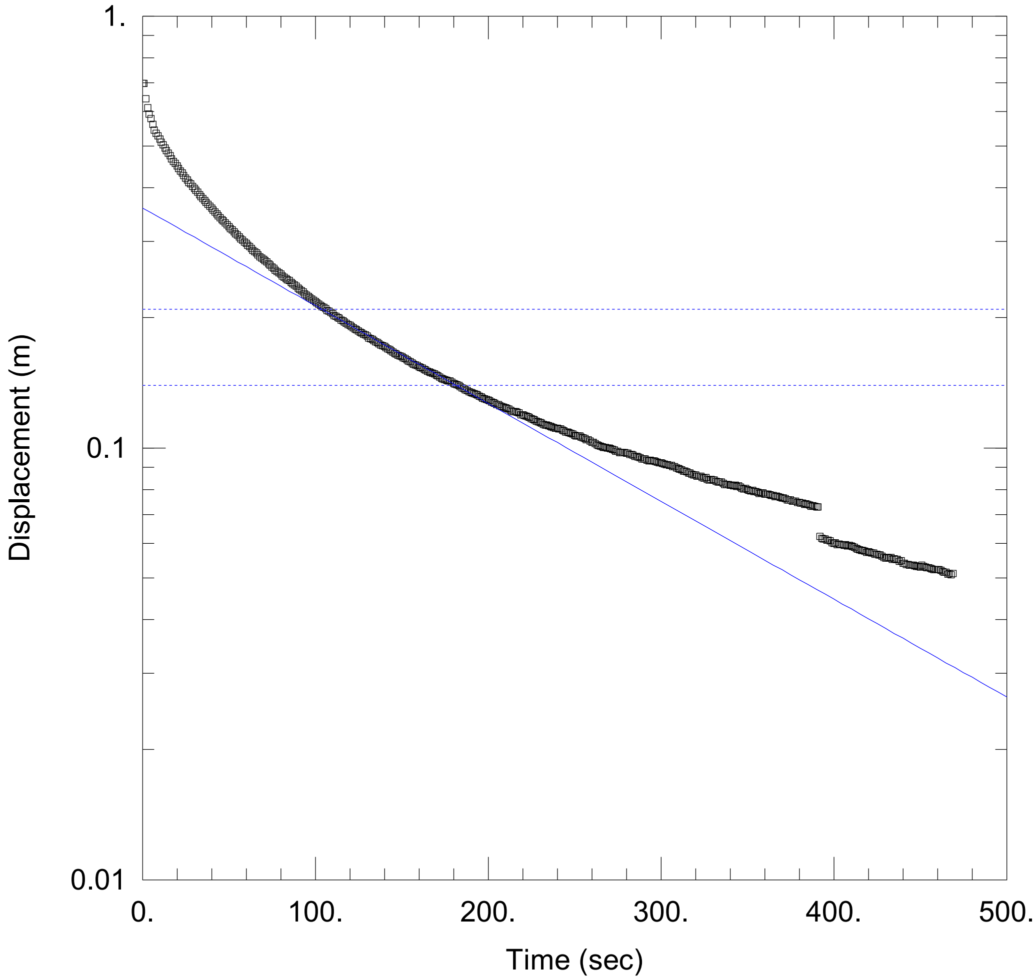
WELL DATA (New Well)

Initial Displacement: 0.4498 m Static Water Column Height: 5.955 m
Total Well Penetration Depth: 5.96 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.01213 m/day y0 = 0.286 m



BH08 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH08.aqt
Date: 06/19/19 Time: 07:06:13

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH0
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

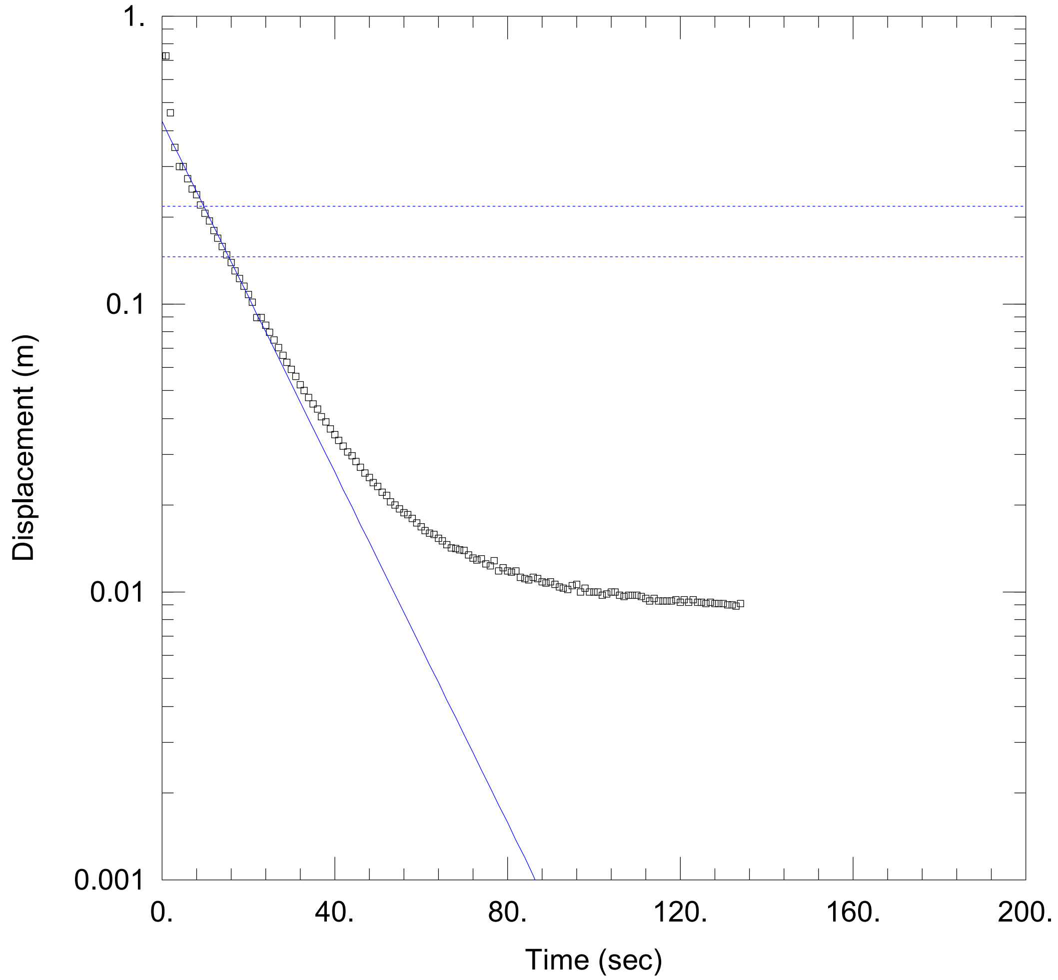
WELL DATA (New Well)

Initial Displacement: 0.6984 m
Total Well Penetration Depth: 5.04 m
Casing Radius: 0.025 m
Static Water Column Height: 5.04 m
Screen Length: 4.4 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.1023 m/day
y0 = 0.3593 m



BH09 FH1	
Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH09.aqt	
Date: 06/19/19	Time: 07:07:53

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH09
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

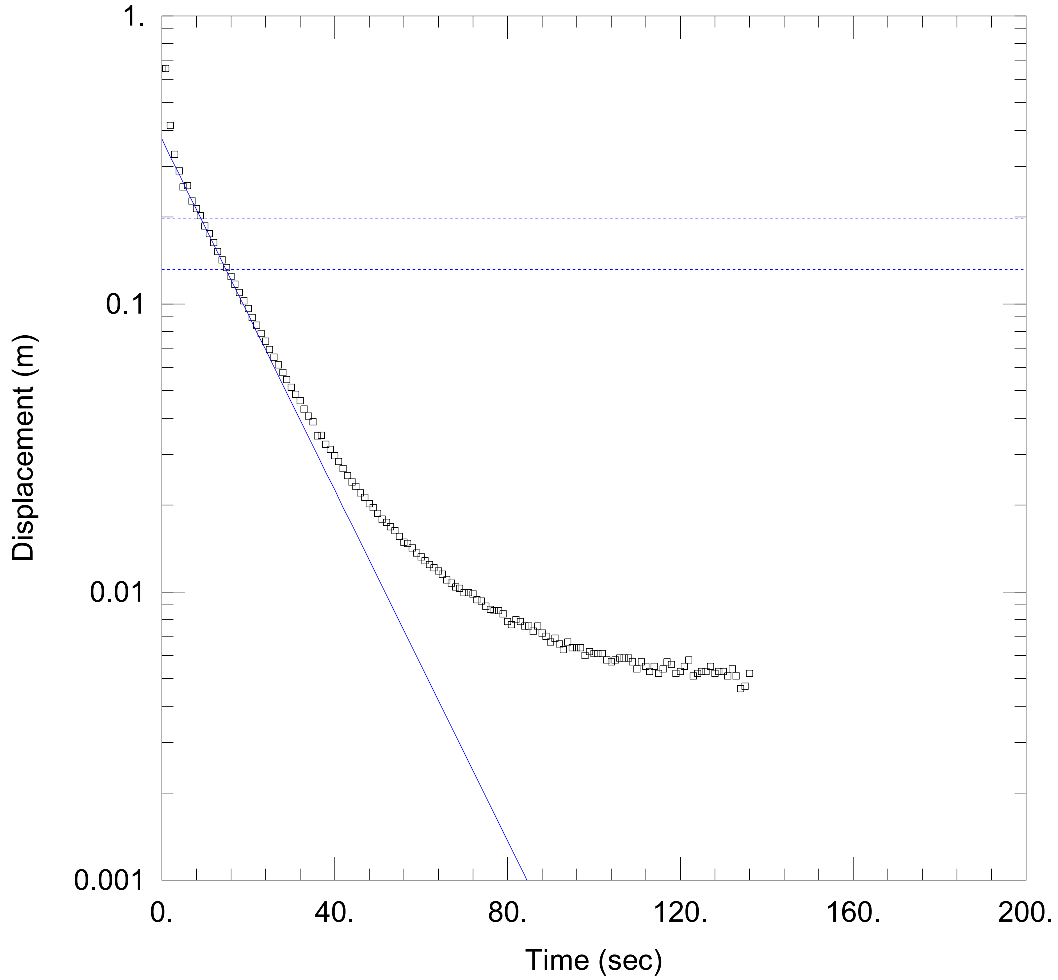
WELL DATA (New Well)

Initial Displacement: 0.7268 m
Total Well Penetration Depth: 4.78 m
Casing Radius: 0.025 m
Static Water Column Height: 4.78 m
Screen Length: 4.5 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 1.335 m/day
y0 = 0.4304 m



BH09 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH09.aqt
Date: 06/19/19 Time: 07:11:18

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH09
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

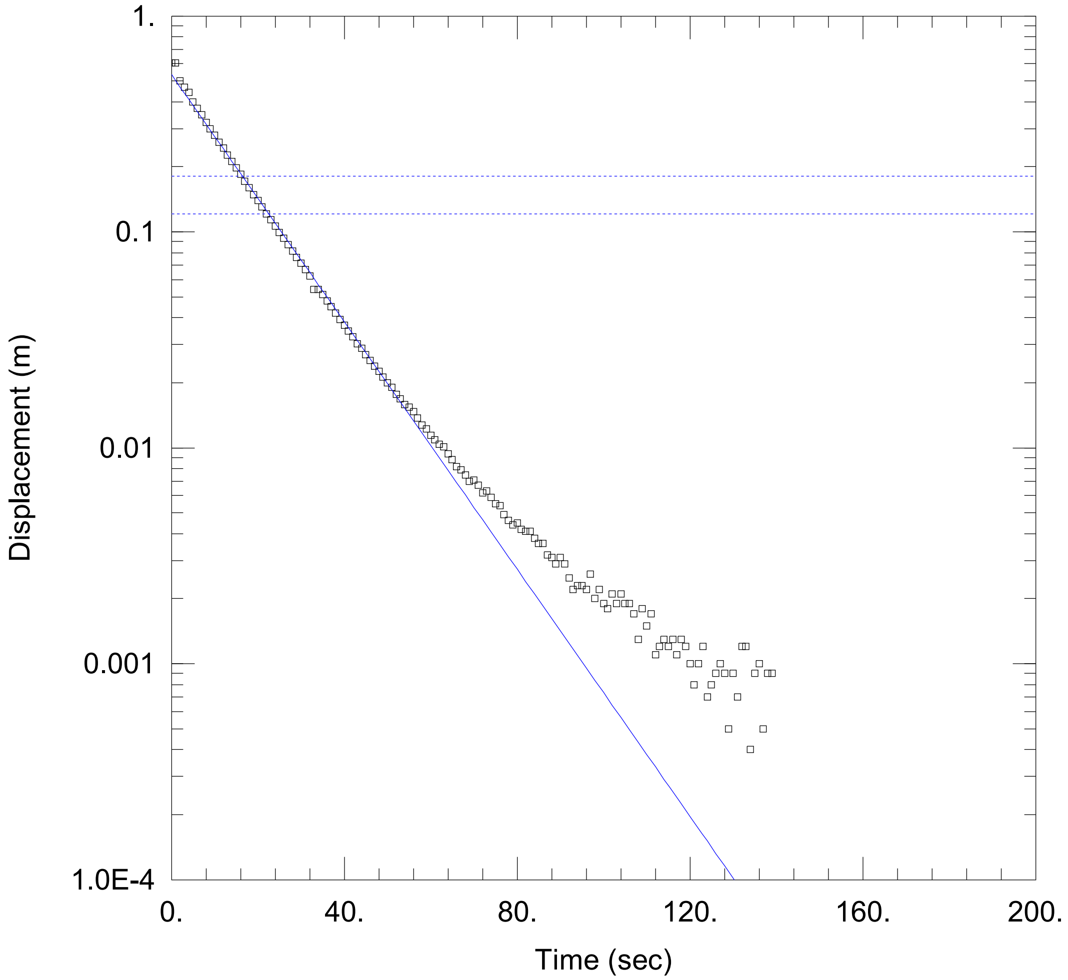
WELL DATA (New Well)

Initial Displacement: 0.6571 m
Total Well Penetration Depth: 4.78 m
Casing Radius: 0.025 m
Static Water Column Height: 4.78 m
Screen Length: 4.5 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.335 m/day y0 = 0.3725 m



BH09 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH09.aqt
Date: 06/19/19 Time: 07:09:05

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH09
Test Date: 13/06/2019

AQUIFER DATA

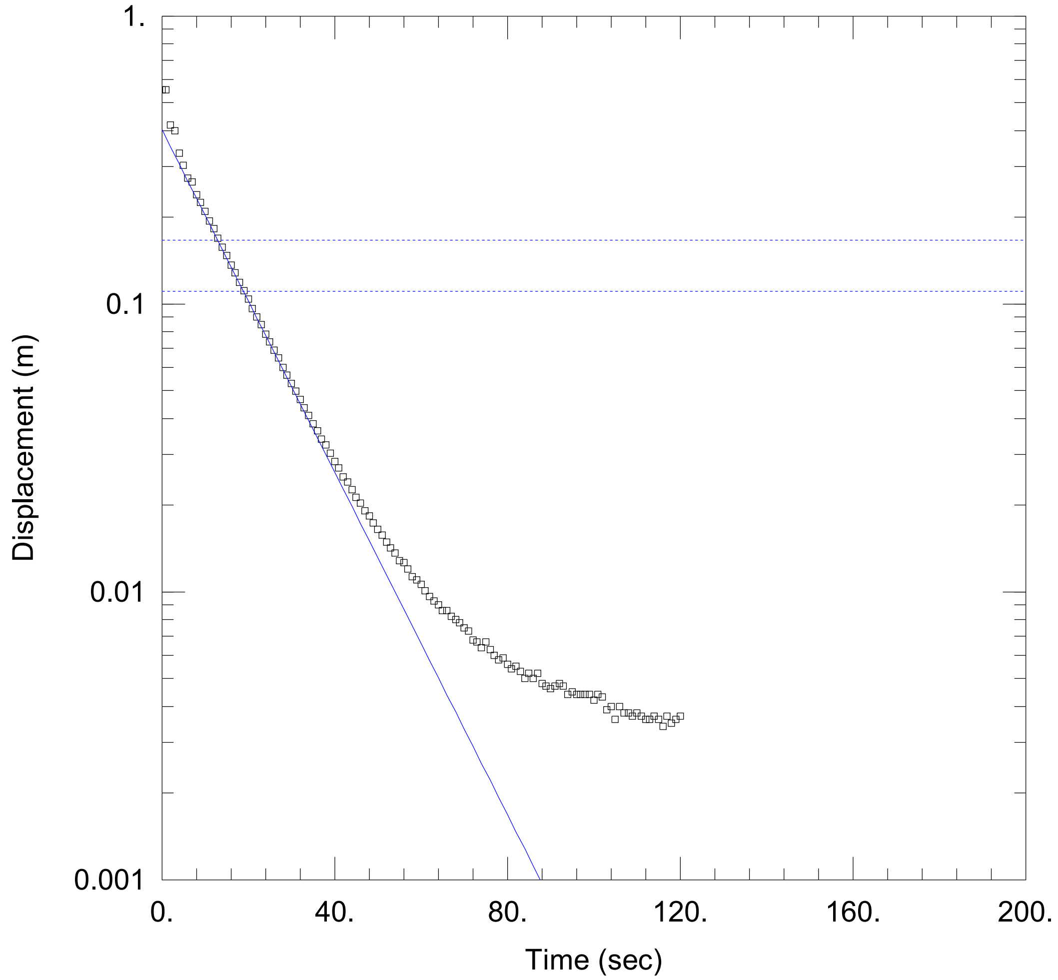
Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

WELL DATA (New Well)

Initial Displacement: 0.6048 m Static Water Column Height: 4.78 m
Total Well Penetration Depth: 4.78 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 1.255 m/day y0 = 0.5345 m



BH09 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH09.aqt
Date: 06/19/19 Time: 07:13:14

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH09
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

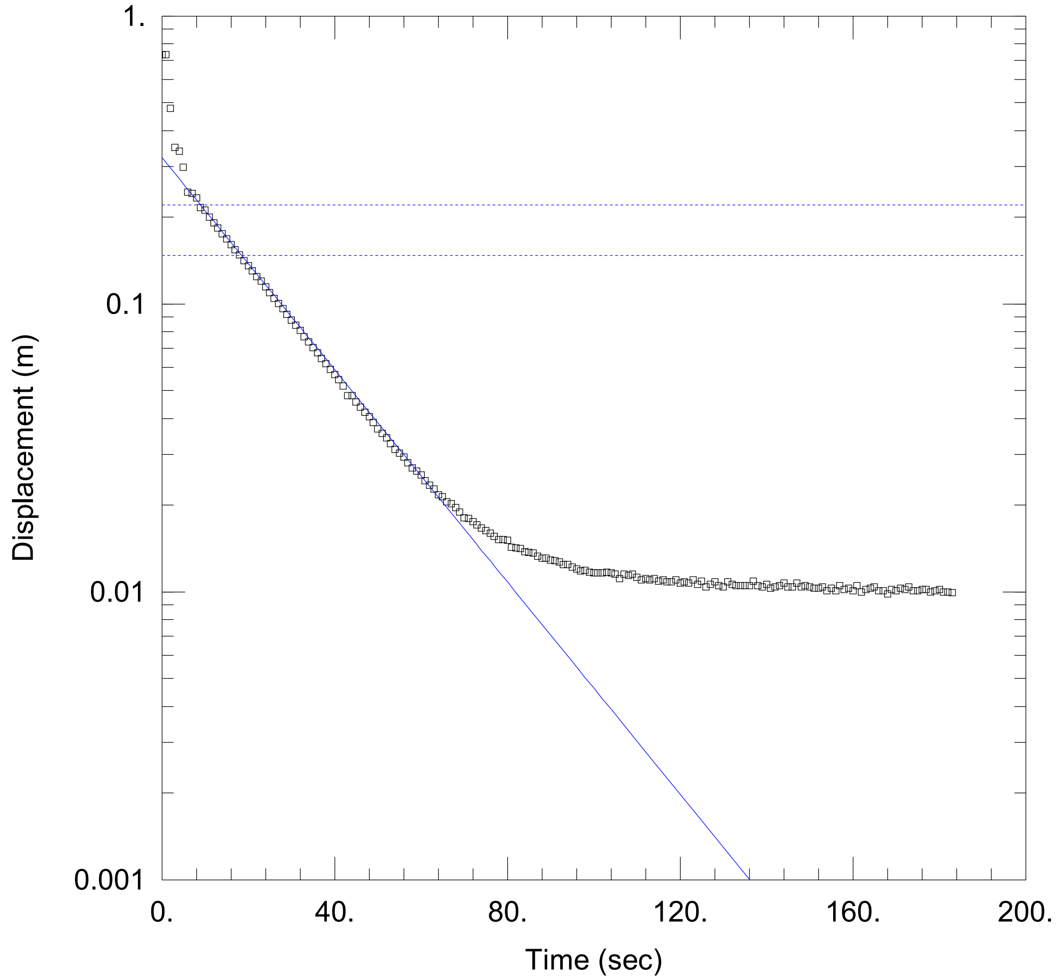
WELL DATA (New Well)

Initial Displacement: 0.5537 m Static Water Column Height: 4.78 m
Total Well Penetration Depth: 4.78 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.304 m/day y0 = 0.4023 m



BH10 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH10.aqt
Date: 06/19/19 Time: 07:16:08

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH10
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

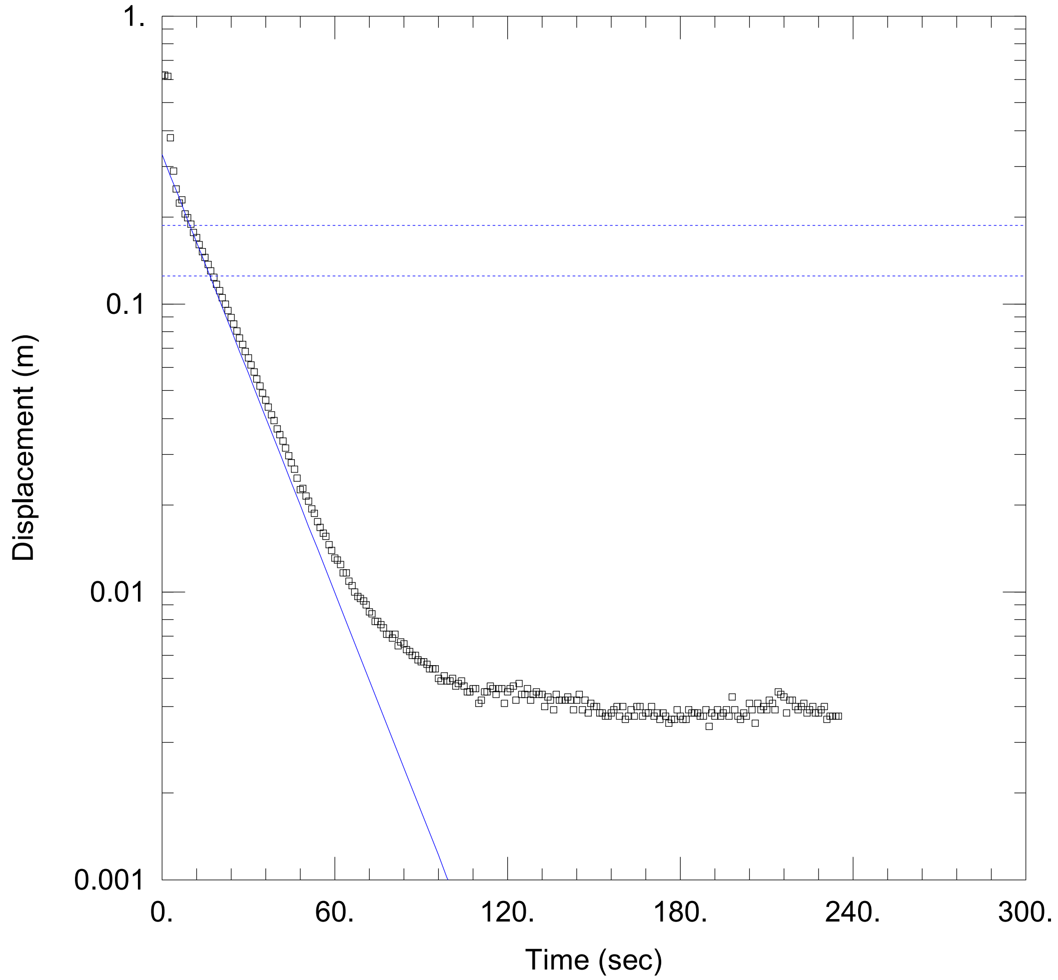
WELL DATA (New Well)

Initial Displacement: 0.7346 m Static Water Column Height: 4.97 m
Total Well Penetration Depth: 4.97 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.8306 m/day y0 = 0.3223 m



BH10 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH10.aqt
Date: 06/19/19 Time: 07:19:09

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH10
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

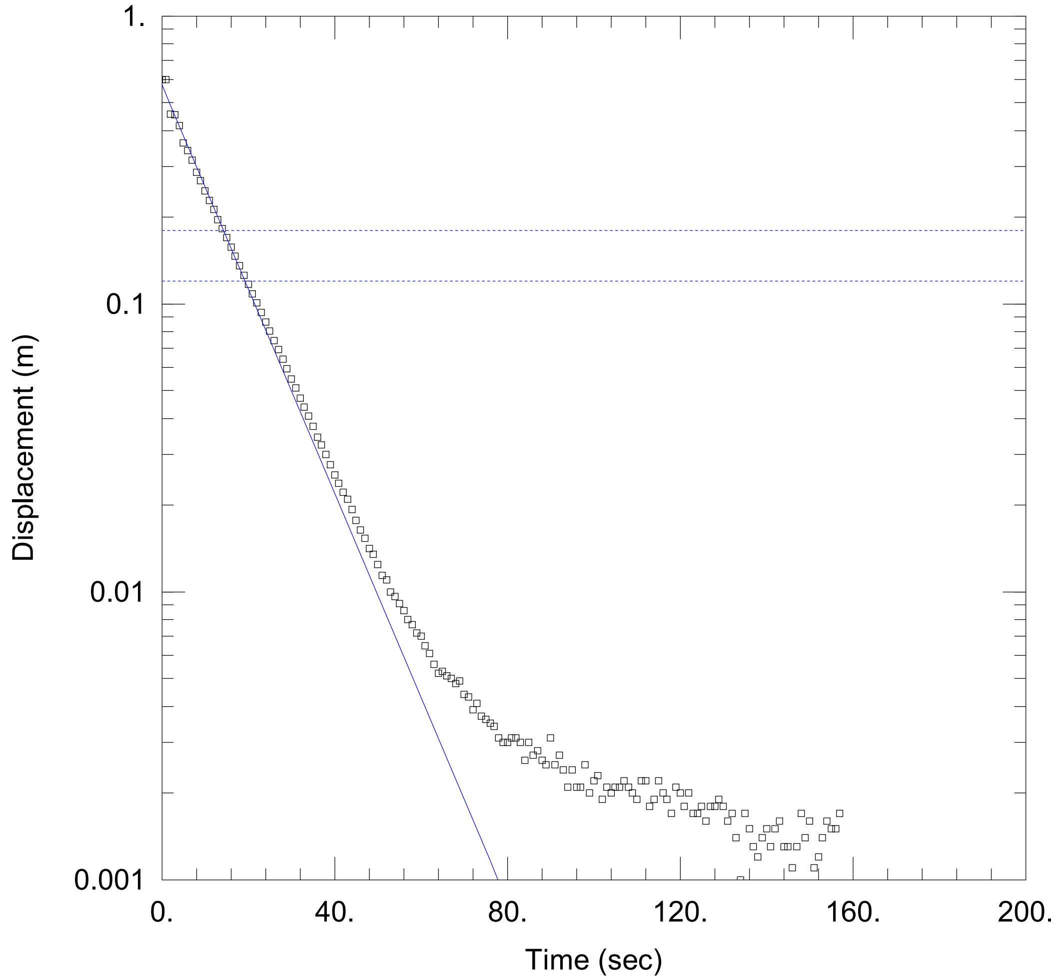
WELL DATA (New Well)

Initial Displacement: 0.6232 m
Total Well Penetration Depth: 4.97 m
Casing Radius: 0.025 m
Static Water Column Height: 4.97 m
Screen Length: 4.4 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 1.143 m/day
y0 = 0.3306 m



BH10 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH10.aqt
Date: 06/19/19 Time: 07:17:30

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH10
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

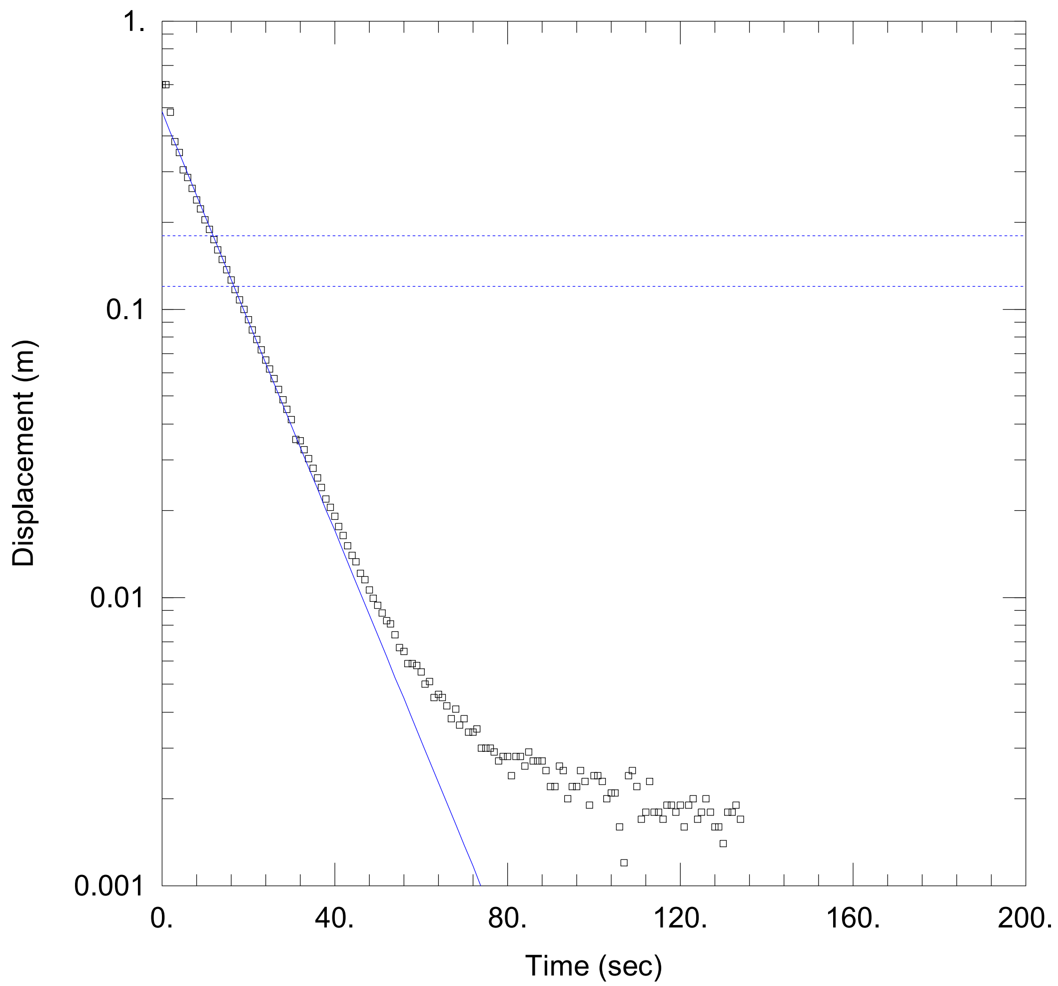
WELL DATA (New Well)

Initial Displacement: 0.5999 m
Total Well Penetration Depth: 4.97 m
Casing Radius: 0.025 m
Static Water Column Height: 4.97 m
Screen Length: 4.4 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 1.598 m/day
y0 = 0.5761 m



BH10 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH10.aqt
Date: 06/19/19 Time: 07:20:17

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH10
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

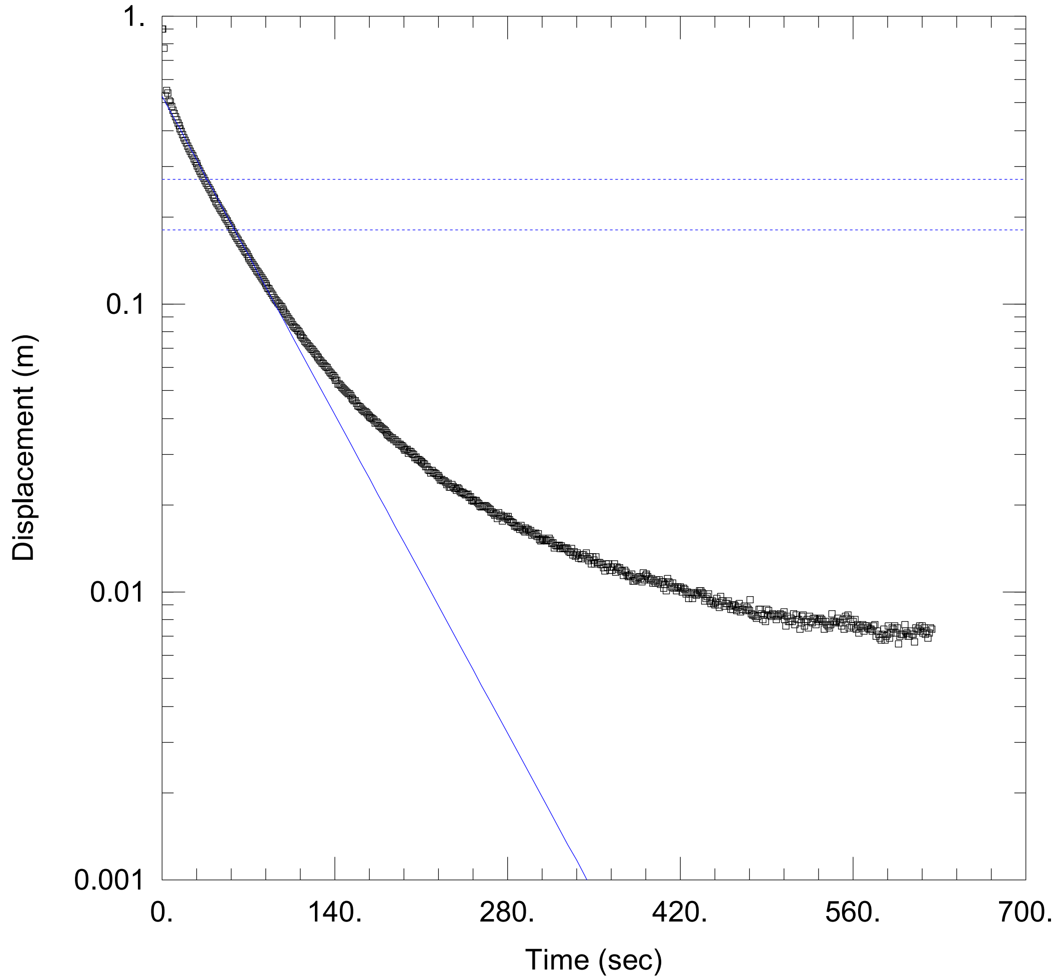
WELL DATA (New Well)

Initial Displacement: 0.6002 m Static Water Column Height: 4.97 m
Total Well Penetration Depth: 4.97 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.639 m/day y0 = 0.4853 m



BH11 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH11.aqt
Date: 06/19/19 Time: 07:23:20

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH11
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

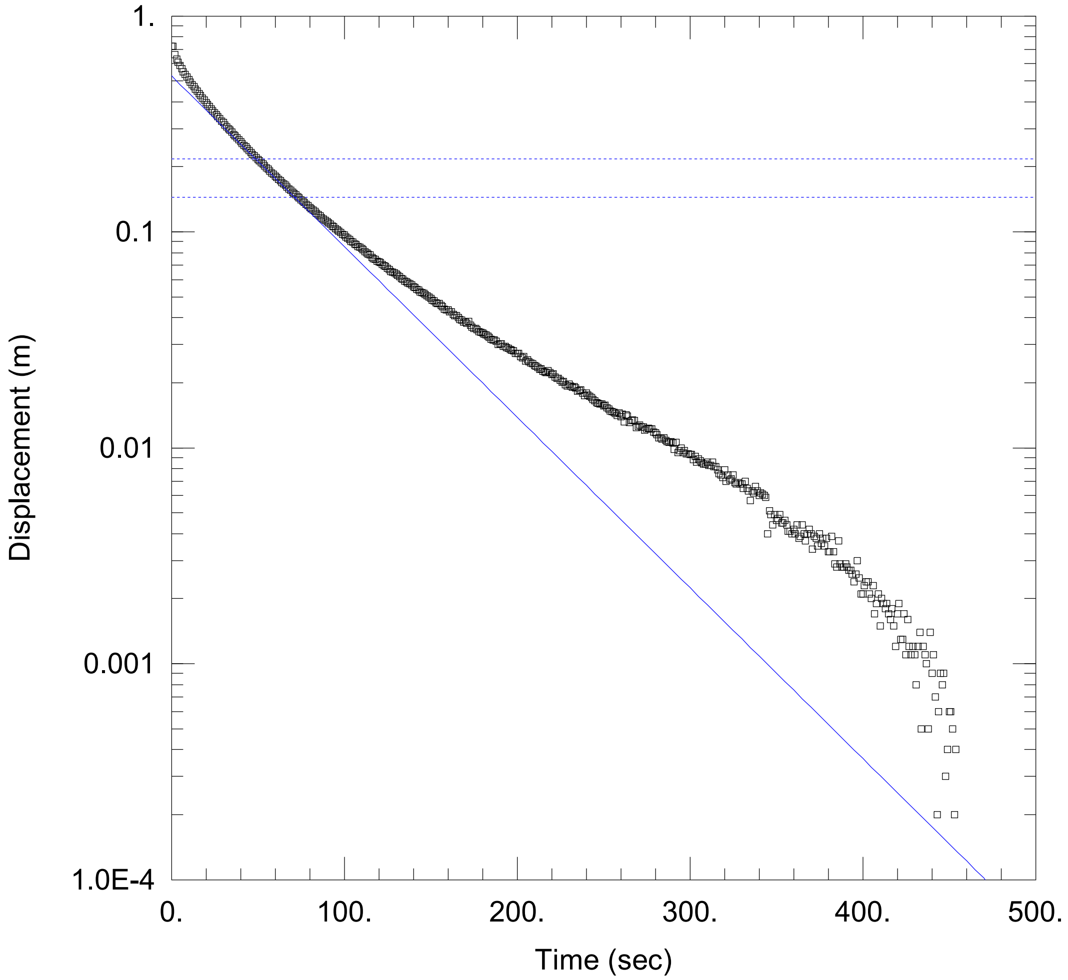
WELL DATA (New Well)

Initial Displacement: 0.9027 m Static Water Column Height: 4.83 m
Total Well Penetration Depth: 4.83 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.3473 m/day y0 = 0.5275 m



BH11 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH11.aqt
Date: 06/19/19 Time: 07:24:50

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH11
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

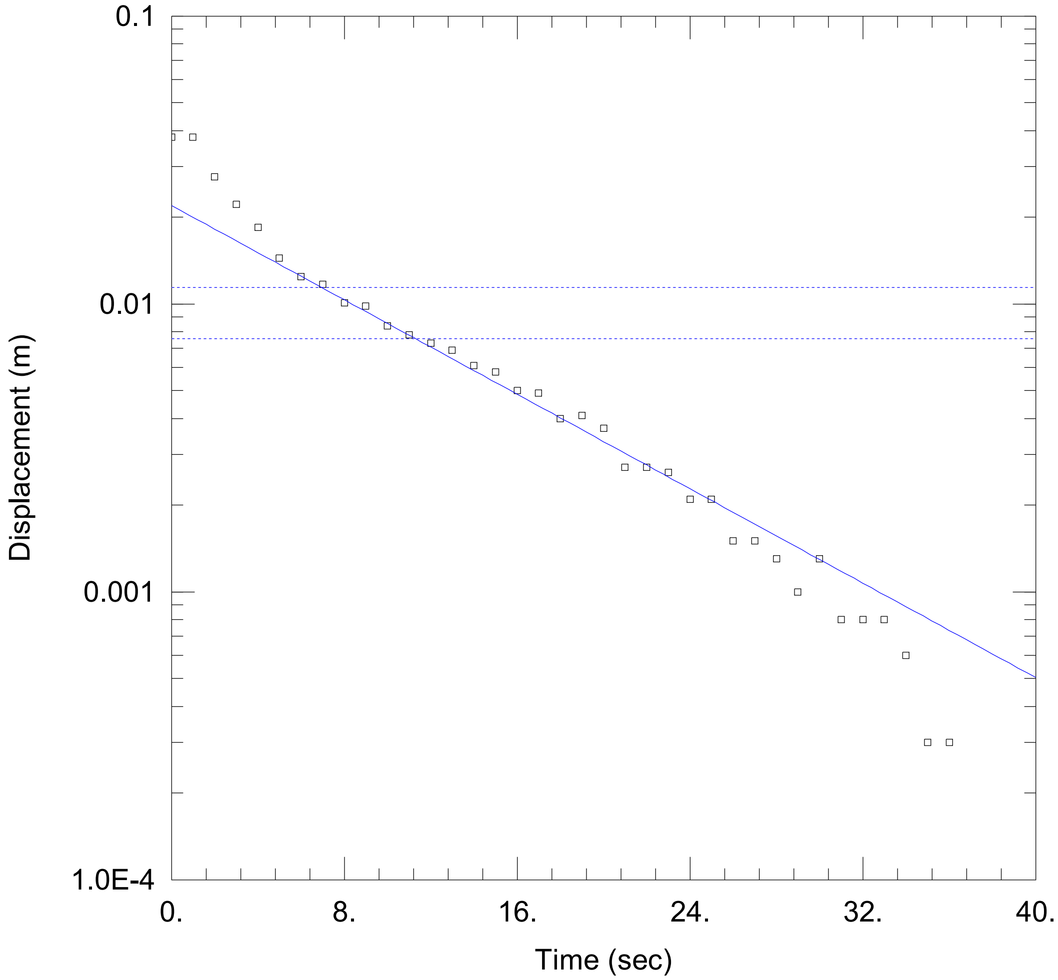
WELL DATA (New Well)

Initial Displacement: 0.7241 m Static Water Column Height: 4.83 m
Total Well Penetration Depth: 4.83 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.3473 m/day y0 = 0.5275 m



BH12 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH12.aqt
Date: 06/19/19
Time: 07:29:39

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH12
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

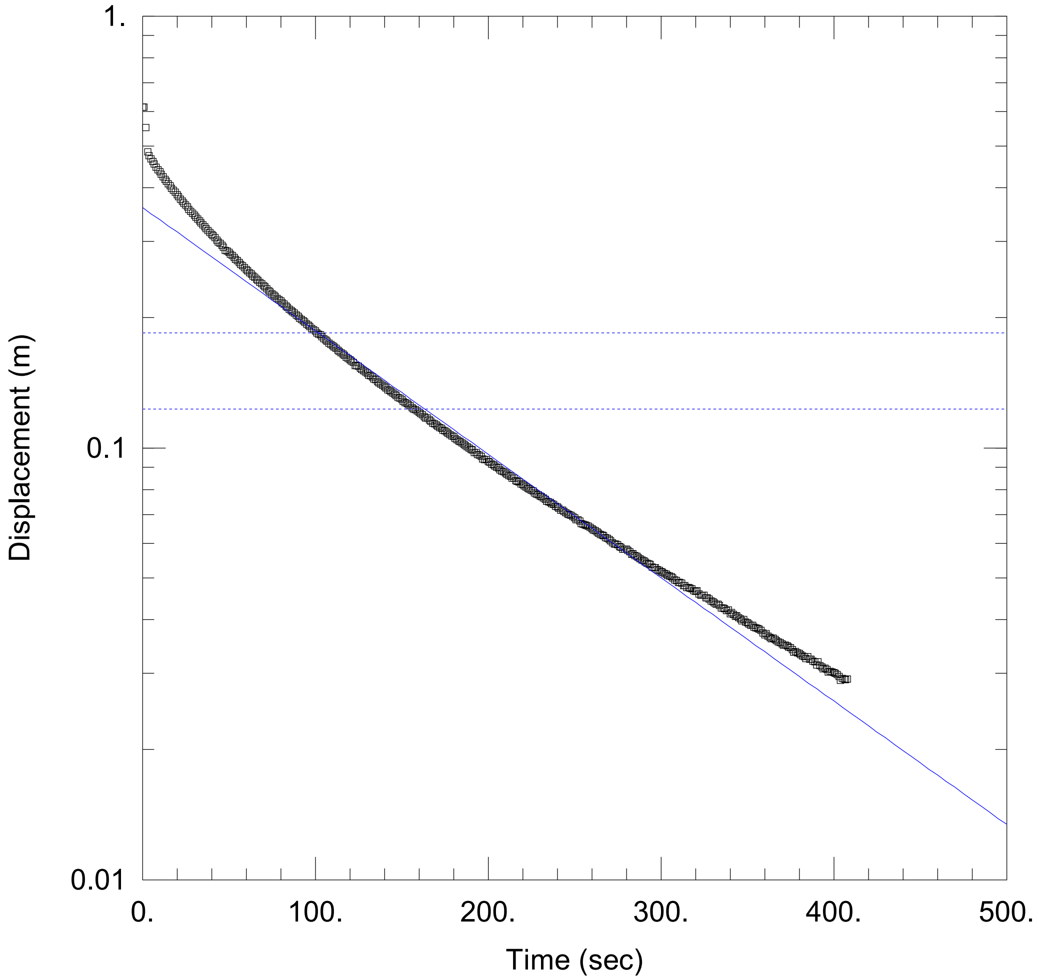
WELL DATA (New Well)

Initial Displacement: 0.0379 m
Static Water Column Height: 2.183 m
Total Well Penetration Depth: 3.22 m
Screen Length: 3.22 m
Casing Radius: 0.013 m
Well Radius: 0.03 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.8201 m/day
y0 = 0.02196 m



BH14 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH14.aqt
Date: 06/19/19 Time: 07:42:46

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH14
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

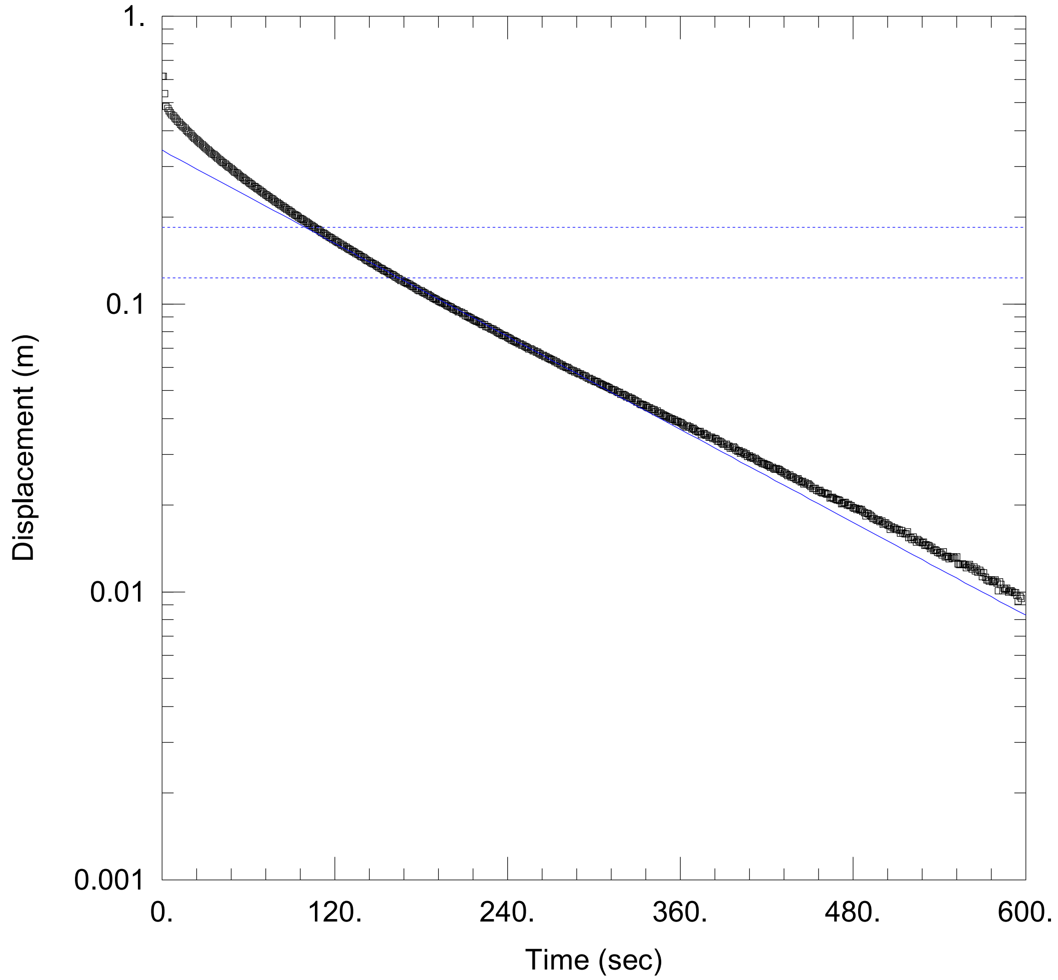
WELL DATA (New Well)

Initial Displacement: 0.6143 m Static Water Column Height: 4.1 m
Total Well Penetration Depth: 4.1 m Screen Length: 4. m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.1353 m/day y0 = 0.3601 m



BH14 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH14.aqt
Date: 06/19/19 Time: 07:34:25

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH14
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

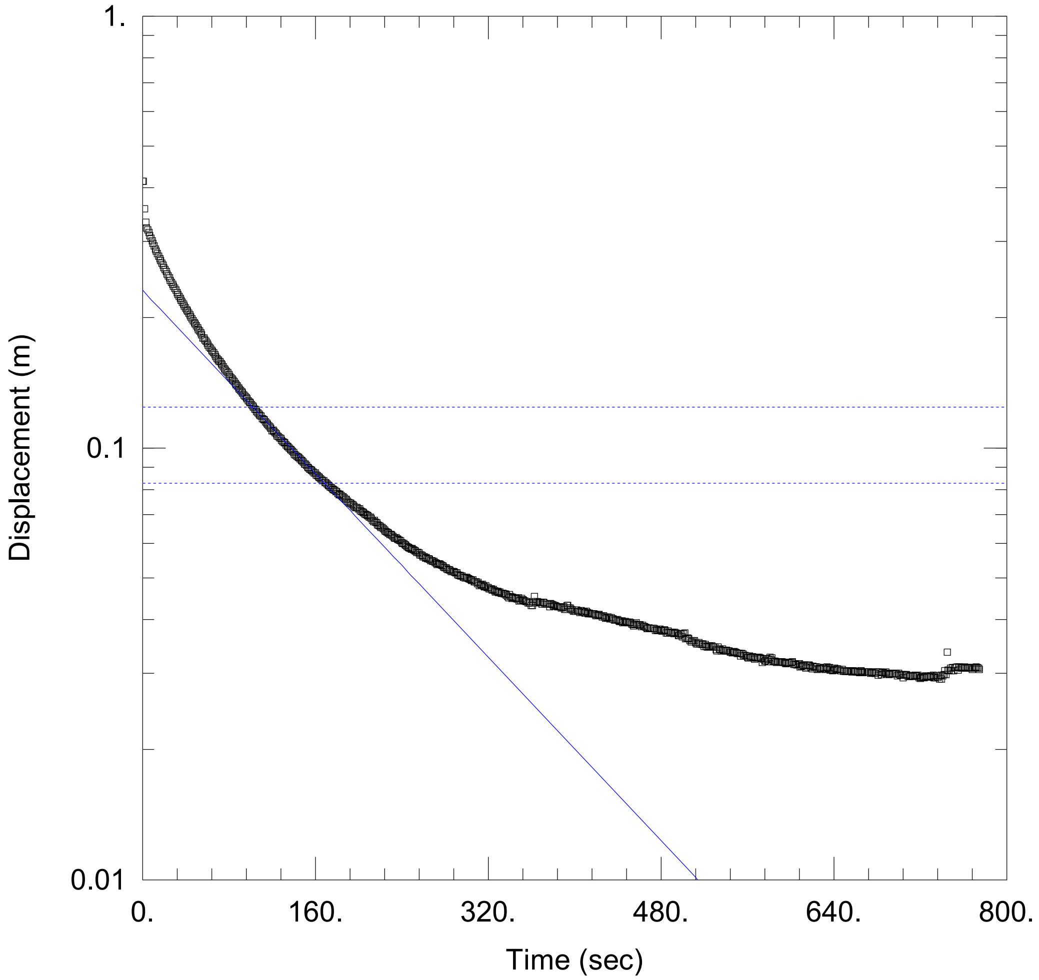
WELL DATA (New Well)

Initial Displacement: 0.6157 m
Total Well Penetration Depth: 4.1 m
Casing Radius: 0.025 m
Static Water Column Height: 4.1 m
Screen Length: 4. m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.1275 m/day y0 = 0.3416 m



BH15 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH15.aqt
Date: 06/19/19 Time: 07:44:59

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH15
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

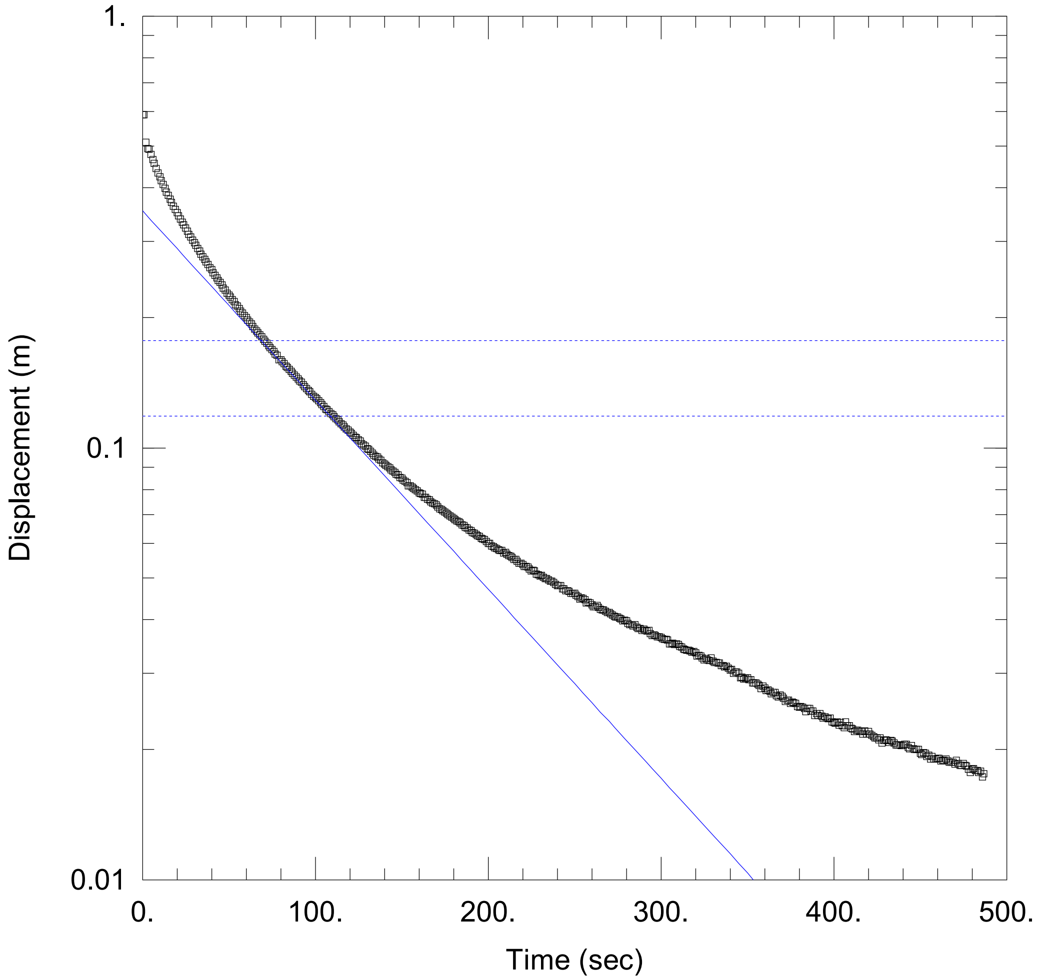
WELL DATA (New Well)

Initial Displacement: 0.4137 m
Total Well Penetration Depth: 5.69 m
Casing Radius: 0.025 m
Static Water Column Height: 5.69 m
Screen Length: 4.5 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.1202 m/day y0 = 0.2316 m



BH15 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH15.aqt
Date: 06/19/19 Time: 07:49:43

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH15
Test Date: 13/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

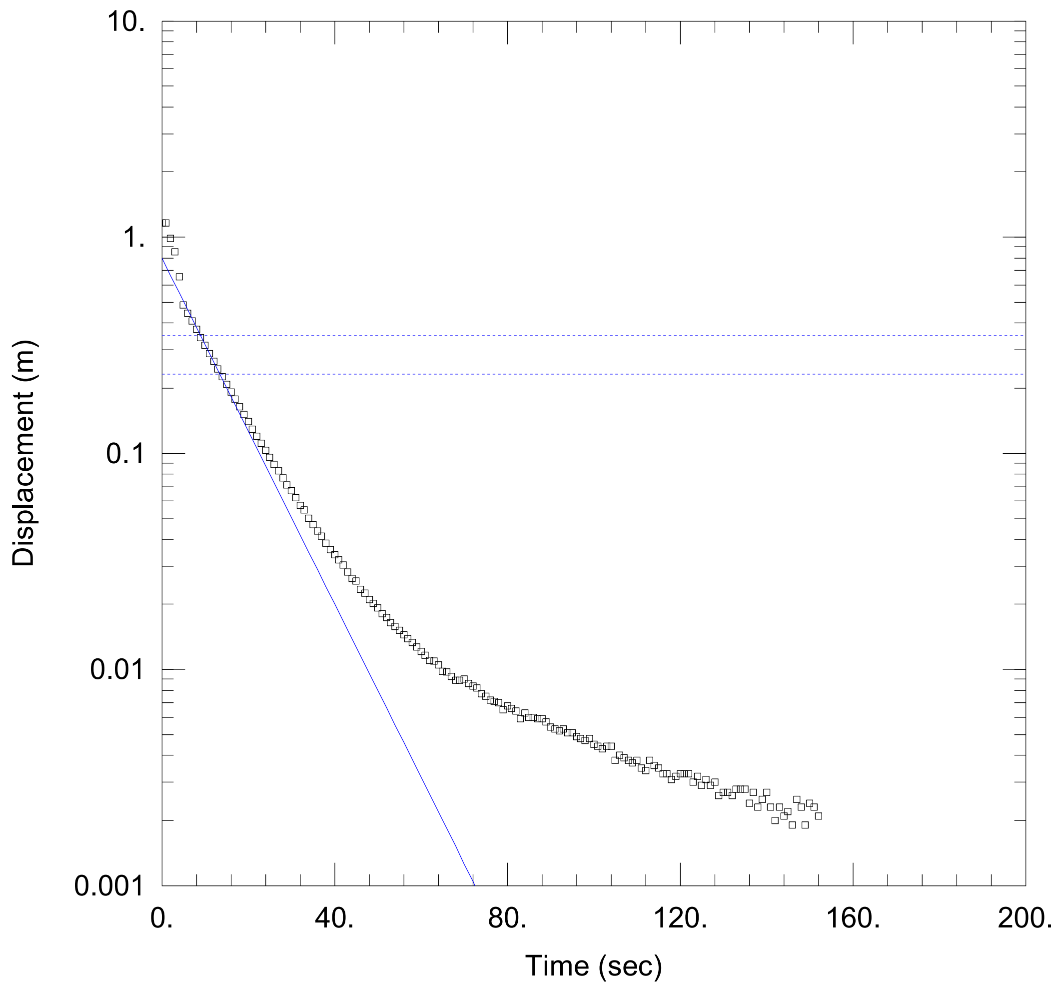
WELL DATA (New Well)

Initial Displacement: 0.591 m Static Water Column Height: 5.69 m
Total Well Penetration Depth: 5.69 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.1983 m/day y0 = 0.3538 m



BH16 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH16.aqt
Date: 06/19/19 Time: 07:53:19

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH16
Test Date: 12/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

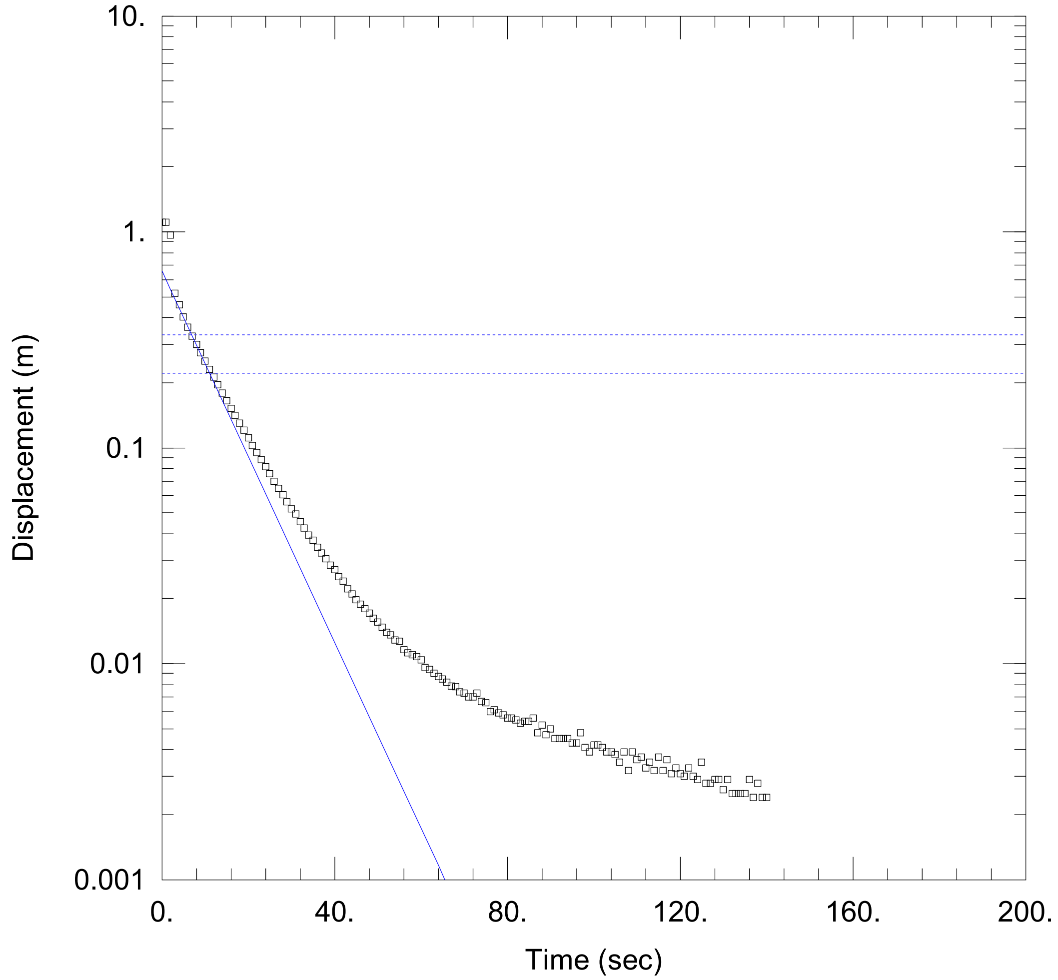
WELL DATA (New Well)

Initial Displacement: 1.165 m Static Water Column Height: 5.37 m
Total Well Penetration Depth: 5.37 m Screen Length: 4.7 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.724 m/day y0 = 0.7966 m



BH16 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH16.aqt
Date: 06/19/19 Time: 07:56:42

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH16
Test Date: 12/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

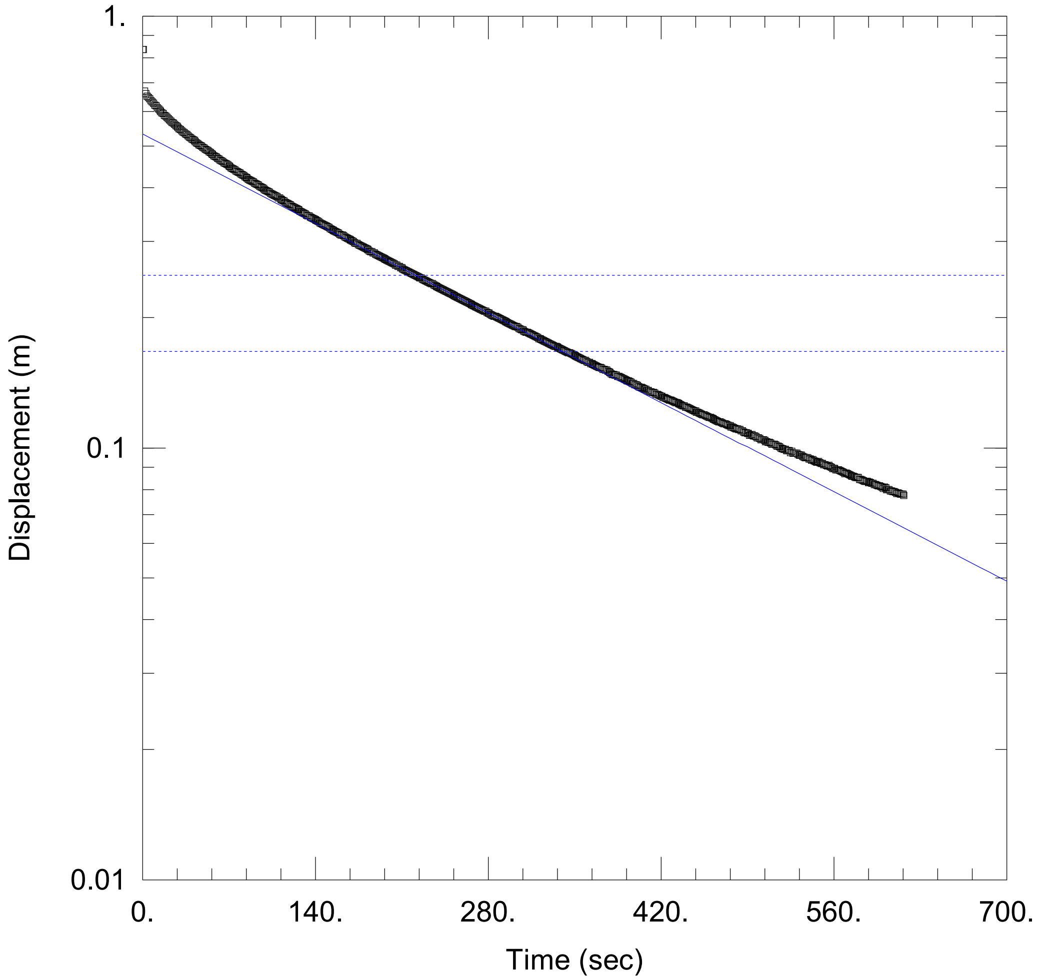
WELL DATA (New Well)

Initial Displacement: 1.108 m Static Water Column Height: 5.37 m
Total Well Penetration Depth: 5.37 m Screen Length: 4.7 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.852 m/day y0 = 0.6577 m



BH17 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH17.aqt
Date: 06/19/19 Time: 08:01:21

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH17
Test Date: 12/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

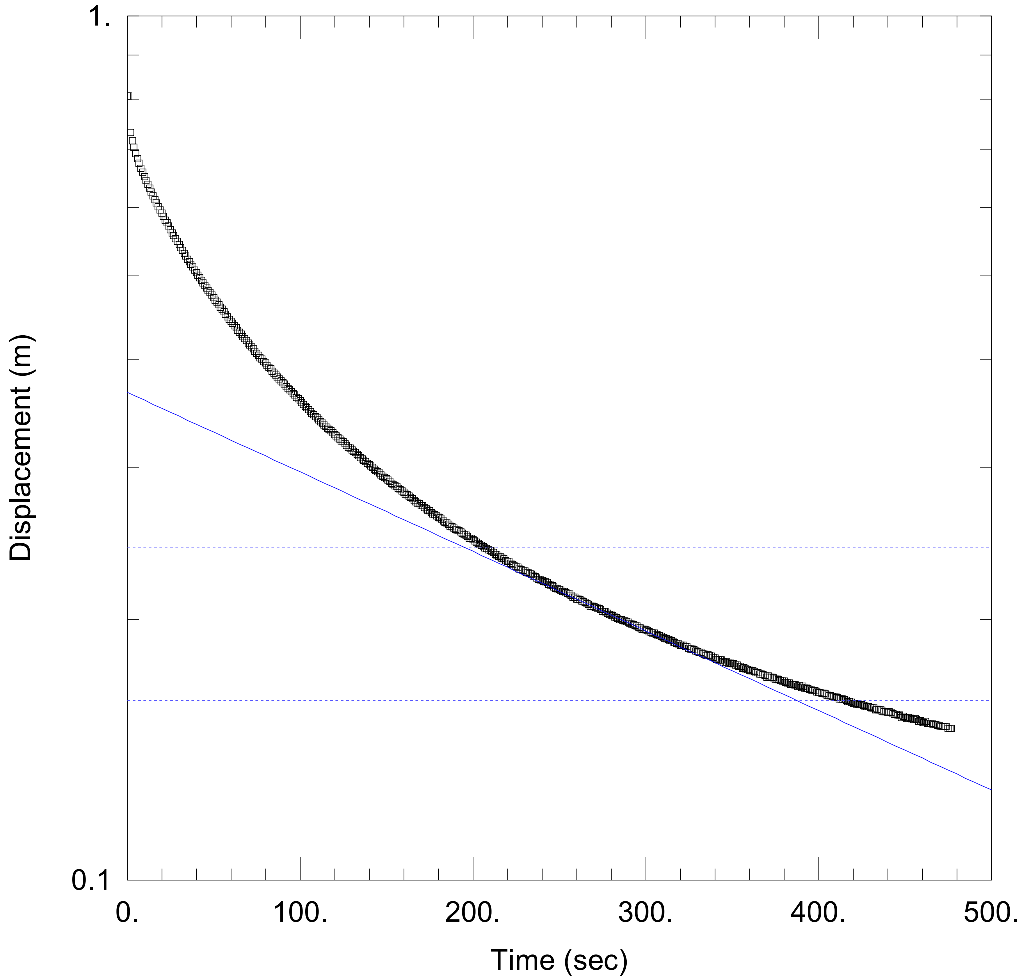
WELL DATA (New Well)

Initial Displacement: 0.8348 m Static Water Column Height: 4.73 m
Total Well Penetration Depth: 4.73 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.06476 m/day y0 = 0.5327 m



BH17 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH17.aqt
Date: 06/19/19 Time: 08:00:08

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH17
Test Date: 12/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

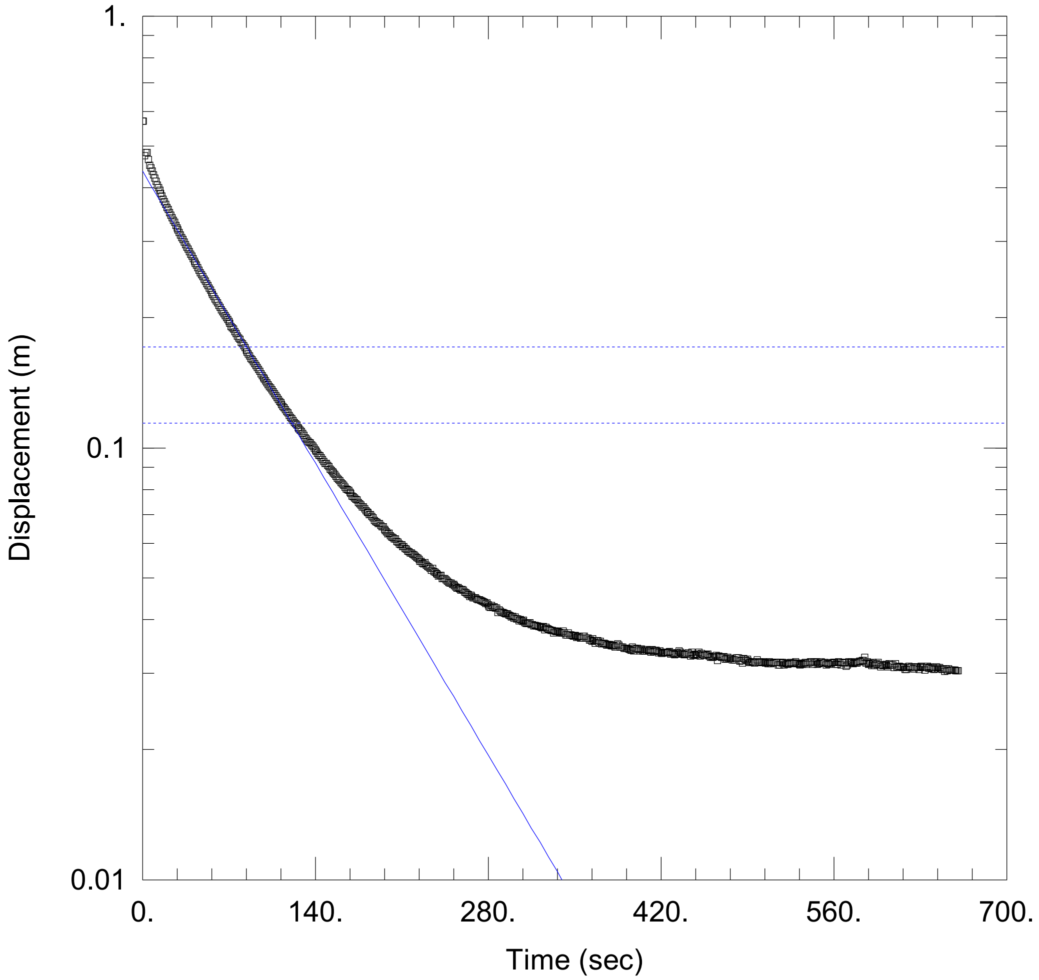
WELL DATA (New Well)

Initial Displacement: 0.8071 m
Static Water Column Height: 4.73 m
Total Well Penetration Depth: 4.73 m
Screen Length: 4.5 m
Casing Radius: 0.025 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.04028 m/day
y0 = 0.3665 m



BH01 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH01.aqt
Date: 06/18/19 Time: 17:05:44

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH01
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

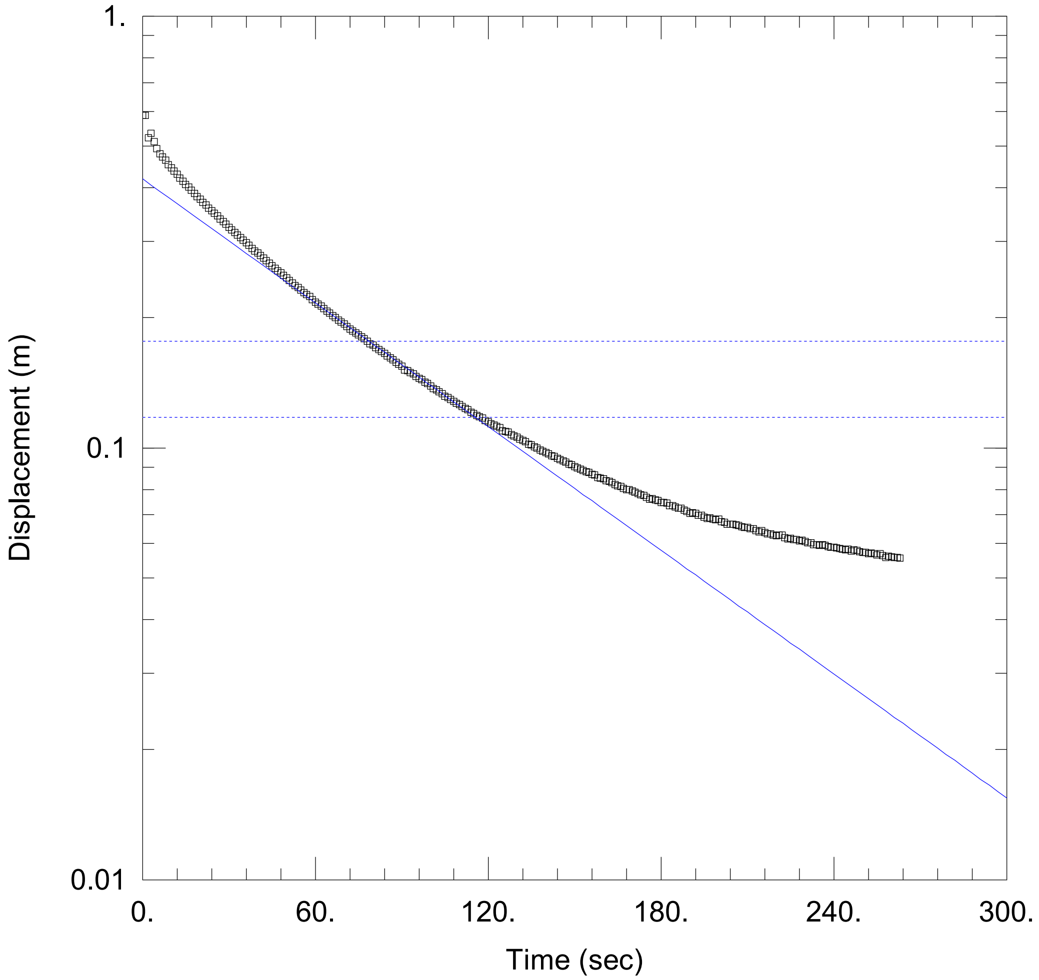
WELL DATA (BH01)

Initial Displacement: 0.5697 m
Static Water Column Height: 5.83 m
Total Well Penetration Depth: 5.83 m
Screen Length: 4.5 m
Casing Radius: 0.025 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.2196 m/day
y0 = 0.4372 m



BH01 RH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH01.aqt
Date: 06/18/19 Time: 17:11:36

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH01
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

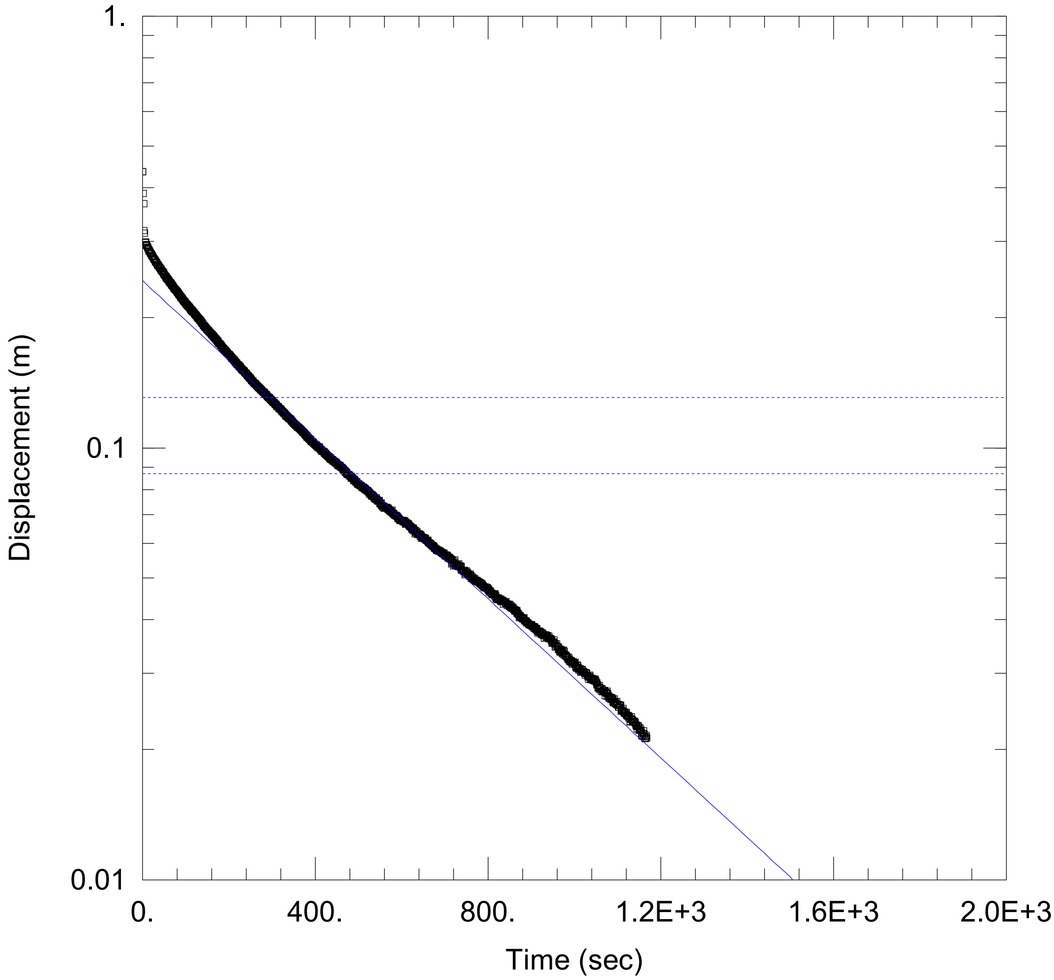
WELL DATA (BH01)

Initial Displacement: 0.5882 m Static Water Column Height: 5.83 m
Total Well Penetration Depth: 5.83 m Screen Length: 4.5 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.2172 m/day y0 = 0.4191 m



BH02 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH02.aqt
Date: 06/18/19
Time: 17:15:00

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH02
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

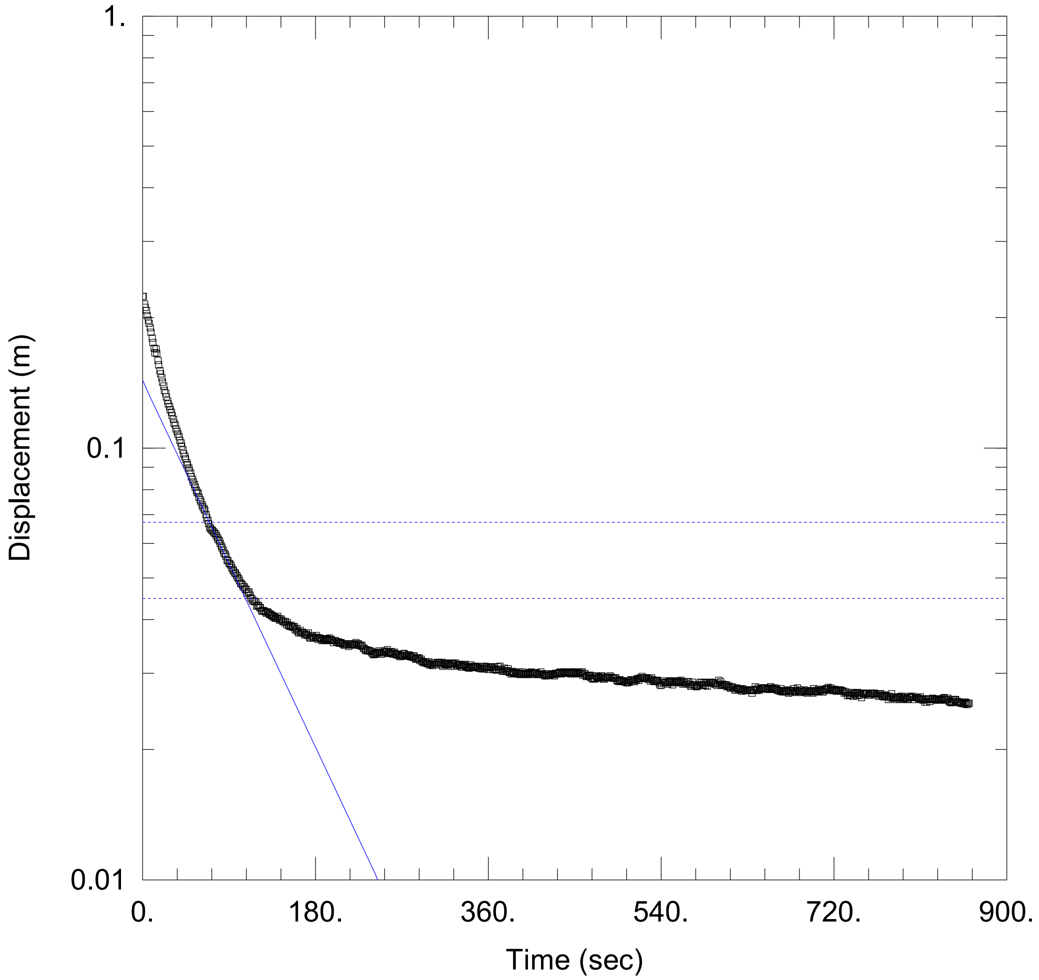
WELL DATA (New Well)

Initial Displacement: 0.4361 m
Total Well Penetration Depth: 3.51 m
Casing Radius: 0.013 m
Static Water Column Height: 3.51 m
Screen Length: 1.6 m
Well Radius: 0.03 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.03471 m/day
y0 = 0.2438 m



BH02 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH02.aqt
Date: 06/18/19 Time: 17:16:27

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH02
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

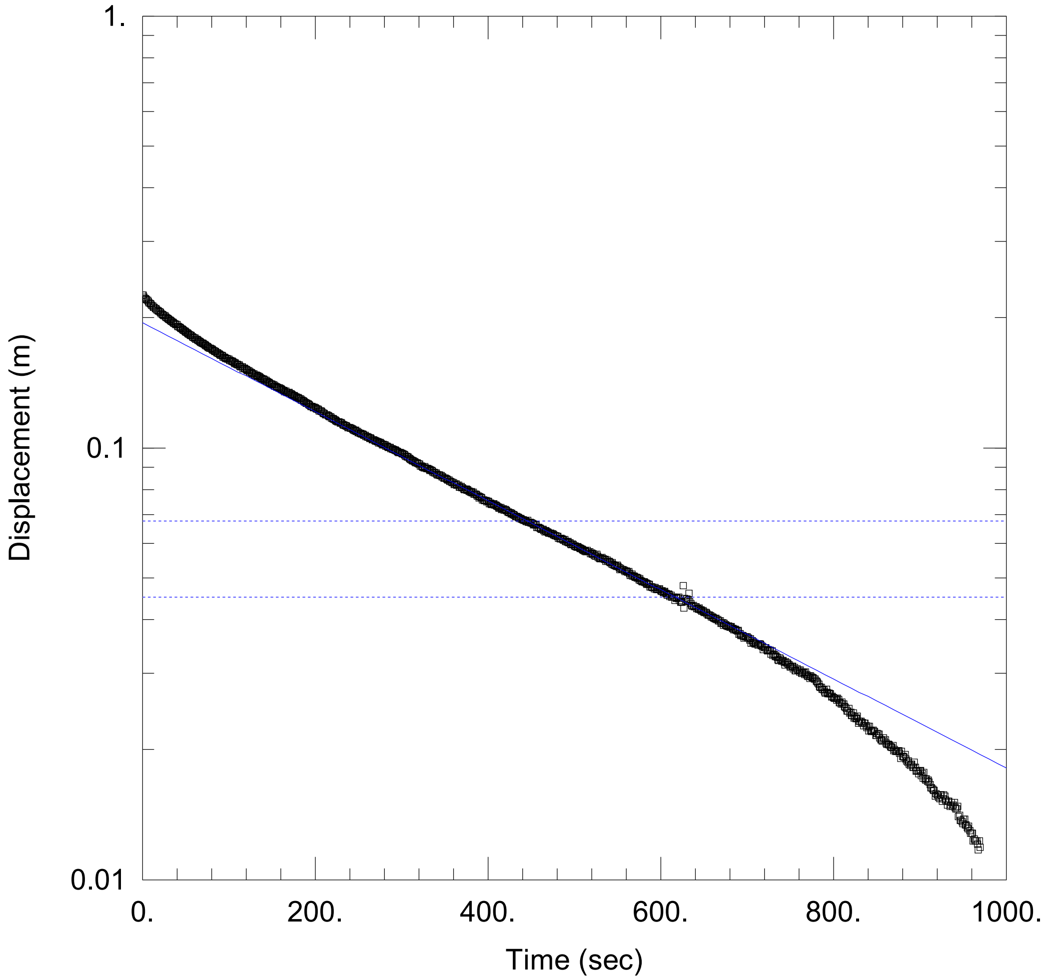
WELL DATA (New Well)

Initial Displacement: 0.224 m Static Water Column Height: 3.51 m
Total Well Penetration Depth: 3.51 m Screen Length: 1.6 m
Casing Radius: 0.013 m Well Radius: 0.03 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.1777 m/day y0 = 0.1432 m



BH03 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH03.aqt
Date: 06/18/19 Time: 17:18:22

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH03
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

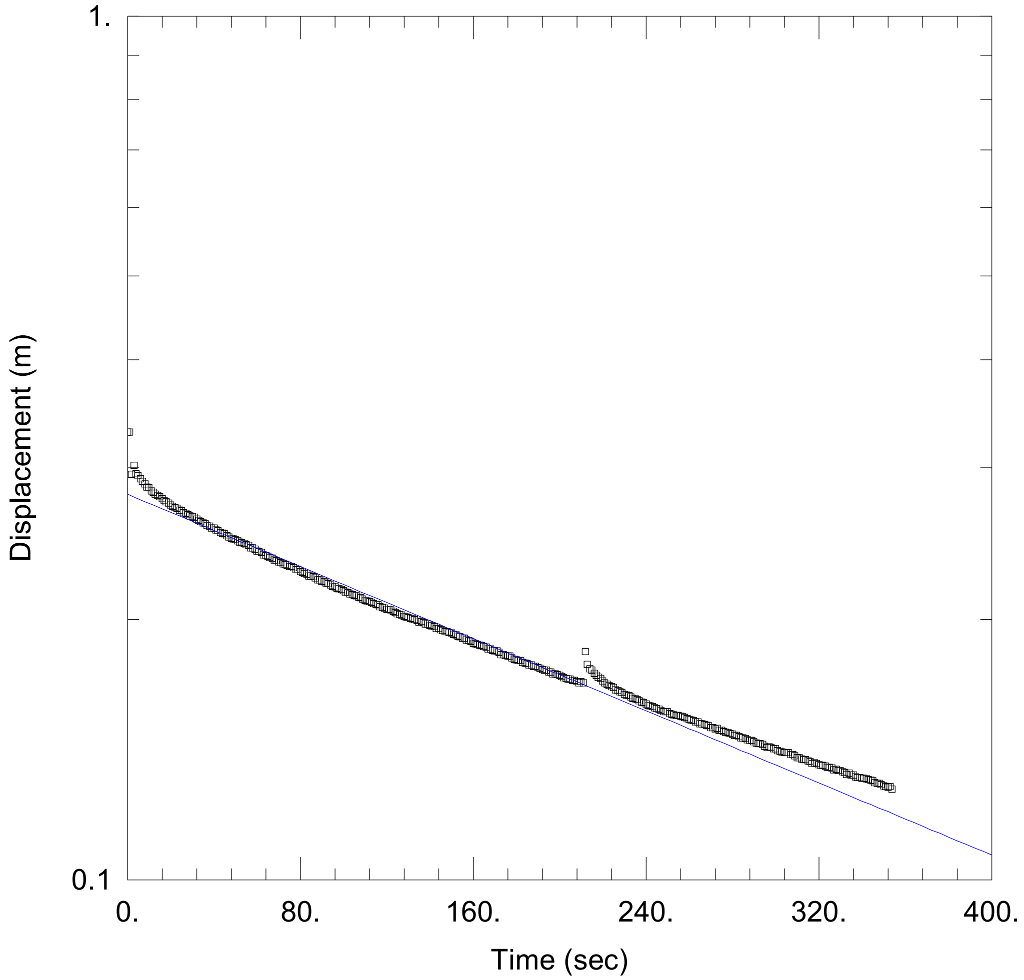
WELL DATA (New Well)

Initial Displacement: 0.2257 m
Static Water Column Height: 3.61 m
Total Well Penetration Depth: 3.61 m
Screen Length: 2.1 m
Casing Radius: 0.013 m
Well Radius: 0.03 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.03068 m/day
y0 = 0.1948 m



BH03 FH2

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH03.aqt
Date: 06/18/19 Time: 17:19:37

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH03
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

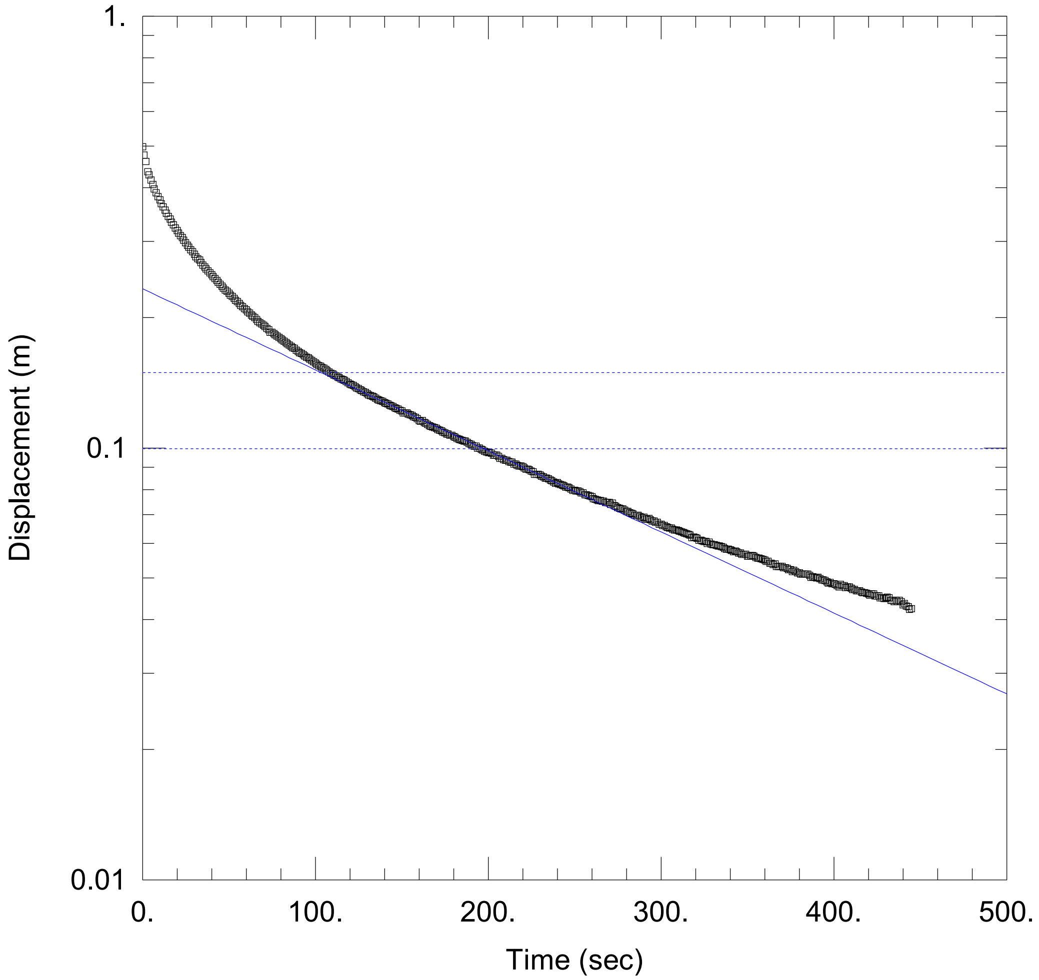
WELL DATA (New Well)

Initial Displacement: 0.3296 m Static Water Column Height: 3.61 m
Total Well Penetration Depth: 3.61 m Screen Length: 2.1 m
Casing Radius: 0.013 m Well Radius: 0.03 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.03108 m/day y0 = 0.2793 m



BH04 FH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH04.aqt
Date: 06/18/19 Time: 17:24:14

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH04
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m
Anisotropy Ratio (Kz/Kr): 0.2

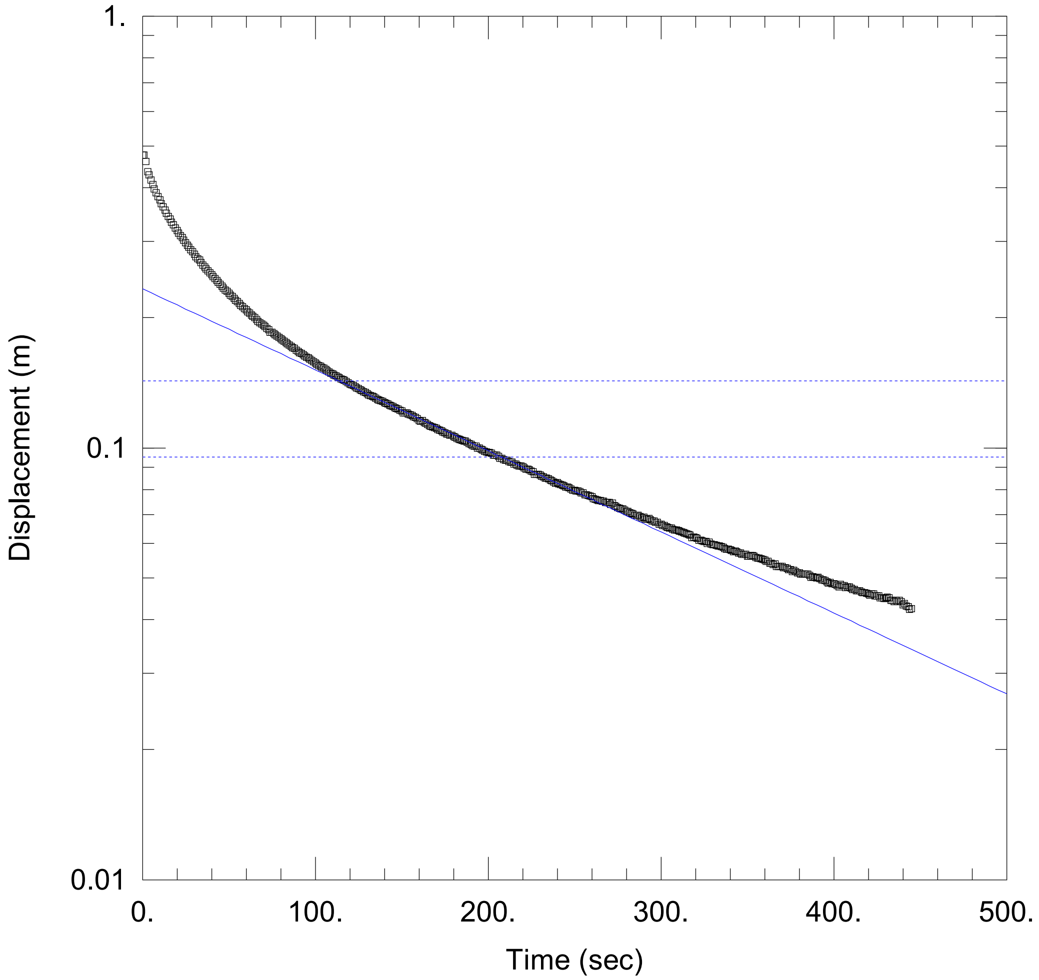
WELL DATA (New Well)

Initial Displacement: 0.497 m
Static Water Column Height: 5.666 m
Total Well Penetration Depth: 5.67 m
Screen Length: 4.4 m
Casing Radius: 0.025 m
Well Radius: 0.1017 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.08663 m/day
y0 = 0.2334 m



BH04 RH1

Data Set: J:\IE\Projects\03_Southern\IS288600\07 Technical\6 - Slug test\BH04.aqt
Date: 06/18/19 Time: 17:26:15

PROJECT INFORMATION

Company: Jacobs
Client: Barwon Water
Project: IS288600
Location: Yeodene Swamp
Test Well: BH04
Test Date: 11/06/2019

AQUIFER DATA

Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.2

WELL DATA (New Well)

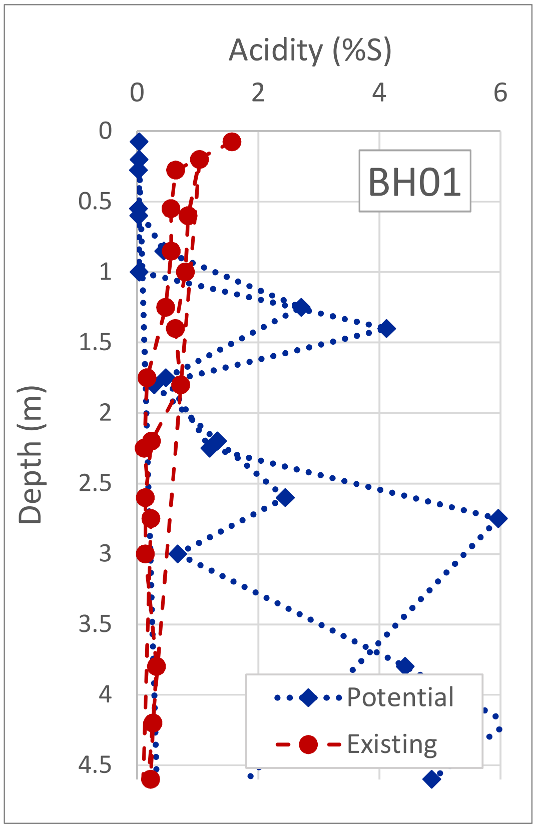
Initial Displacement: 0.4756 m Static Water Column Height: 5.666 m
Total Well Penetration Depth: 5.67 m Screen Length: 4.4 m
Casing Radius: 0.025 m Well Radius: 0.1017 m

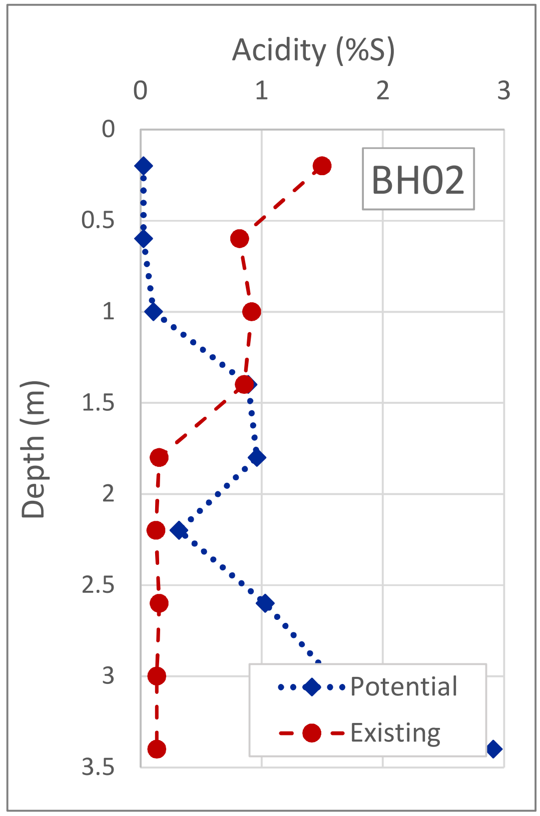
SOLUTION

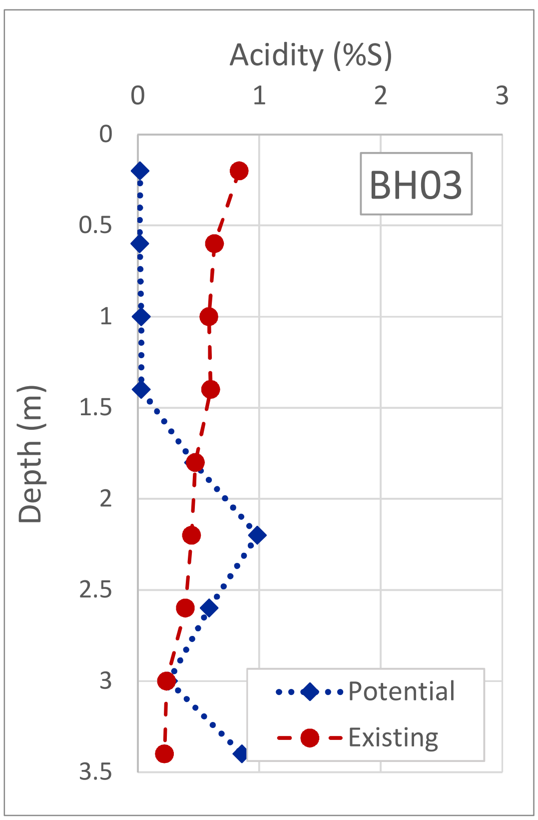
Aquifer Model: Unconfined Solution Method: Bouwer-Rice

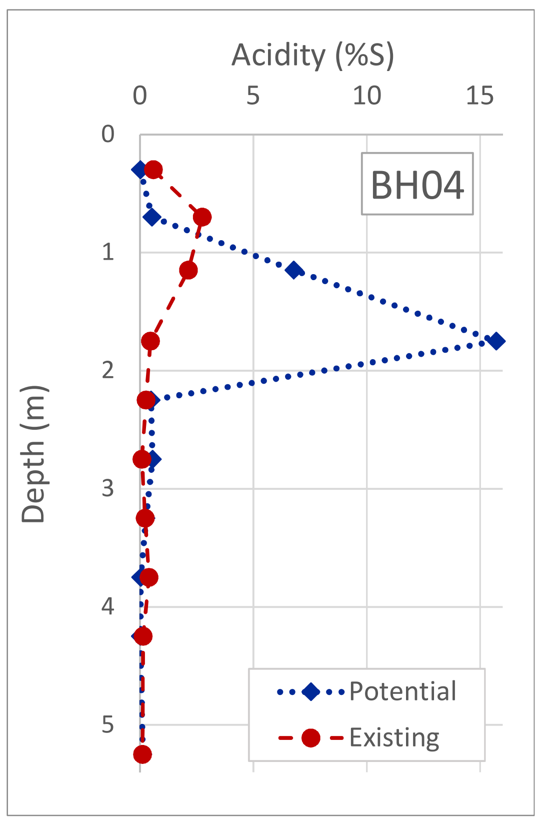
K = 0.08663 m/day y0 = 0.2334 m

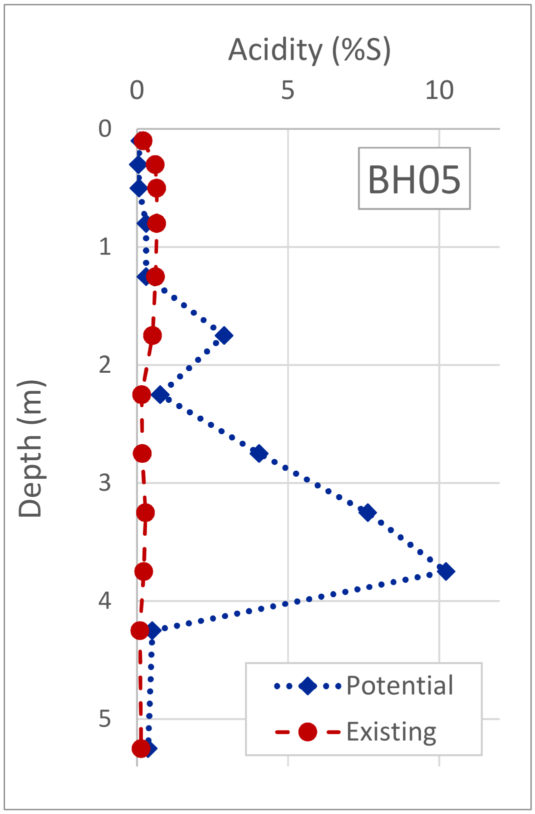
Appendix G. Laboratory results

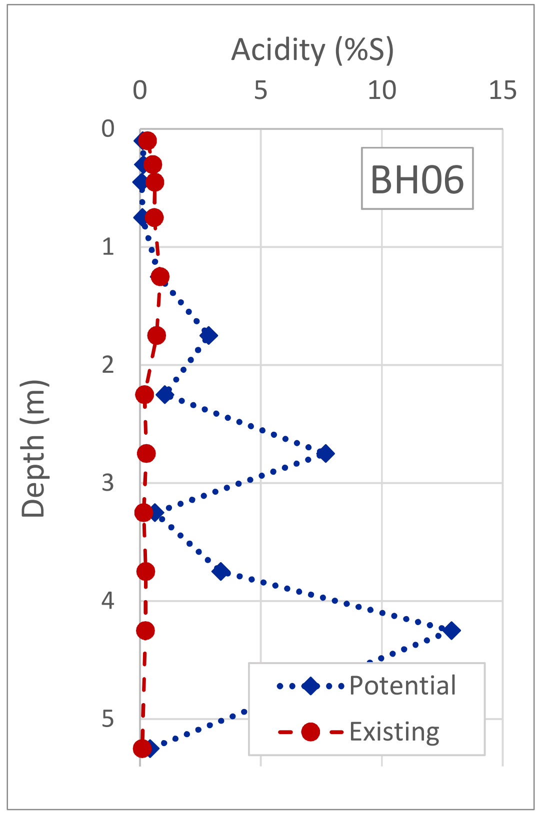

Acidity (%S)
0 2 4 6
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Depth (m)
BH01
Potential
Existing

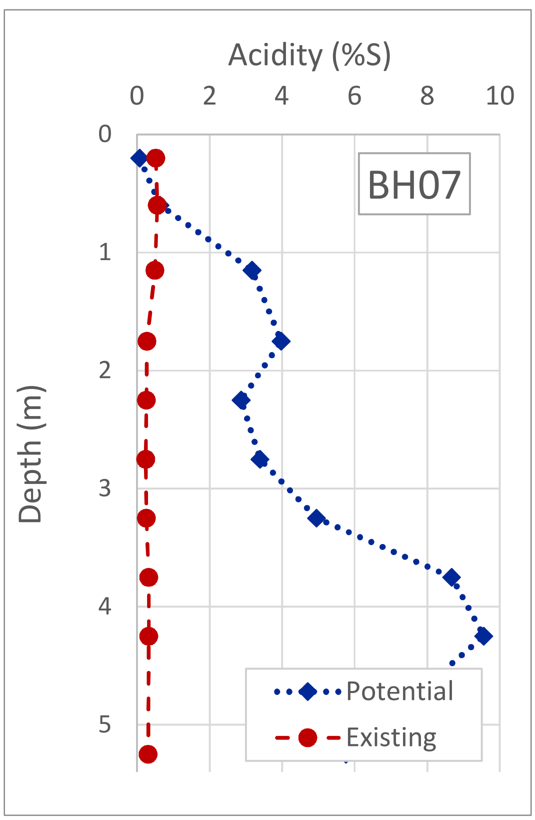

Acidity (%S)
0 1 2 3
0 0.5 1 1.5 2 2.5 3 3.5
Depth (m)
BH02
Potential
Existing

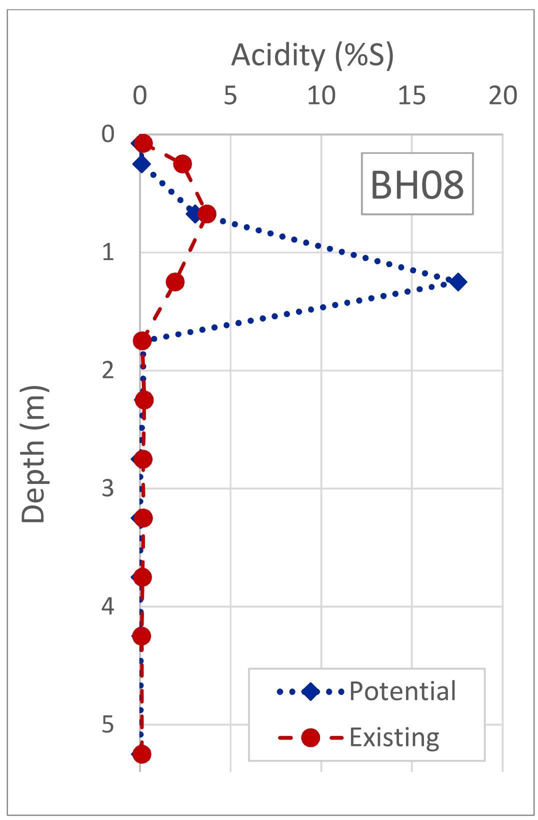

Acidity (%S)
0 1 2 3
0 0.5 1 1.5 2 2.5 3 3.5
Depth (m)
BH03
Potential
Existing

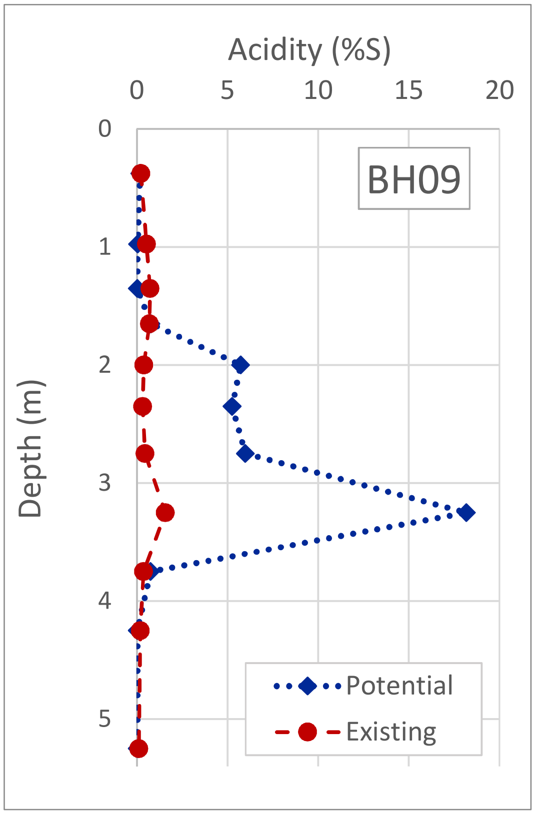

Acidity (%S)
0 5 10 15
0 1 2 3 4 5
Depth (m)
BH04
Potential
Existing

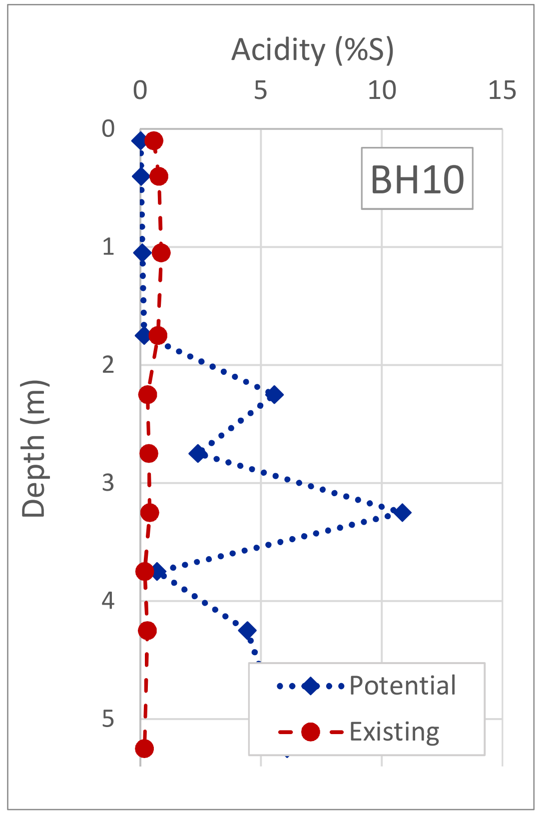

Acidity (%S)
0
5
10
0
1
2
3
4
5
Depth (m)
BH05
Potential
Existing

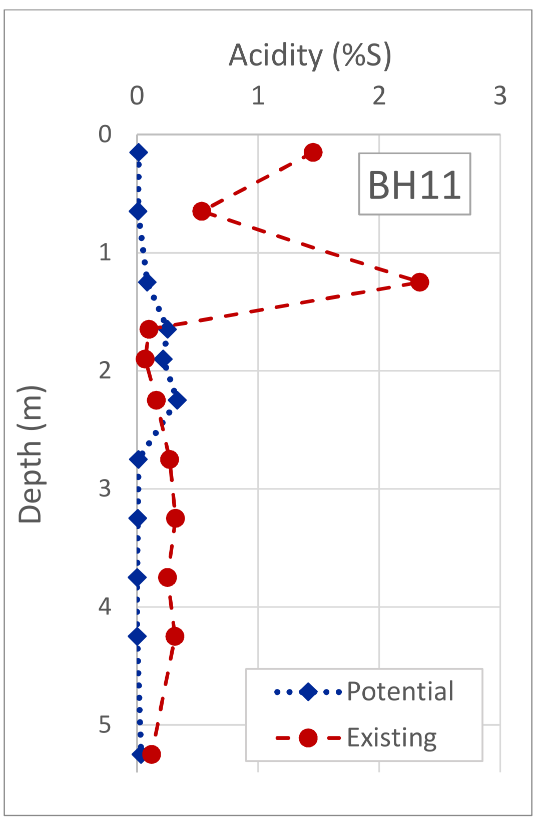

Acidity (%S)
0
5
10
15
0
1
2
3
4
5
Depth (m)
BH06
Potential
Existing

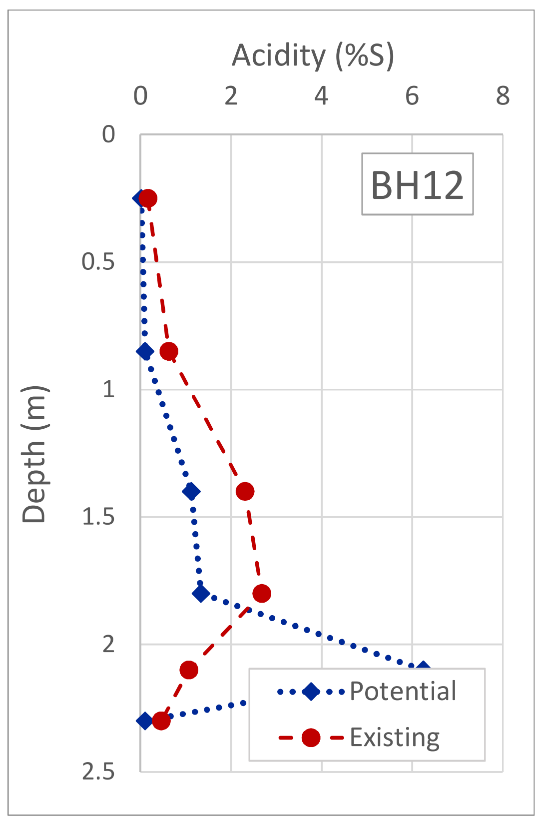

Acidity (%S)
0
2
4
6
8
10
0
1
2
3
4
5
Depth (m)
BH07
Potential
Existing

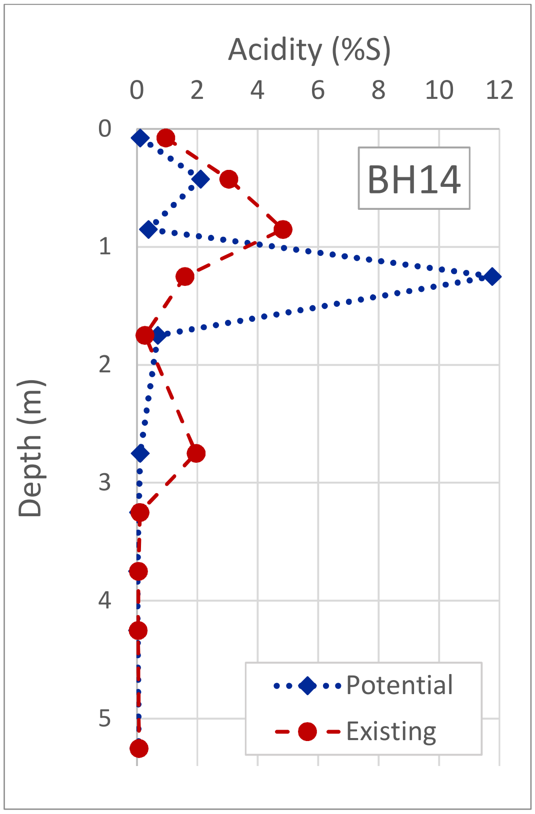

Acidity (%S)
0
5
10
15
20
0
1
2
3
4
5
Depth (m)
BH08
Potential
Existing


Acidity (%S)
0 5 10 15 20
Depth (m)
0 1 2 3 4 5
BH09
Potential
Existing

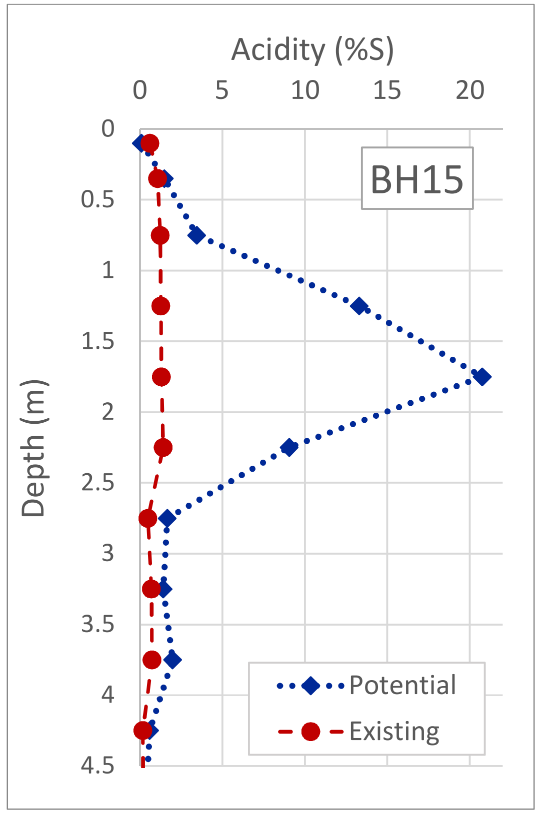

Acidity (%S)
0 5 10 15
Depth (m)
0 1 2 3 4 5
BH10
Potential
Existing


Acidity (%S)
0 1 2 3
Depth (m)
0 1 2 3 4 5
BH11
Potential
Existing

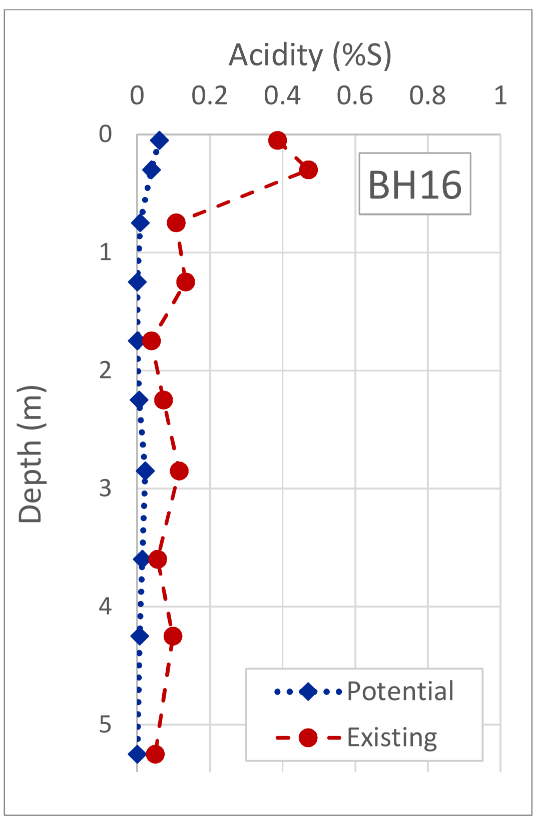

Acidity (%S)
0 2 4 6 8
Depth (m)
0 0.5 1 1.5 2 2.5
BH12
Potential
Existing



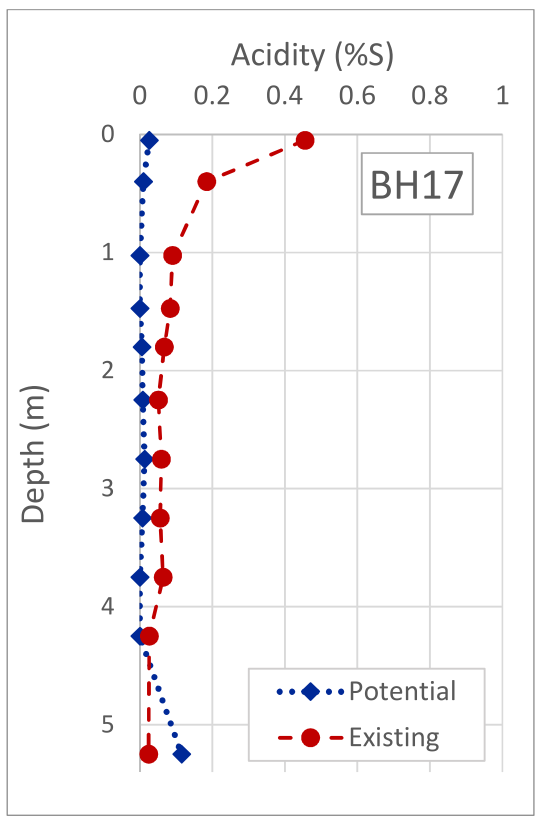
Acidity (%S)
0
2
4
6
8
10
12
0
1
2
3
4
5
Depth (m)
BH14
Potential
Existing



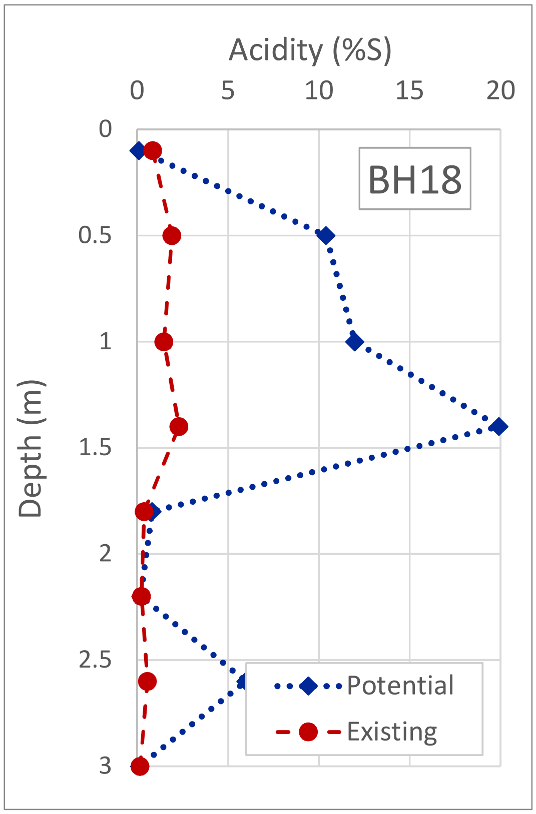
Acidity (%S)
0
5
10
15
20
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Depth (m)
BH15
Potential
Existing



Acidity (%S)
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
Depth (m)
BH16
Potential
Existing



Acidity (%S)
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
Depth (m)
BH17
Potential
Existing


Acidity (%S)
0
5
10
15
20
0
0.5
1
1.5
2
2.5
3
Depth (m)
BH18
Potential
Existing

Yeodene (Big) Swamp

Groundwater and surface water modelling

002 | FINAL

12 December 2019

Barwon Water

Groundwater and surface water modelling for Big Swamp

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Document No.:	002
Revision:	FINAL
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Date:	12 December 2019
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Author:	Phil Pedruco & Brian Barnett
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Revision	Date	Description	Author	Checked	Reviewed	Approved
Draft 001	26/11/2019	Draft report	BB, PP	LL	LL	LL
Final	12/12/2019	Final report	BB, PP	LL	LL	LL

Contents

Executive Summary

This report has been prepared to fulfil the requirements of a Section 78 Ministerial Notice pursuant to Section 78 of the Water Act 1989, directing the corporation to develop and implement a Remediation Plan for the Boundary Creek, Big Swamp and the surrounding environment. The primary issue in driving the deterioration of water quality of the swamp and in the downstream reaches is the oxidation of acid sulfate soils present in the swamp as a result of declining groundwater levels and catchment runoff. Management options to remediate the swamp were investigated in a loosely coupled groundwater surface water modelling framework.

The management options investigated aimed to increase the area of inundation and raise groundwater levels to limit the future production of acid. Specifically, these options involve providing supplementary flow to Boundary Creek, the introduction of a hydraulic barrier to the downstream end of the swamp as well as a combination of both of these. The loosely coupled groundwater surface water model was calibrated to available surface water and groundwater data and was used to investigate these options.

The modelling approach integrated surface water accumulation and flow in Boundary Creek with an unsaturated/saturated zone groundwater flow model of the underlying aquifer system with Boundary Creek as a boundary condition. The surface water modelling calculated the inundation extents and water level (stage) throughout Boundary Creek and the swamp and these model outputs were applied as boundary conditions to the groundwater model. The groundwater model simulates exchange fluxes (the transfer of water between Boundary Creek and the underlying aquifer system) and quantifies groundwater levels throughout the swamp. This approach provided quantitative estimates of stream flow through Boundary Creek and Big Swamp together with estimates of the exchange fluxes and resultant changes in groundwater levels throughout the swamp.

Calibration of the individual component surface water and groundwater models has been limited by the quality and length of the available stream flow and groundwater head monitoring data. In particular, the available groundwater level records for bores in the swamp (June to September 2019) is of insufficient duration to allow a robust transient calibration that tests the model over a range of climatic and surface water hydrological conditions.

The exchange of data between the surface water inundation model and groundwater model provides a significant challenge for the transient models required to fully characterise groundwater responses to changes in river conditions. These problems largely revolve around the difference in response times in the hydraulic model and groundwater model. Simulation of surface water flow in the swamp requires a calculation time step of about one second while the groundwater model is required to run over periods of months or years to fully characterise the groundwater response to a change in river flow conditions. While these difficulties have hindered the development of a fully coupled model, simplifications have been introduced to the representation of surface water boundary conditions in the groundwater model and have enabled the generation of appropriate predictive outcomes for this investigation.

The modelling results indicate that a supplementary flow of 2 ML/d with no other interventions such as hydraulic barrier is not effective in increasing the inundated area or raising groundwater levels above those typically experienced at the end of winter (nominally September). However, the modelling suggests that this level of flow release will ensure flows through the swamp through all seasons and hence represents an improvement in historic groundwater levels throughout the swamp. While this scenario is conservative, in that no additional flows (from runoff or interflow) to the system were modelled, it is not unrealistic over the summer where extended periods of low flow are experienced. Increasing the supplementary flow to 20 ML/d was shown to be effective in increasing both the area inundated and groundwater levels; however, the flow rates represents the average high winter flows in recent years and its continuous delivery is not feasible. These results indicate that supplementary flows, with no other intervention, are not feasible to achieve the necessary increases in inundation extent and raising groundwater levels required to manage acid export.

The hydraulic barrier scenarios have demonstrated significant increase in the extent of inundation as well as increases in groundwater levels although these benefits were limited to immediate surrounds. Further, the surface water results of a barrier with different supplementary flows found that there were diminishing returns with higher flows, that is, increased flow rates did not result is a significantly larger area inundated behind the barrier.

The modelling suggests that a modest supplementary flow with multiple hydraulic barriers within the swamp would provide the greatest benefit and limit the export of acid water. While it has not been possible to model additional hydraulic barriers within the available time for this investigation, it is recommended that the location of additional barriers be investigated and modelled in the future with suitable locations selected on the basis of topography to assess the expected beneficial impacts on vegetation and the predicted reduction in acid generation and export.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to assess the feasibility of the proposed remediation option for Yeodene Swamp using an integrated groundwater and surface water modelling approach. These works have been carried out in accordance with the scope of services as set out in Barwon Water's Request for proposal (contract no: 001291), and the proposal for groundwater and surface water modelling for Big Swamp submitted to Barwon Water by Jacobs in August 2019.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and concludes as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Barwon Water, the Bureau of Meteorology and DELWP as outlined in this report.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by the law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in another other context.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs' client, Barwon Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Barwon Water. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

This report has been prepared to fulfil the requirements of a Section 78 Ministerial Notice pursuant to Section 78 of the Water Act 1989, directing the corporation to develop and implement a Remediation Plan for the Boundary Creek, Big Swamp and the surrounding environment.

The Section 78 covers Boundary Creek, Big Swamp and the surrounding environment. A loosely coupled groundwater surface water model was developed to inform the remediation plan for Boundary Creek and Big Swamp. The models are described as being loosely coupled as they do not run concurrently, rather the models are run one after the other with results from a surface water model run transferred to the groundwater model as an input data set. The coupling is not dynamic in that the models do not simultaneously transfer data between models at every calculation time step.

Areas outside the Boundary Creek catchment that may also have been impacted by historic borefield pumping will be considered in a separate investigation plan. This report documents the development, calibration and results obtained from the coupled groundwater surface water model specifically to assess remediation options for Boundary Creek & Big Swamp.

1.1 Background

Big Swamp is a peat swamp located on Boundary Creek, upstream of the confluence with the Barwon River. The peat swamp contains acid sulfate soils that have dried out, resulting in the release of acidic water to the lower reach of Boundary Creek and ultimately, to the Barwon River.

The current state of the swamp reflects the culmination of numerous events throughout the catchment's history. This includes:

- The initial deposition of acid sulfate soils in the swamp
- The construction of nearby agricultural drains and farming in the area over 100 years ago
- Step changes in climate (including the Millennium Drought)
- The construction of an on-stream dam (McDonalds Dam) upstream of the swamp
- Groundwater extraction by Barwon Water and the release of supplementary flows to Boundary Creek, and
- Peat fires in the swamp and the excavation of trenches by CFA to control these fires.

Until recently, there has been limited understanding of the relative contributions of each of these factors to the generation and release of acidic waters in Big Swamp. There have also been limited scientific studies focussing on characterising the lower reaches of Boundary Creek.

Consultation with the community resulted in Barwon Water's commitment to develop and implement a remediation plan for Boundary Creek. The intention of this plan is to improve streamflow and water quality within Boundary Creek and Big Swamp, with the ultimate goal of improving ecological function of Big Swamp and water quality in Boundary Creek. The 2017-2018 Technical Works Program resulted in an improved conceptual understanding of the local hydrology, hydrogeology and interaction between the surface water and groundwater systems. A high-level assessment of six remediation options found that inundating the swamp would likely prove to be the most technically feasible.

Although Barwon Water had committed to remediation of the swamp, this was formalised when Barwon Water received a Ministerial Notice pursuant to Section 78 of the Water Act 1989 in September 2018. The Section 78 Notice directs the corporation (Barwon Water) to develop and implement a Remediation Plan for the Boundary Creek and Big Swamp environments.

The scope of works developed to meet the requirements of the Section 78 notice outlines a detailed program of works required to inform the remediation of the swamp, including an extensive field program to collect soil and groundwater data and subsequent analysis, collection of LiDAR data, installation of additional monitoring assets as well as groundwater and surface water modelling and hydro-geochemistry modelling.

Previous investigations undertaken by Jacobs concluded that the management of the acid sulfate soils in Big Swamp would require the management of both the surface water system and groundwater system, as well as the interaction between the two. In response to this, Jacobs has developed a loosely coupled groundwater-surface water model scheme to help inform the assessment of remediation options for Boundary Creek and Big Swamp.

2. Catchment description

Boundary Creek is located in south-west Victoria and originates south of Colac and flows in an easterly direction for approximately 18km discharging to the Barwon River. There are a number of streamflow gauges upstream of Yeodene as discussed in Section 4.1.

The Boundary Creek catchment was delineated using the Statewide 10 m resolution DEM and terrain analysis tools available within ESRI ArcGIS. Catchments were calculated for four streamflow gauging locations as indicated in Figure 2-1. Table 2.1 presents a summary of each of the sub catchments.

Table 2.1: Summary of subcatchments adopted for this investigation

Catchment Name	Area (km^2)	Description	Geology
Upstream of Barongarook (233273)	18.7	• Extends from the origin of Boundary Creek (south of Colac) to Barongarook, just downstream of where Boundary Creek meets Gardiners Road.	• Boundary Creek flows over outcropping bedrock characterised by impermeable Palaeozoic sandstone, siltstone and mudstone.
Barongarook (233273) to upstream McDonalds Dam (233231)	5.4	• Extends from Boundary Creek at Barongarook, downstream of where Boundary Creek meets Gardiners Road, to the streamflow gauge upstream of McDonalds Dam.	• Boundary Creek flows over outcropping bedrock characterised by impermeable Palaeozoic sandstone, siltstone and mudstone.
Upstream McDonalds Dam (233231) to downstream McDonalds Dam (233229)	2.7	• Extends from the streamflow gauge upstream of McDonalds Dam to the gauge downstream of McDonalds Dam • Contains McDonalds Dam, a privately-owned on-stream dam which was constructed in 1979	• Boundary Creek flows over alluvial sediments overlying Lower Teritary Aquifer characterised by permeable sands of the Mepunga, Dilwyn and Pebble point formations and Mid Tertiary Aquatard comprising marls and clays associated with Gellibrand Marl
Downstream McDonalds Dam (233229) to Yeodene (233228)	12.6	• Extends from the streamflow gauge downstream of McDonalds Dam down to Yeodene, where Boundary Creek intersects with Colac-Forest Road. • This catchment contains Big Swamp, a peat swamp. Upstream of Big Swamp the flow path of Boundary Creek is disperse, forming marshes and deeper pools.	• Boundary Creek flows over alluvial sediments overlying Mid Tertiary Aquatard comprising marls and clays associated with Gellibrand Marl

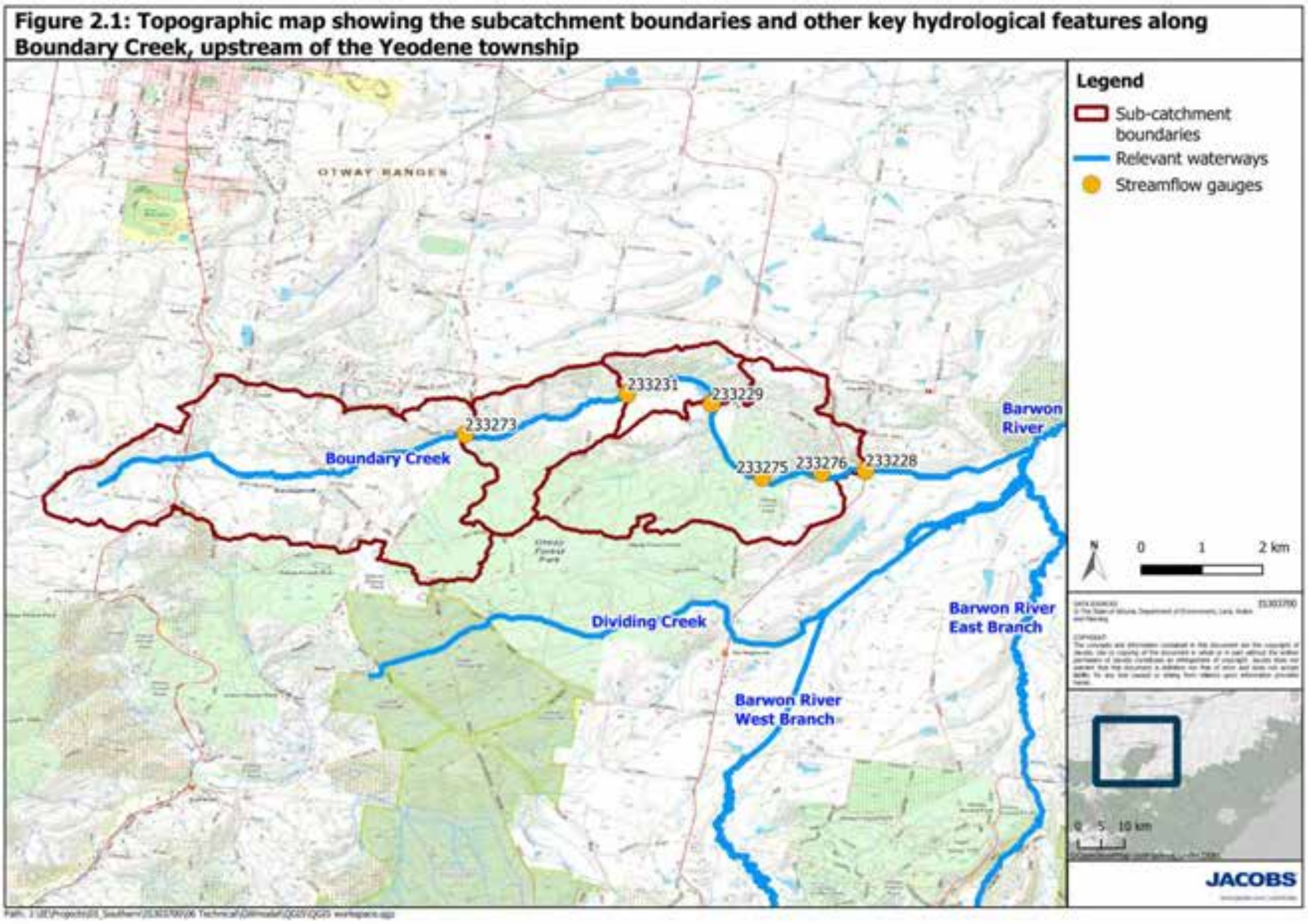


Figure 2-1: Topographic map showing the subcatchment boundaries and other key hydrological features along Boundary Creek, upstream of the Yeodene township

3. Approach to coupled groundwater surface water model

Previous groundwater modelling and subsequent detailed site investigations at Big Swamp and Boundary Creek in general has highlighted the fact that the regional groundwater flow model does not provide the spatial refinement required to represent the detailed system geometry important in simulating the local hydrogeology of the swamp. This is most graphically illustrated in the fact that the regional model does not include alluvial sediments that bound the creek and that dominate the surface geology through the swamp. While the alluvial sediments are not significant to the regional scale groundwater model, they are of particular significance when it comes to assessing groundwater behaviour in the swamp.

It is also recognised that the interaction between groundwater and surface water in Boundary Creek is of critical importance when assessing historic behaviour of the swamp and in considering the future condition of the swamp. An approach to modelling has been proposed that integrates surface water accumulation and flow in Boundary Creek with an unsaturated/saturated zone groundwater flow model of the underlying aquifer system in which Boundary Creek is represented as a boundary condition. The intention is that the surface water modelling will produce estimates of the wetted area and water level (stage) throughout Boundary Creek and the swamp and that these model outputs will be used as boundary conditions for the groundwater model. The groundwater model will simulate exchange fluxes (the transfer of water between Boundary Creek and the underlying aquifer system) and will also quantify groundwater levels throughout the swamp. The integrated model will, in theory provide quantitative estimates of stream flow through Boundary Creek and Big Swamp together with estimates of the exchange fluxes and resultant changes in groundwater levels throughout the swamp and investigate management scenarios.

Details of the surface water and groundwater models are provided in Sections 5 to 8 below.

A limited amount of historic river gauging and groundwater level measurements are available and have been used to help calibrate both the surface water and groundwater models. The duration and quality of the available groundwater data have provided challenges for the calibration process and currently limit the confidence with which the groundwater modelling results can be used to predict future aquifer behaviour.

Perhaps the biggest challenge in integrating the models is the different time scales that are of relevance. A groundwater model is typically required to consider behaviour over a period of months and years as the response times in groundwater can be slow. On the other hand, water flow in the creek is extremely dynamic and requires a fine time scale (in the order of seconds) to be able to capture the processes of importance. Linking models of this type is challenging and a significant level of simplification has been necessary to achieve modelling outcomes within the available time for this project. While a more rigorous coupling of the models may help to provide more accurate transient groundwater behaviour in the hours following a significant flow event, it is unlikely that this level of precision is required to assess the longer term impacts of long term flow releases in Boundary Creek.

4. Data review

4.1 Streamflow

Streamflow data was sourced from the Bureau of Meteorology's Water Data Online (2019) or provided by Barwon Water. The location of these streamflow gauges is shown in Figure 2-1. Table 4.1 below presents a summary of the available streamflow data acquired for this investigation. These streamflow gauges are situated along Boundary Creek, upstream of the Yeodene township. The record lengths of available daily data are presented in Figure 4-1. Note that daily flow is representative of the average daily flow over the 24-hour period to 0900 local time.

Table 4.1: Summary of available streamflow data

Gauge No	Gauge Description	Data Provider	Data frequency	Period of record	% Missing [1]	Notes [1]
233273	Boundary Creek at Barongarook	BoM	Daily / Irregular	Jul 2014 – Current	10%	57% of available data is best quality
233231	Boundary Creek at Upstream McDonalds Dam	BoM	Daily / Irregular	Dec 1989 – Current	72%	100% of available data is best quality
233229	Boundary Creek Downstream at Downstream McDonalds Dam	BoM	Daily / Irregular	Dec 1989 – Current	72%	[2 80% of available data is best quality; In 2019, data was missing for all flows greater than approx. 0.13 m^3/s (12ML/d)
233275A	Boundary Creek Upstream Big Swamp	Barwon Water	Predominately 15min intervals	Jun 2019 – Current	34%	[2 Missing data up to 10-days at a time; Available data is good quality; Data was missing for flows greater than approx. 0.13 m^3/s (12ML/d)
233276A	Boundary Creek Downstream Big Swamp	Barwon Water	Predominately 15min intervals	Jun 2019 – Current	32%	[2 Missing data up to 10-days at a time; Available data is good quality; Data was missing for flows greater than approx. 0.13 m^3/s (12ML/d)
233228	Boundary Creek at Yeodene	BoM	Daily / Irregular	Mar 1985 – Current	1%	90% of available data is best quality
ME763	Boundary Creek at Yeodene	Barwon Water / BoM	Daily / Irregular	Dec 2015 – Current	0%	100% of available data is best quality

[1] Where data were acquired as both a daily average or as all available points, the percentage of missing data and quality assessment was based on the daily timeseries.

[2] The gauge was installed to capture flows of 0 to 12 ML/day accurately and flows above this were not reported.

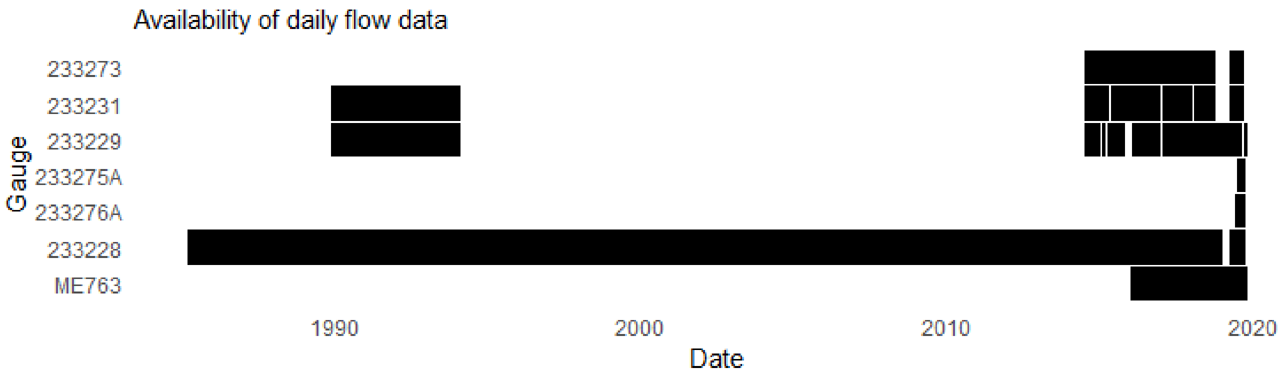


Figure 4-1: Timeline of available streamflow data

4.2 Climate

Gridded data of rainfall and Morton's wet areal potential evapotranspiration (PET) was sourced from SILO (Department of Environment and Science, 2019). SILO is a database of Australian climate data from 1889 to the present. Data are provided on a continuous, daily time-step and are constructed from observed data. Rainfall data was downloaded to the end of September 2019 while PET data was only available until the end of June 2019.

Subcatchment average rainfall and Morton's wet areal potential evapotranspiration was calculated using geospatial packages compatible with the Python 3 programming language. The average monthly evapotranspiration (expressed in units of mm/d) was derived and used to infill the missing data between July and September of 2019. Figure 4-2 presents the resulting catchment average monthly rainfall and evapotranspiration over the Boundary Creek at Yeodene catchment over the period 1990 – September 2019.

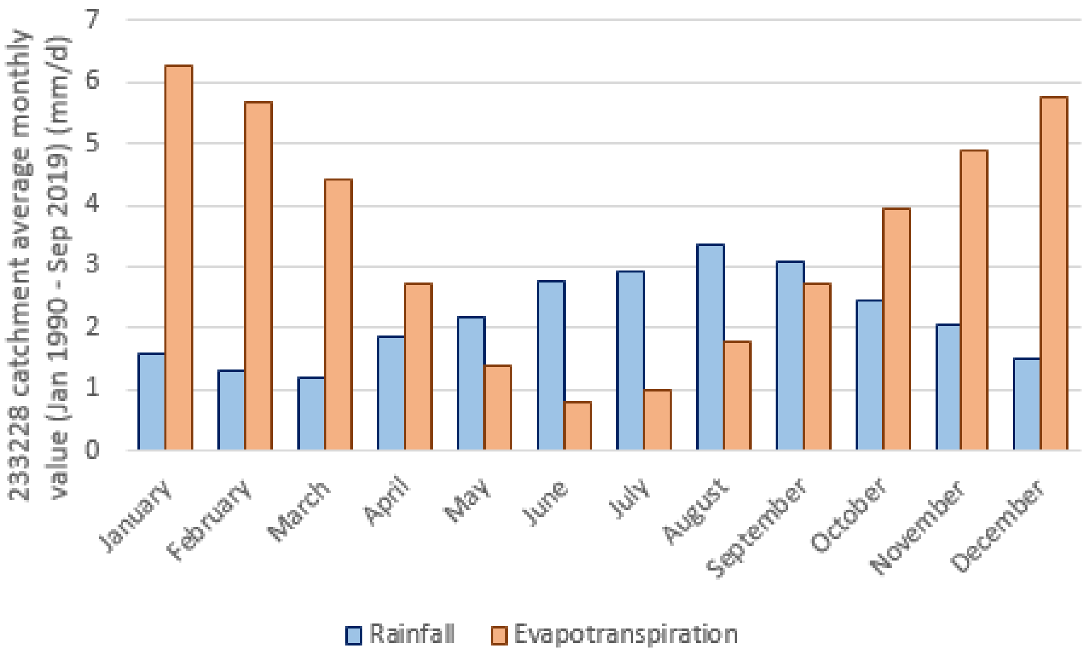


Figure 4-2: Monthly average rainfall and evapotranspiration (mm/d) which falls over the Boundary Creek catchment upstream of the Yeodene township (233229) between 1990 – Sep 2019.

4.3 Elevation

A number of topographic elevation datasets were obtained as part of the project, including:

- A 1 m gridded DEM of LiDAR captured in May 2019 provided by Barwon Water; and
- Statewide 10 m DEM (VICMAP Elevation DTM 10 m, (DSE, 2008))

4.4 Aerial photography

Aerial photography of the Swamp and immediate surround was captured as part of the LiDAR survey which was undertaken in May 2019 and represents the current catchment conditions. The resolution of the photography was 70mm. Lower resolution images for areas beyond the recent LIDAR data were sourced from Google Maps (Google Maps, 2019). All sources of aerial imagery were of sufficient quality and accuracy for modelling purposes.

5. Surface water models

The surface water modelling involved two modelling approaches – rainfall runoff modelling and hydraulic modelling. These are discussed in the following sections.

5.1 Objectives

The surface water models, rainfall runoff and hydraulic, were developed for the following purposes:

- The rainfall-runoff model objectives are to:
  - Calculate information on the streamflow in Boundary Creek downstream of McDonalds Dam and at Yeodene to infill missing gauged data;
  - Determine the catchment runoff for the intermediate catchment between McDonalds Dam and Yeodene;
  - Undertake streamflow loss analysis; and
  - Determine monthly flow patterns to help develop transient data sets for the groundwater model.
- The hydraulic model objectives are to:
  - Provide surface water level conditions (both the inundated area and levels or stage) for inputs to the groundwater model.
  - Assess different management scenarios by determining the extent of inundation and losses from the surface water system.

5.2 Rainfall runoff model

In order to understand the hydrological characteristics of the catchment, a rainfall-runoff model was developed. In addition to characterising the catchment in terms of hydrology, the model was used to infill missing streamflow data and estimate runoff from the subcatchment between McDonalds Dam and Yeodene.

A continuous daily GR4J rainfall-runoff model was created to produce an estimate of the surface runoff in response to input climate conditions (represented by a timeseries of both rainfall and potential evapotranspiration). The transformation of climate inputs into runoff is controlled by the model structure and parameters. The GR4J sub-catchment breakup is shown in Figure 5-1. More detail on the GR4J model is provided in Appendix A.

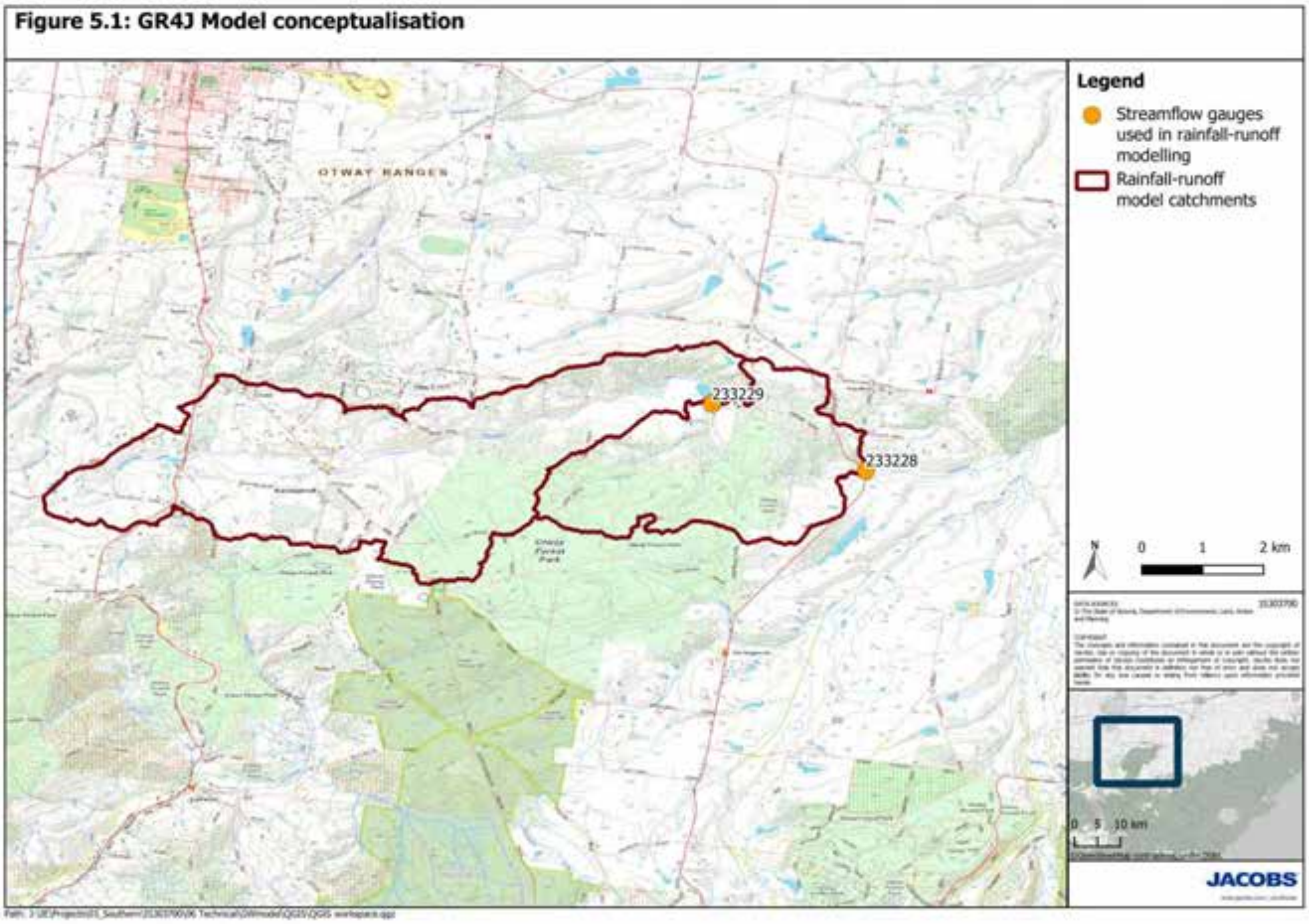


Figure 5-1: GR4J Model conceptualisation

The rainfall-runoff model was calibrated to the most relevant gauge with an acceptable length of record namely; the gauge downstream of McDonalds Dam (233229) and the Yeodene (233228) gauge. The two had a period of concurrent data from 01/01/2015 – 30/09/2019 which was used for calibration and validation as set out in Table 5.1. Initial results indicated that data and model setup did not support two parameter sets; one for the upstream catchment to the gauge downstream of McDonalds Dam and another set to the Yeodene gauge. The model was therefore calibrated to the Yeodene gauge only.

The resulting calibration together with diagnostic plots is shown in Figure 5-2 with further details in Appendix A. These results demonstrate that the model is able to replicate the rainfall-runoff response of the catchment.

Table 5.1: Rainfall Runoff model calibration and validation periods

Model period	Calibration	Validation
Warm-up period	01/07/2014 – 31/12/2014	1/07/2017 – 31/12/2017
Simulation period	01/01/2015 – 31/12/2017	1/01/2017 – 31/12/2018

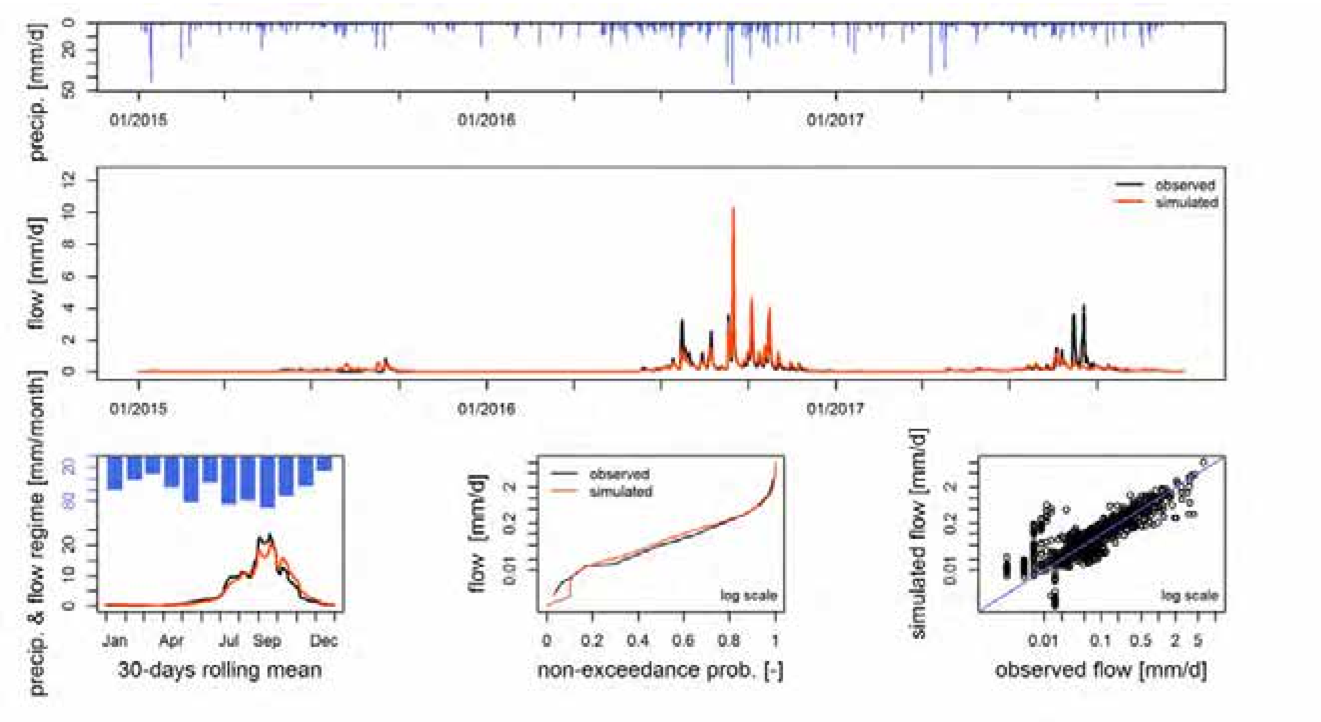


Figure 5-2 : Yeodene (233228) gauge calibration diagnostic plots

The rainfall-runoff model was run over the full simulation period (01/01/2015 – 30/09/2019). Figure 5-3 presents a flow duration curve of the timeseries outputs for the following:

- Simulated flow at the gauge location 233229: Boundary Creek at Downstream McDonalds Dam
- Simulated flow at the gauge location 233228: Boundary Creek at Yeodene
- Simulated catchment runoff between the two gauges.

A plot of average monthly flow (ML/d) is presented in Figure 5-4.

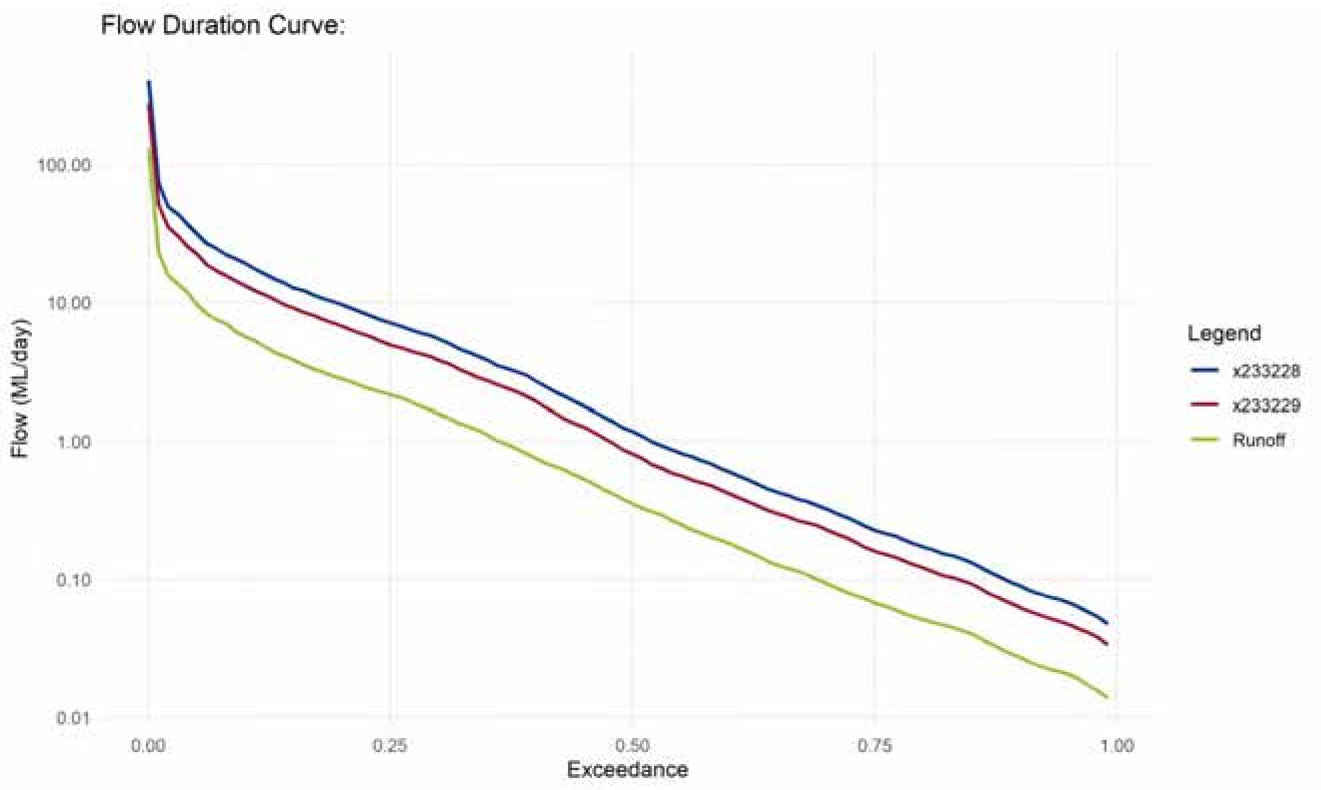


Figure 5-3: Exceedance curve of flow over the full record of simulation (1/01/2015 – 30/09/2019).

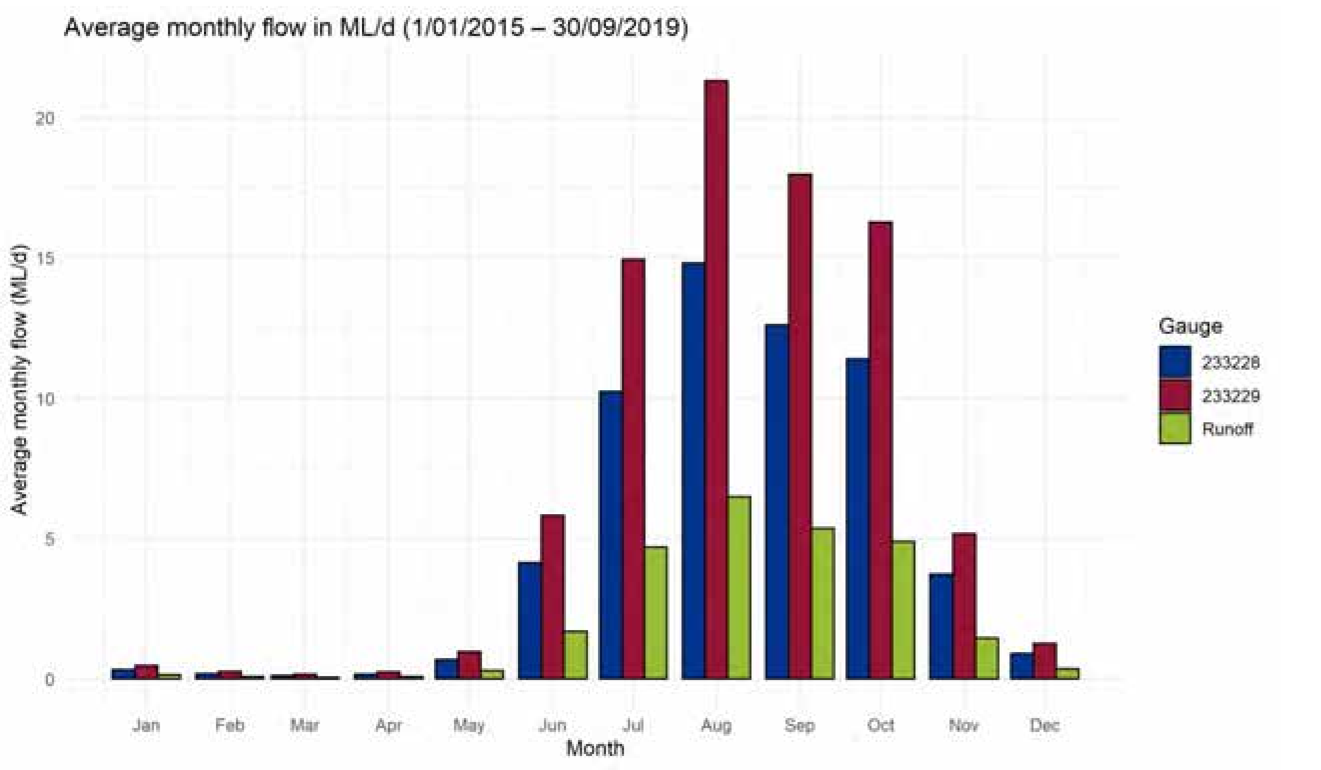


Figure 5-4: Average monthly flow (ML/d) over the full record of simulation (1/01/2015 – 30/09/2019).

5.2.1 Loss analysis

Flow losses in the downstream sub-catchment were analysed using the stream flow data with infilling of missing data from the rainfall-runoff model. The difference in flow between the gauge downstream of McDonalds Dam (233229) and the Yeodene (233228) gauge was computed. A negative change is indicative of losses from the surface water, while a positive change indicates a gain. Note that this calculation does not explicitly account for runoff from the downstream subcatchment and hence the losses may be greater than calculated.

Figure 5-5 presents the results from the loss analysis. These results indicate that on average, between September and October catchment runoff (for the catchment bounded by the streamflow gauges 233229 and 233228) results in a net gain in streamflow to Boundary Creek. From November through to August however the system appears to result in a net loss of streamflow, with the magnitude of losses greatest in April through to August. The losses, assumed to represent seepage to groundwater, range from 0.5 ML/day to 2.5 ML/day.

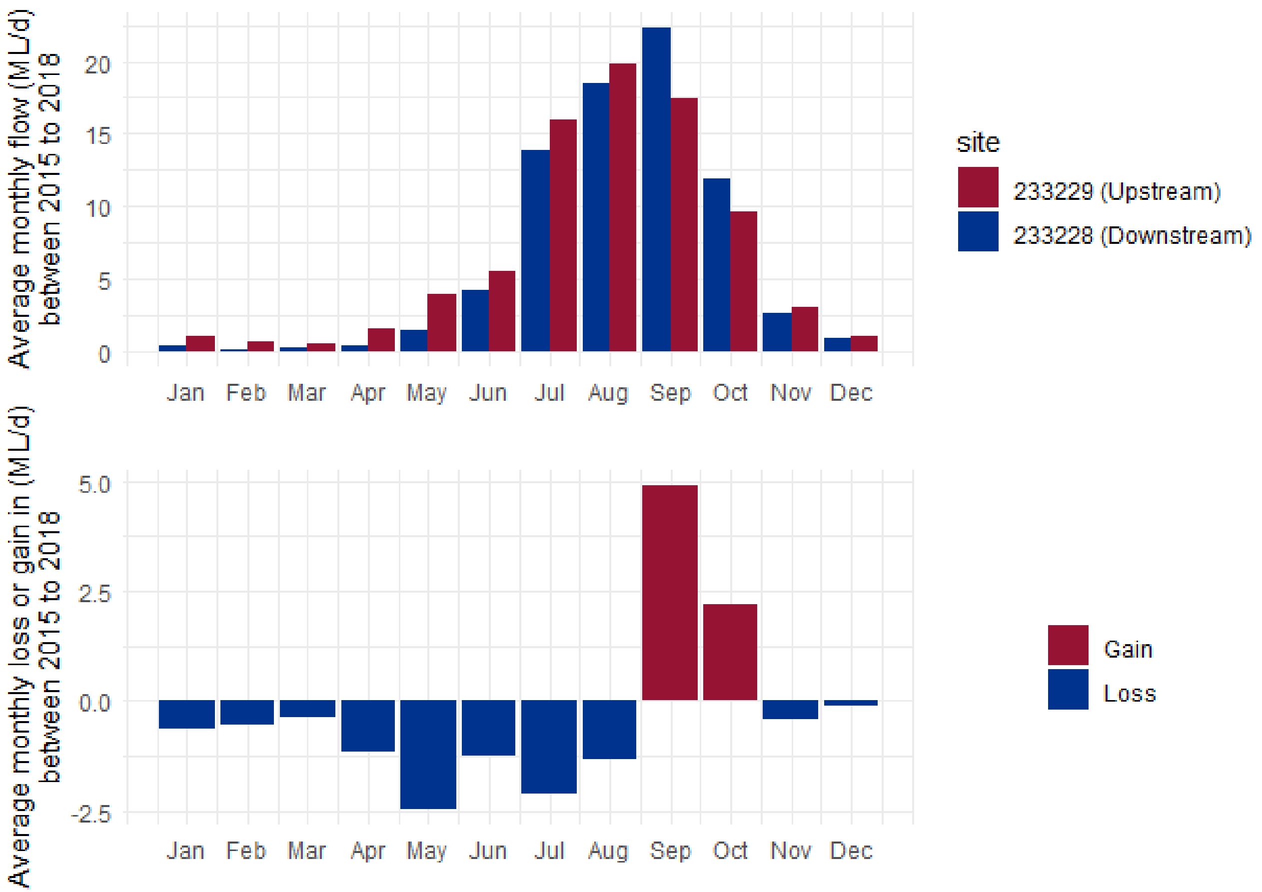


Figure 5-5: Average monthly flow the key streamflow gauges (233229 and 233228) and average monthly loss/gain to Boundary Creek occurring between these two gauges.

5.2.2 Discussion and recommendations

The daily rainfall-runoff model was able to reasonably replicate the hydrological characteristics of Boundary Creek; however, the model has been calibrated (and validated) over a relatively short period due to limited available data. There are a number of recommendations to improve the calibration for potential future assessments.

Suggested model improvements:

- At present the model assumes that McDonalds dam was full and did not affect runoff as sufficient data to characterise the dam were not available (stage-storage-elevation data, usage data, etc). It is recommended that the dam be included in future revisions of the model. It is expected that the inclusion of this information will improve the model calibration.
- Presently Barwon Water releases 2 ML/d into the Boundary Creek system and it is recommended that this inflow be considered explicitly rather than implicitly in the rainfall-runoff model. This will allow transparent assessment of supplementary flows.
- As additional streamflow data becomes available it is recommended that the rainfall runoff model be re-calibrated (and validated) against this additional information. Further, once the newly installed gauges immediately upstream and downstream of Big Swamp have an adequate period of good quality record, the rainfall runoff model should be validated against this data. This could then allow for an analysis of the losses over the swamp and upstream of the swamp to McDonalds Dam separately.
- Once the additional data and the model is updated to incorporate the changes above, it should be calibrated with two sets of parameters for each sub-catchment. This would provide a better understanding of losses in the downstream catchment.

Additionally, the rainfall-runoff model could also be used to:

- Simulate longer timeseries of streamflow records and catchment runoff.
- Investigate the expected impact of climate change on runoff using, for instance, the DELWP Climate Change Guidelines (DELWP, 2016).
- Generate a drought sequence, such as the Millennium Drought (which is largely missing from the available streamflow records).

These assessments could provide insights into drying characteristics in the swamp under different climatic conditions and provide an understand of the continued effectiveness of management scenarios.

5.3 Hydraulic modelling

The surface water flow paths in Big Swamp are complex with flow breaking out of the watercourses to form dynamic overland flow paths that lead to ponding and inundation across the swamp. To investigate and map the extent of surface water in Big Swamp a hydraulic model was developed. Given the nature of the inundation, TUFLOW, a fully 2D hydraulic modelling package, was adopted for this study. TUFLOW calculates the movement of water across a regular grid that represents the topography of the area being modelled.

The TUFLOW hydraulic model to calculate the extent, depth and level of surface water in Big Swamp for a variety of historic and future management flows. The model provides an understanding of the way water moves through the swamp, including an understanding of the inundation extent, levels and water depths. In addition, the hydraulic model has been built to be loosely coupled with the groundwater model, through the provision of a level timeseries to characterise head dependent boundary conditions included in the groundwater model. By way of feedback, the groundwater model is able to inform the loss parameters included in the surface water model.

The following sections provides details of the hydraulic modelling, including model schematisation, inputs and results.

5.3.1 Model conceptualisation

The model is required to simulate the surface water movement within Big Swamp and the conceptual representation of the major hydrologic features are shown in Figure 5-6. The physical extent of the model was designed to cover the entire area of the swamp as shown in Figure 5-7.

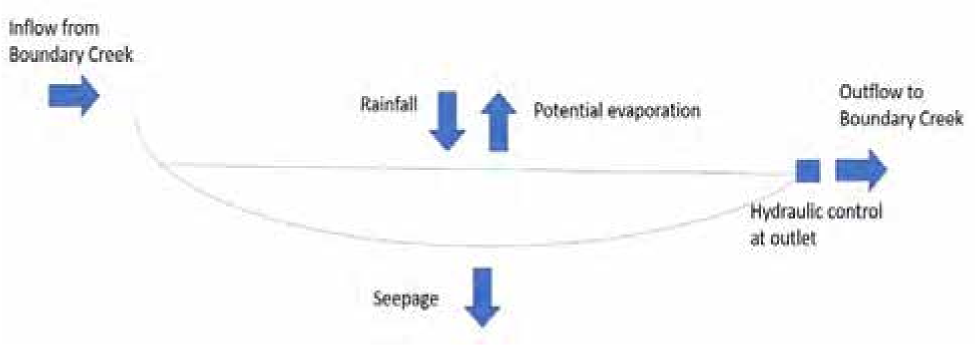


Figure 5-6: Conceptual model of the major hydrologic features included in the hydraulic model

Inflows to the model occur at the upstream boundary and through catchment runoff, while outflows occur at the downstream boundary and through losses to evapotranspiration and to groundwater. In addition to these, the TUFLOW model incorporates culverts and channels, used to modify the topography, to satisfy the conceptual understanding of the systems flow path. Each of these concepts are explored in further detail below.

The hydraulic model covers an area of approximately 1.3 km^2, extending from the streamflow gauge south of McDonalds Dam, 233229, to the gauge on Boundary Creek at Yeodene, 233228, which is adjacent to the intersection of Colac-Forest Road with Boundary Creek.

The topography of the area was represented by a Digital Elevation Model (DEM) developed from the LiDAR data.

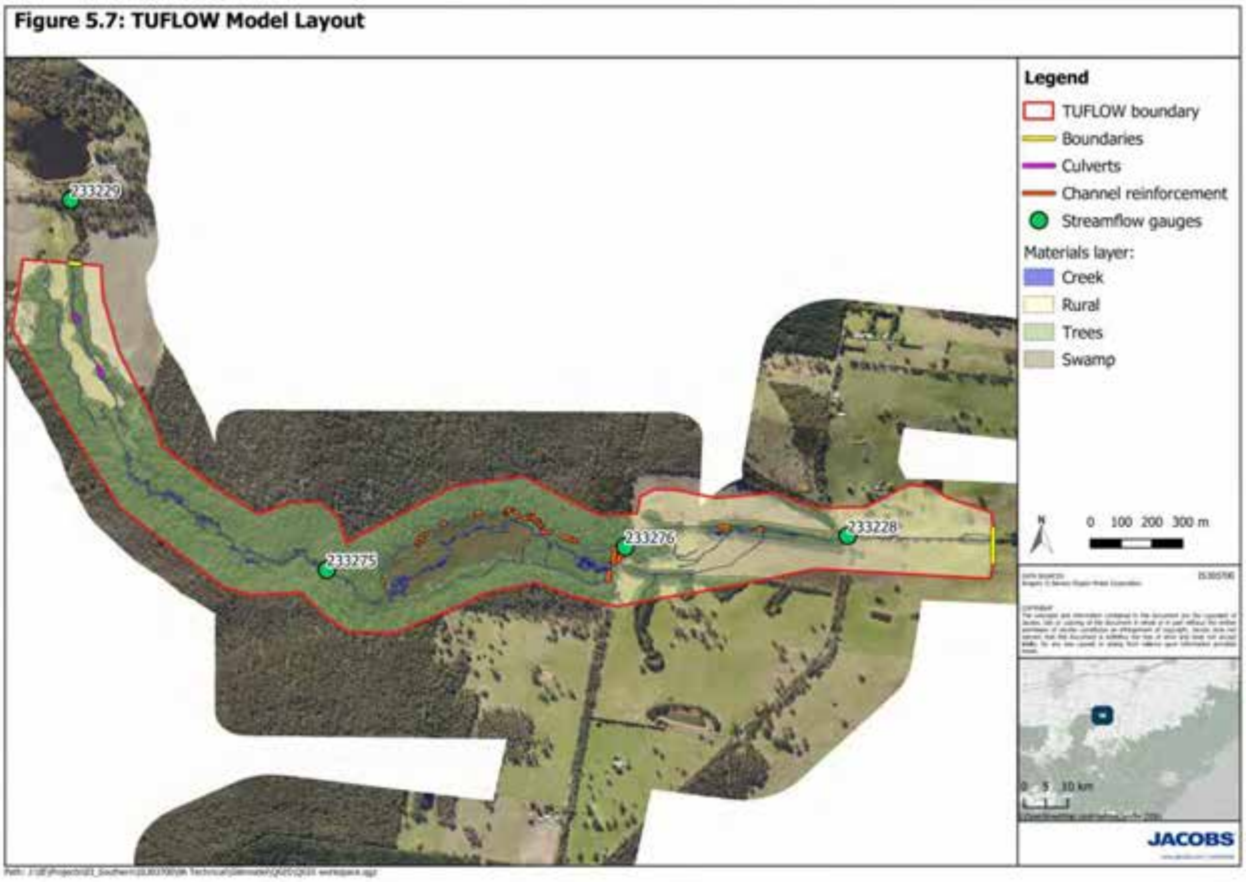


Figure 5-7: TUFLOW Model Layout

TUFLOW version 2018-03-AD-iSP-w64 was used for this assessment and was run using TUFLOW HPC computational scheme.

5.3.2 Topography

The topography of the model is based on the LiDAR data. The resolution of the DEM is an important part of the model that dictates its accuracy; however, model runtimes are directly proportional to the DEM resolution. To balance the model run times whilst still providing an accurate representation of the creek channels, a 2 m grid resolution was selected. Each square grid element contains information on ground topography and surface resistance to flow (Manning's n value) sampled from the DEM and aerial photography at 1 m spacing. This DEM is considered to be a high-resolution model.

The topography was modified in a number of cases to better represent actual ground levels and to reproduce observed flow. The following topography modifications were undertaken in order to force water to flow along known flow paths:

- TUFLOW terrain modifications for sections of Boundary Creek, especially along the Northern Channel
- TUFLOW terrain modifications for flow along the agricultural drain and fire trench where it meets with Boundary Creek

Figure 5-7 shows the locations of channels and culverts and terrain modifications to represent existing conditions over the study location.

5.3.3 Boundary conditions

Boundary conditions in the TUFLOW model add or remove water from the model, as illustrated in Figure 5-6 the following boundary conditions were incorporated into the model:

- Upstream inflow – An external inflow was applied to the TUFLOW model at the upstream boundary to represent flows in Boundary Creek. The location of this boundary is shown in Figure 5-7.
- Swamp catchment inflow – Flows generated from the catchment below the dam were applied to the model. These flows were applied as a flow timeseries and distributed along the channel.
- Downstream outlet – Flow at the downstream boundary was represented by a rating curve or discharge – level boundary. This downstream boundary is located sufficiently downstream of the Site (Figure 5-7), to minimise the influence of boundary assumptions on the flood model results.
- Loss or seepage to groundwater – The Green-Ampt infiltration losses were used to calculate the losses from the surface water. The Green-Ampt parameters were taken from the USDA soil types classification (Rawls, et al. 1983) for a 'Sandy Clay' type soil, presented in Table 5.2.
- Evapotranspiration / Rainfall – An internal rainfall boundary applies a rainfall and evapotranspiration depth to all active cells within the model domain, based on an input timeseries. For model calibration rainfall and evapotranspiration were both incorporated and applied to the model as a timeseries of effective rainfall.

Table 5.2: USDA soil types classification for Sandy Clay

USDA Soil Type	Suction (mm)	Hydraulic Conductivity (mm/hr)	Porosity (as a fraction)
Sandy Clay	239.0	0.6	0.321

5.3.4 Hydraulic structures

Three culvert structures were incorporated into the model upstream of Big Swamp, as shown in Figure 5-7. These culverts were included in the model as embedded 1D elements. The flow through the structures is assumed to be unimpeded by the presence of flood debris and therefore no blockage factors were applied to any structures. This assumption is not considered to impact results.

5.3.5 Manning's 'n' coefficients

The roughness layer, or Manning's 'n' layer, is based on areas of different land-use types, which were determined from aerial photography and site inspections. These land use types (referred to as 'materials') are presented in Figure 5-7 and the adopted coefficients are summarised in Table 5.3. The values used are based on the range of values provided in the Australian Rainfall and Runoff (ARR) (Ball et al., 2019).

Table 5.3: **2D domain Manning's 'n' Values**

Land Use	Manning's 'n'
Creek	0.06
Urban	0.04
Trees	0.09
Swamp	0.10

5.3.6 Calibration

Given that the hydraulic model is to be coupled to the groundwater model it was necessary to have a common calibration period. Section 2 outlines the available streamflow data and the borehole data that is required to calibrate the groundwater model is limited to the period 12/06/2019 to 02/09/2019. The hydraulic model was calibrated for this period.

The gauge downstream of McDonalds Dam (233228) has recently been impacted by road and culvert works undertaken by Council. This resulted in the gauge being offline for a period of time and following re-instatement the site has required re-establishment of the stage-discharge relationship for monitoring of flow. Given the limited flow ranges experienced since reinstatement, the streamflow ratings have been confined to within banks flow and therefore flow above approximately 0.09 m^3/s (7.8 ML/day) has not been rated. For this reason, the available flow series monitoring is missing flow peaks above this range and therefore it was necessary to infill these gaps.

As the temporal resolution required for the hydraulic model is sub-daily it was not possible to use results of the rainfall runoff model which has a daily resolution. As a result, streamflow data for June to September 2019 was infilled through correlation with the upstream gauge at Barongarook. Flows at Barongarook were offset by 8.5 hours and increased by 22% to infill flows downstream of McDonalds Dam. This was based on a sample of 17 events which were analysed, and the mean differences calculated. Of the events analysed 13 had peak flows with a ratio of +/- 10% and 12 were within +/- 2 hours. This is considered to be of sufficient accuracy for the purposes of the modelling. Further, with these assumptions the model was able to calibrate to the downstream gauge. An example output of this infilling process is shown in Figure 5-8.

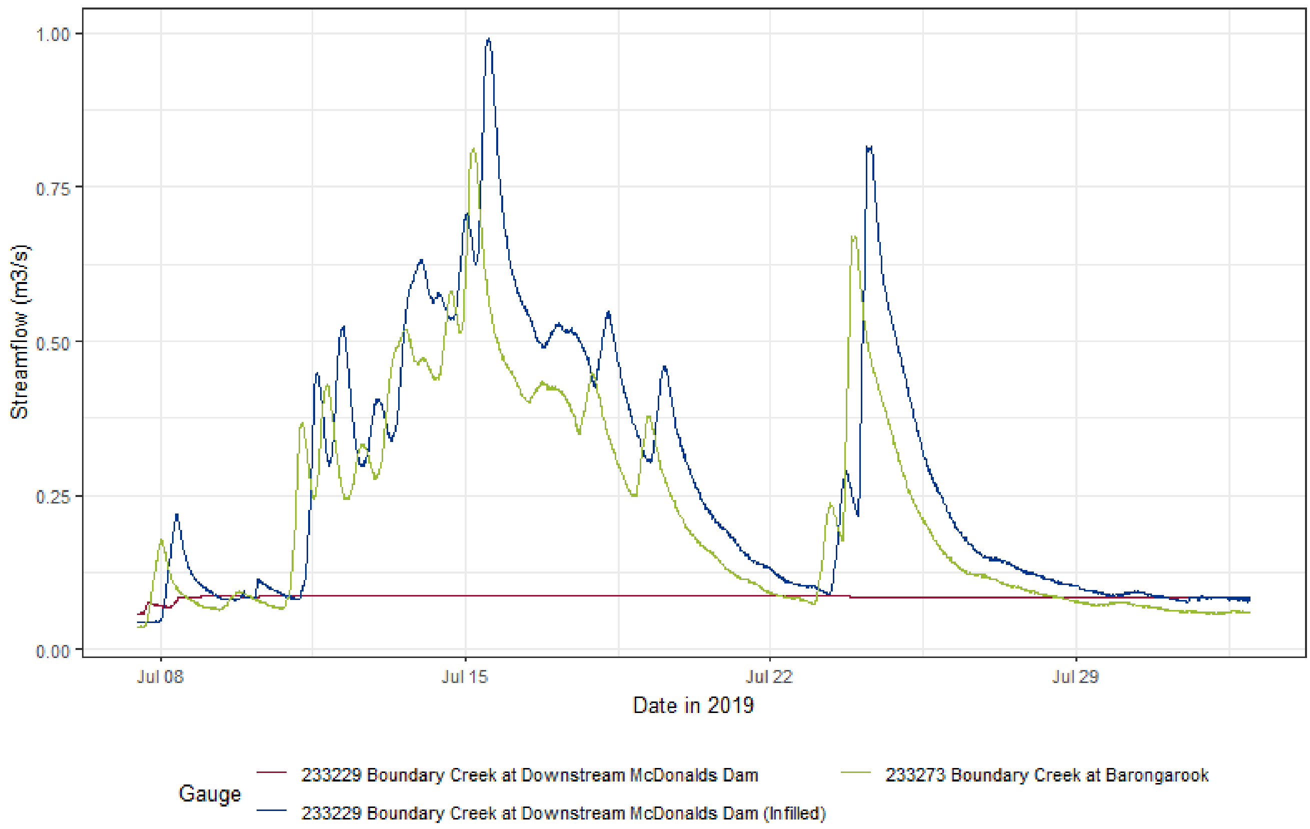


Figure 5-8: Infilling of streamflow at 233229 (Boundary Creek at downstream McDonalds Dam) through application of peak ratios with 233273 (Boundary Ck at Barongarook)

The results of calibration are presented in Figure 5-9, which shows a comparison of the observed and modelled flow at the four gauge locations within the hydraulic modelling domain (see Figure 5-7) and Figure 5-10 presents the maximum water level over the calibration record.

The results in Figure 5-9 represent an excellent fit to the data indicating that hydraulic model can appropriately predict the flow at the gauge locations. Note that for the Big Swamp gauges which had missing peaks in their records (233275A and 233276A), where there is data at these gauges for lower flows, there is a slight overestimate of discharge of around 2.5ML/s. The sensitivity of this tested by increasing losses from the surface water system and it was found that maximum water levels and extents did not significantly alter.

The calibration results at Yeodene (233228) are excellent across the full flow record indicating that the model provides an accurate simulation of flow during periods of low, peak and recession streamflow.

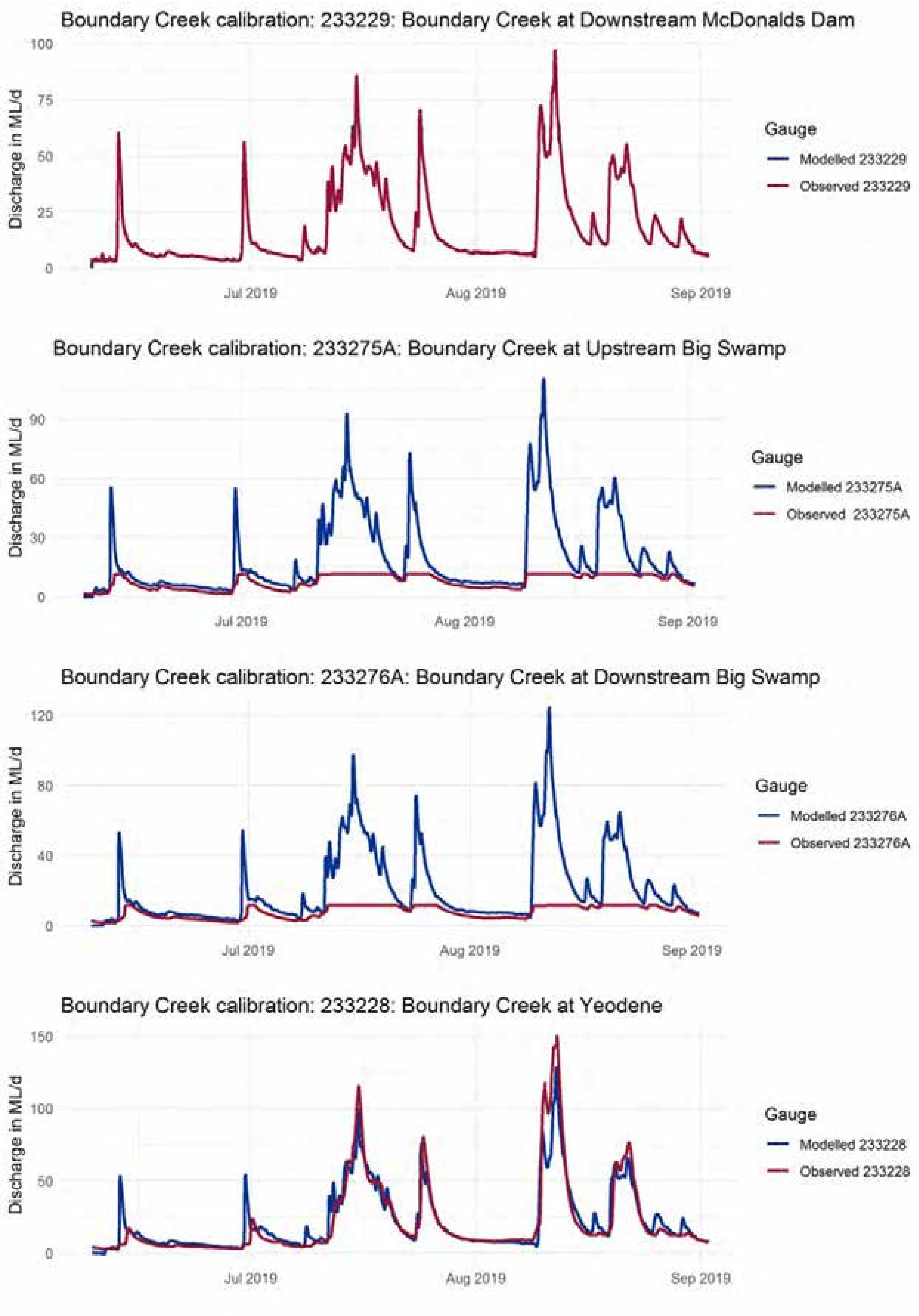


Figure 5-9: Calibration of the hydraulic model at the gauges in the modelling domain over the 2019 calibration period

Figure 5.10: Maximum water level over the swamp for the 2019 calibration period

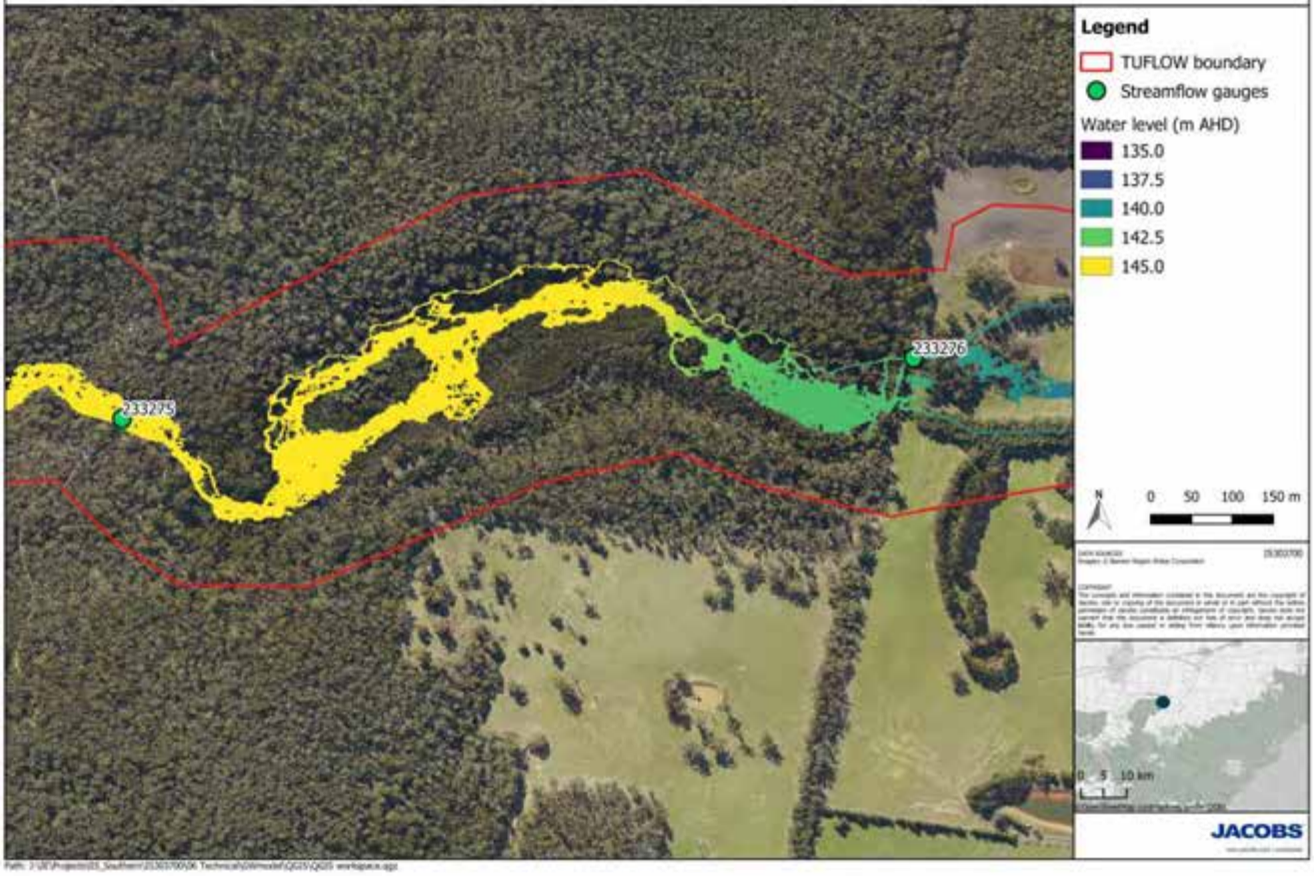


Figure 5-10: Maximum water level over the swamp for the 2019 calibration period

5.3.7 Discussion and recommendations

The hydraulic model is calibrated well to the available data, particularly at Yeodene gauge demonstrating its suitability to investigate future flow scenarios. While the model is well calibrated, there are a number of recommendations that would improve certainty in the results, in particular the interaction between surface water and groundwater, these are:

- As additional data becomes available it is recommended that the hydraulic model be calibrated or validated to additional events. This would increase confidence in the modelled outputs.
- The new streamflow ratings for the gauges upstream of the Yeodene gauge do not contain any high flow information due to limited high flow events to inform development of stage-discharge relationships and subsequent flow ratings. When this information becomes available the results of the hydraulic modelling should be compared to this information.
- The modelled hydraulic water levels should be compared to the borehole monitoring records where these have recorded water levels above the ground surface.
- Due to time limitations only one iteration between the hydraulic model and the groundwater model was possible and this has not allowed an update of the hydraulic model loss parameters (Green & Ampt) based on the groundwater model results. It is expected that further iteration with the groundwater model will improve loss estimates and potentially improve the low flow calibration in the swamp where modelled results were noted to be slightly higher than the recorded flows.
- The results from the hydraulic model are used to inform future data collection programs to demonstrate the effectiveness of any management plan. This additional data will also increase the understanding of the system and can be used to improve the numerical models.

6. Surface water scenario modelling

Six scenarios have been developed for the coupled surface water groundwater model to investigate a variety of management options. These scenarios were designed to replicate conditions under low and high flow over short periods of time (6 months) and a longer term scenario with typical average flows. All scenarios were run with and without a hydraulic barrier at the eastern end of the swamp to determine the influence of the barrier on inundation areas and groundwater levels.

These scenarios have been designed to increase the area inundated in the swamp and to raise groundwater levels. This section presents the surface water results for these scenarios as well as for additional scenarios that assume flows that are intermediate between the maximum and minimum flow releases.

All scenarios assume dry conditions with creek flow entirely supported by supplementary flow released immediately downstream of the dam. That is, they represent worst case conditions for flow in the creek and swamp. The scenarios have been designed to include an upper (20 ML/d) and lower estimate (2 ML/d) of the supplementary flow that may be required and hence provide limits within which results can be interpolated for intermediate rates of supplementary flow.

The additional intermediate scenarios have been completed to allow interpolation of results between the 2 ML/d and 20 ML/d extremes of flow releases.

Scenarios 5 and 6 are transient groundwater model scenarios run over a ten-year period using a repeating sequence of assumed monthly flows where the boundary conditions for the creek are obtained from the Scenario and Intermediate runs as described below. In this instance, Scenarios 5 and 6 were not run explicitly through the hydraulic model as the model runtime would have been infeasible (more than 2 months for 10 years of model time).

A consistent set of definitions for the scenarios has been determined as outlined below, together with the intermediate scenarios:

- **Scenario 1** assumes a constant release of 2 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Scenario 2** assumes a constant release of 2 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier.
- **Intermediate 1** assumes a constant release of 5 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Intermediate 2** assumes a constant release of 5 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier.
- **Intermediate 3** assumes a constant release of 10 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Intermediate 4** assumes a constant release of 10 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier.
- **Scenario 3** assumes a constant release of 20 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Scenario 4** assumes a constant release of 20 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier
- **Scenario 5** is a ten year **transient** simulation that assumes an annual cycle of flows with no hydraulic barrier. This was not assessed through a single surface water model run.
- **Scenario 6** is a ten year **transient** simulation that assumes an annual cycle of flows with a hydraulic barrier. This was not assessed through a single surface water model run.

6.1 Surface water scenario model set up

A constant supplementary flow corresponding to each scenario was applied as a steady state release to Boundary Creek with no other inflow. In all other respects the hydraulic model was setup as for the calibration run for the supplementary flow scenarios with no hydraulic barrier.

For the hydraulic barrier scenarios, a levee was applied to the downstream end of the swamp and the height of the levee was set at a level of 142.5 m AHD as shown in Figure 6-1. Over the cross-section depicted in Figure 6-1, the maximum height of the levee above the surface was 1.3m, with a typical height of 0.5m. The location of the barrier is shown in Figure 6-4

Figure 6-4. This barrier blocked the 'agricultural drain' and 'fire trench' flow paths forcing water to pond upstream of the barrier. Eventually, the water would pond to a height that would discharge to the northern channel.

6.2 Scenario results

Figure 6-4 to Figure 6-11 present the modelled extent and level of inundation across the swamp under each scenario. An increase in the volume released from McDonalds Dam from 2 ML/d to 5 ML/d causes the flow path to split and move towards the centre of Big Swamp. Further increases up to a release of 20 ML/d simply causes a buffering effect of the area inundated. Furthermore, the inclusion of the hydraulic barrier shows little effect on the extent and depth of the inundation when the flow rate is increased from 2 ML/d.

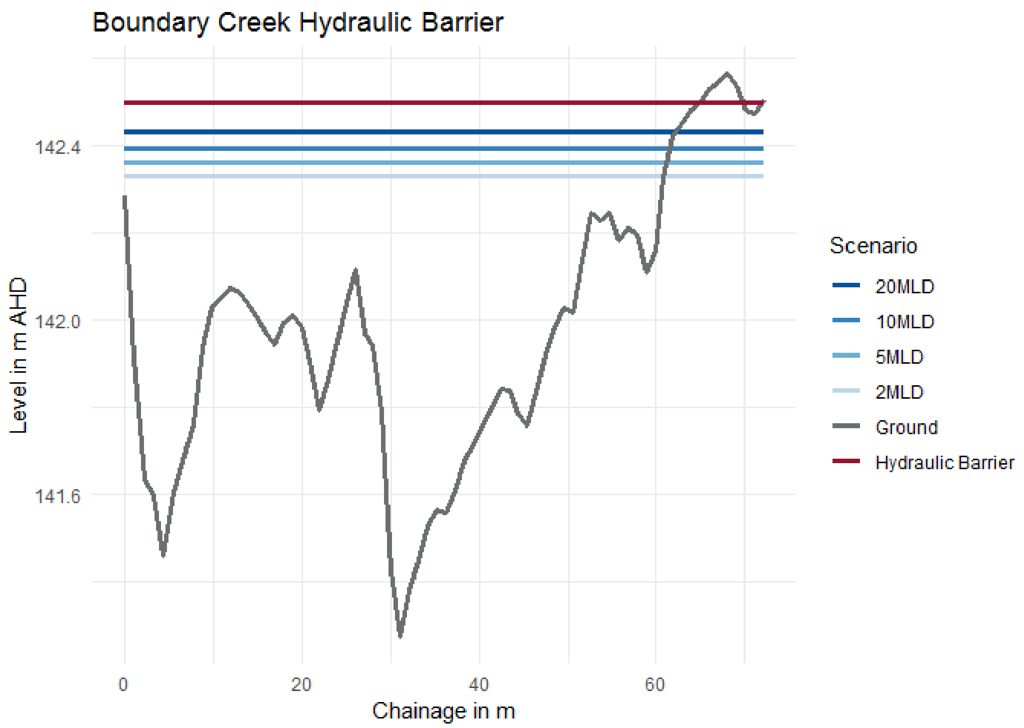


Figure 6-1: Peak water levels immediately adjacent to the hydraulic barrier for various scenarios

Figure 6-2 presents a timeseries of the modelled flow rate at the Yeodene gauge for each scenario. As expected, the system reaches steady state conditions more rapidly under the higher flow rate scenarios. The Scenario 1 (2 ML/d supplementary flow) results in a steady state flow of 1.1 ML/d at the Yeodene gauge. When the hydraulic barrier is incorporated (Scenario 2) a flow rate of 0.9 ML/d is achieved compared to the 1 ML/d requirement at this gauge. For both the 20 ML/d scenarios (Scenario 3 and Scenario 4) a steady state flow of 3.7 ML/d at Yeodene was calculated.

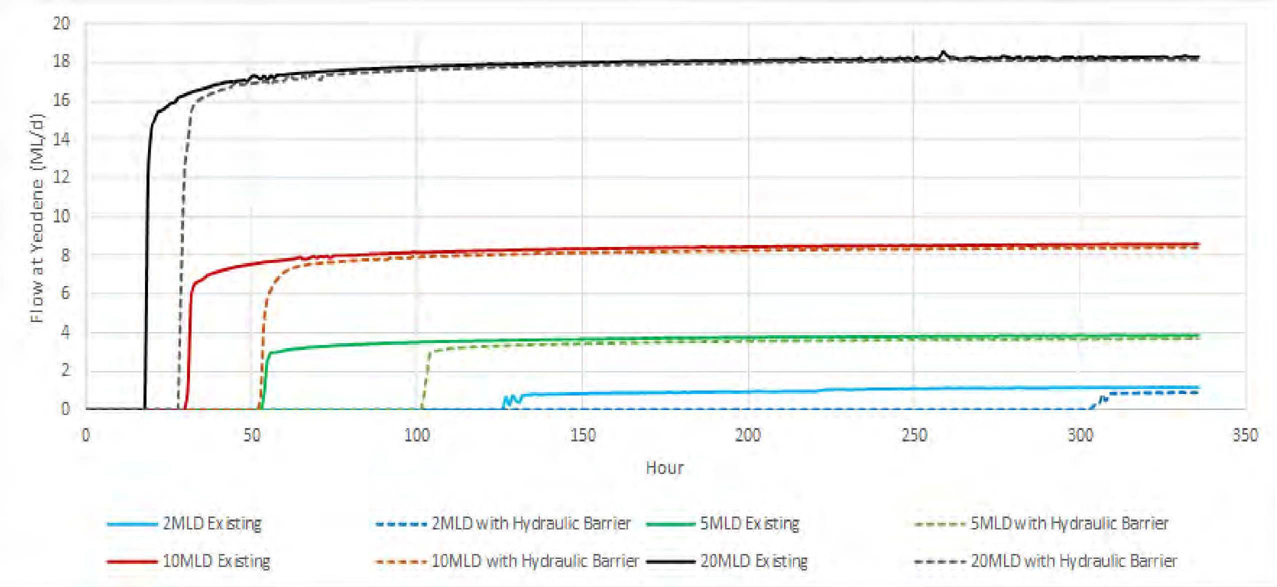


Figure 6-2: TUFLOW modelled flow under each scenario at the streamflow gauge 233228, Boundary Creek at Yeodene

For each scenario the volume of infiltration over the swamp under steady state conditions was derived, with the results presented in Figure 6-3. In order to derive this volume from the infiltration rate results at the final timestep which was at steady state (see Figure 6-2). This was calculated for the area of inundation over the swamp, which was defined as being bounded by the streamflow gauges 233275A and 233276A.

Figure 6-3 shows that an increase in the magnitude of supplementary flow results in an increased loss in Big Swamp. Similarly, the inclusion of the hydraulic barrier also increases the volume lost to infiltration (ie groundwater).

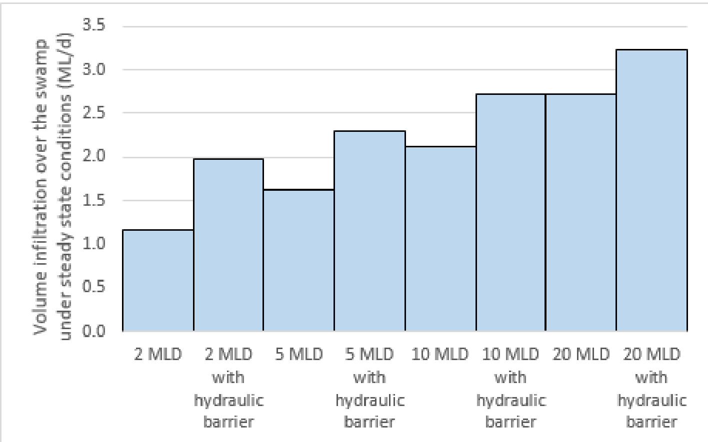


Figure 6-3: Volume of infiltration (ML/d) over the swamp under steady state conditions for each modelled scenario

The area of inundation over Big Swamp under each scenario is presented in Table 6.1 with the water levels immediately adjacent to the hydraulic barrier presented in Figure 6-1. These results show that the area of inundation in the swamp and depth adjacent to the barrier increases with an increased upstream flow rate and increases with the presence of the hydraulic barrier. Although the additional area of inundation due to the hydraulic barrier is diminished with higher supplementary flows. This is due to the relatively minor increases in inundation extent immediately behind the hydraulic barrier as illustrated in Figure 6-5, Figure 6-7, Figure 6-9 and Figure 6-11. Any increased inundation is due to the introduction of new flow paths upstream of the pool caused by the hydraulic barrier.

Table 6.1: Area of inundation over the swamp for each scenario

Flow released from McDonalds Dam (ML/d)	Area of inundation under existing model structure (m^2)		Area of inundation with the inclusion of the hydraulic barrier (m^2)	
	m^2	%	m^2	%
2 ML/d	17,800	8.5	27,500	13.0
5 ML/d	25,100	11.9	34,100	16.2
10 ML/d	33,300	15.8	41,100	19.5
20 ML/d	41,700	19.8	48,500	23.0

6.3 Discussion

The hydraulic model has been used to investigate the effectiveness of a number of scenarios designed to increase both, the surface water inundation and groundwater levels in the swamp as required to manage the production of and export of acidic water from the swamp. The effectiveness of the scenarios in increasing groundwater levels is discussed in Section 8 and a discussion of the surface water results is provided below. The hydraulic modelling has demonstrated the following:

- The introduction of supplementary flow inundates the swamp. The 2ML/d does not increase the extent of inundation beyond what is typically experienced in late winter early spring. The supplementary flow becomes more effective with increasing flow, for instance a supplementary flow of 5 ML/d results in an increase in inundation extent of 40% over the 2 ML/d supplementary flow. A supplementary flow of 10 ML/d results in an increase in inundation extent of 85% and a supplementary flow of 20 ML/d results in an increase in inundation extent of 130% compared to the 2 ML/d supplementary flow.
- The hydraulic barrier at the downstream end of the swamp was found to be effective in increasing the aerial extent of inundation compared to scenarios that simulate supplementary flows on their own. However, there are diminishing returns in terms of the area inundated with increased supplementary flows. This is due to the topographic properties of the pool immediately upstream of the hydraulic barrier. Comparing Figure 6-5, Figure 6-7, Figure 6-9 and Figure 6-11 and the results in Table 6.1, it can be seen that the extent of the pool does not significantly increase with increased flow. These results indicate that there is limited benefit in doubling the supplementary flow from 10 ML/d to 20 ML/d with the hydraulic barrier located at the end of the swamp.

While the results presented here demonstrate that the scenarios would be effective in achieving the management aims, there would be more benefit in installing multiple hydraulic barriers distributed through the swamp to increase the extent of the inundation. To maximise the benefit of additional hydraulic barriers the locations should be selected to inundate areas of potential acidity where the topography allows. This is further discussed in Section 9.

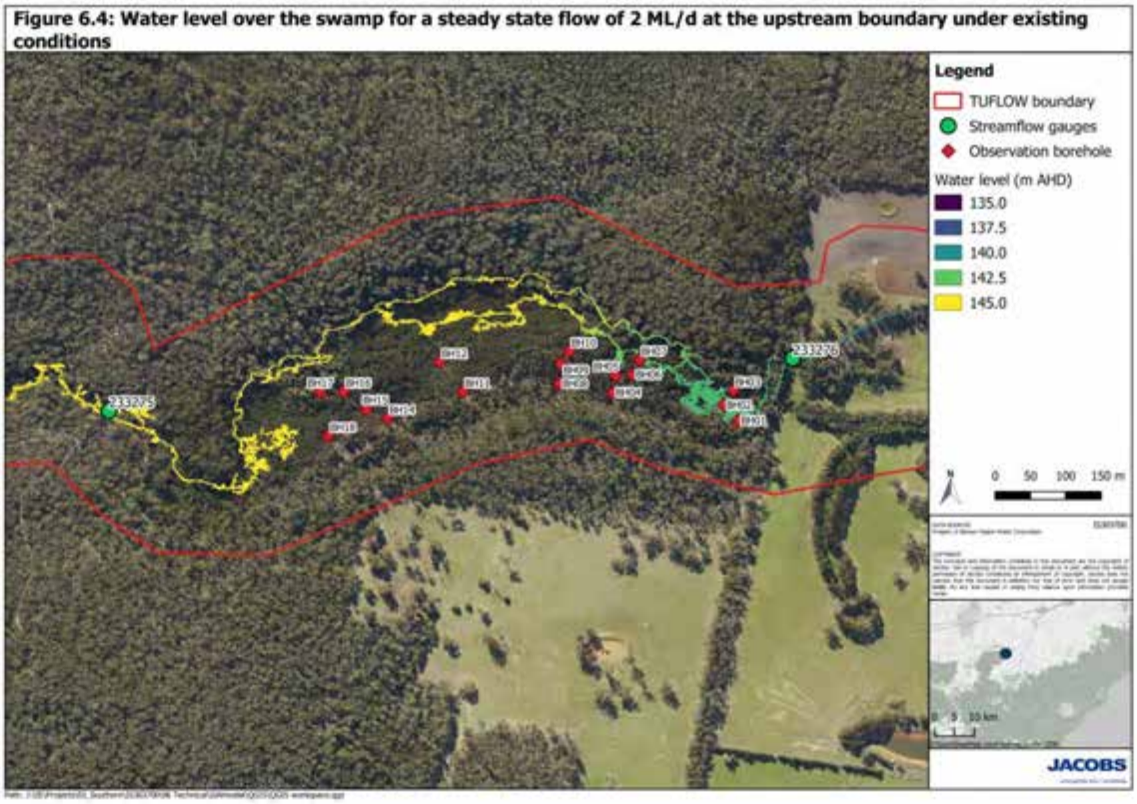


Figure 6-4: Water level over the swamp for a steady state flow of 2 ML/d at the upstream boundary under existing conditions

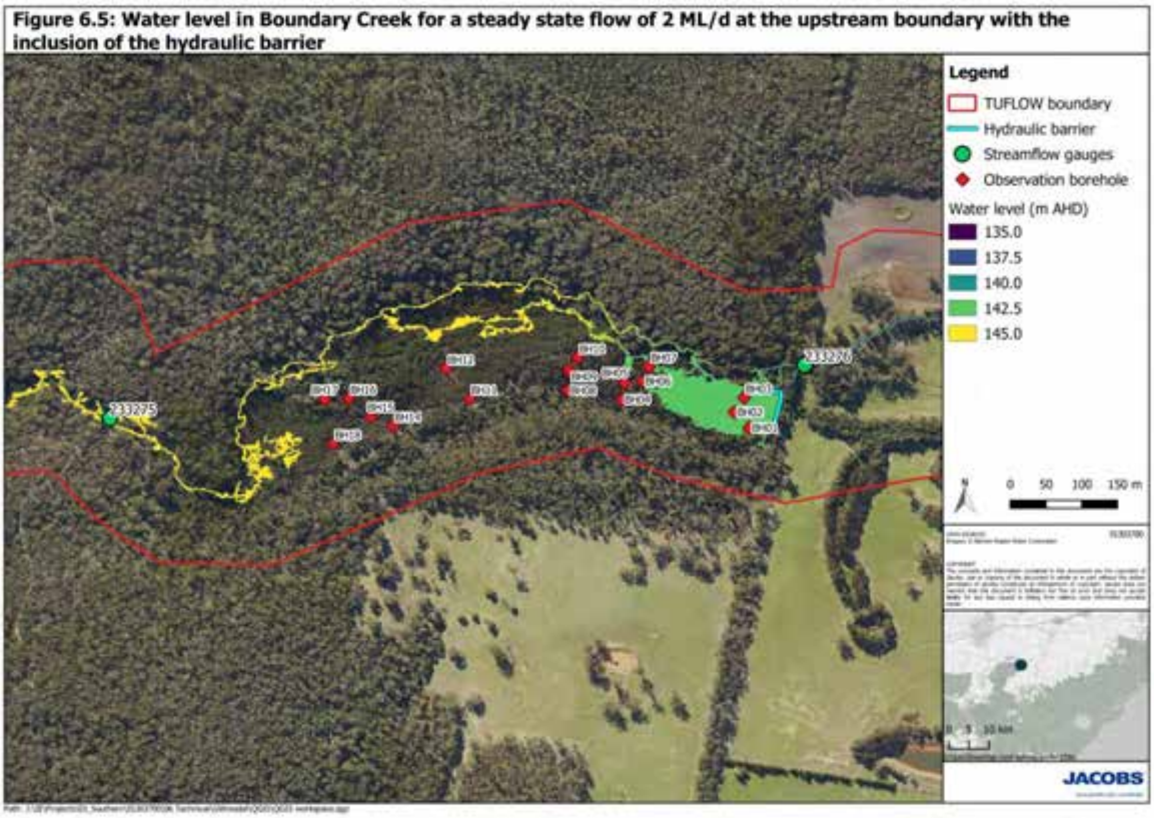


Figure 6-5: Water level in Boundary Creek for a steady state flow of 2 ML/d at the upstream boundary with the inclusion of the hydraulic barrier

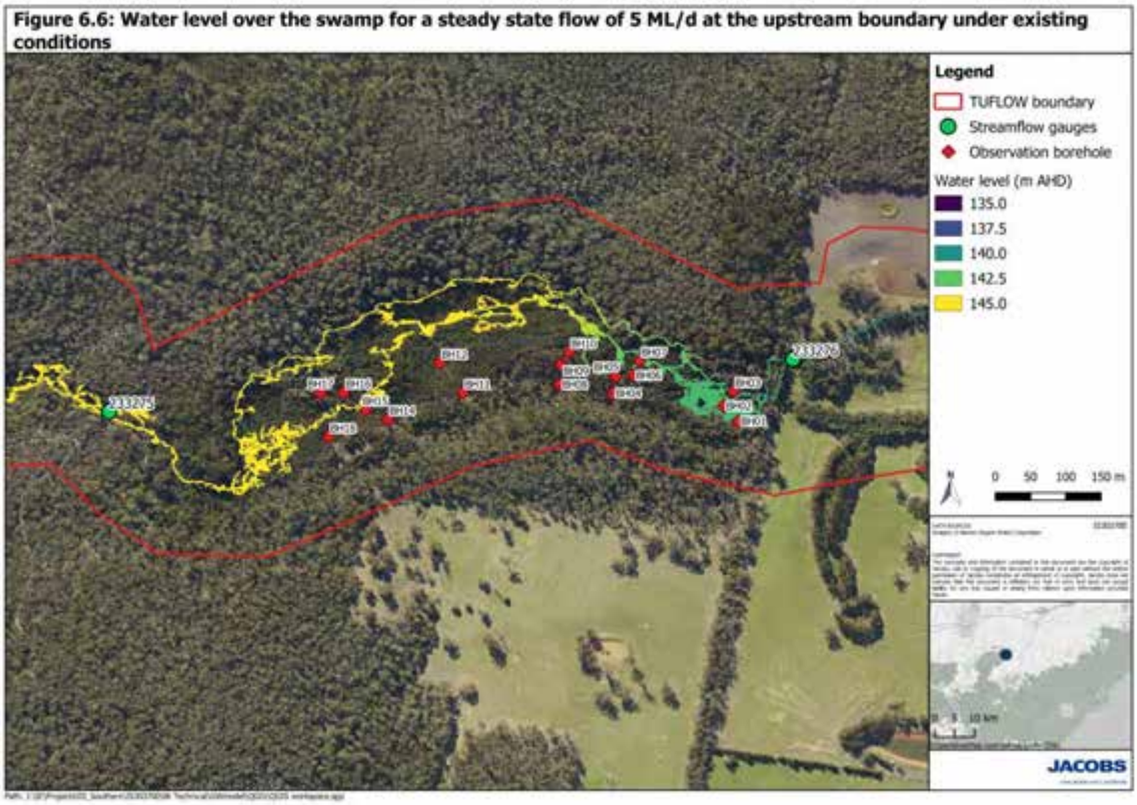


Figure 6-6: Water level over the swamp for a steady state flow of 5 ML/d at the upstream boundary under existing conditions

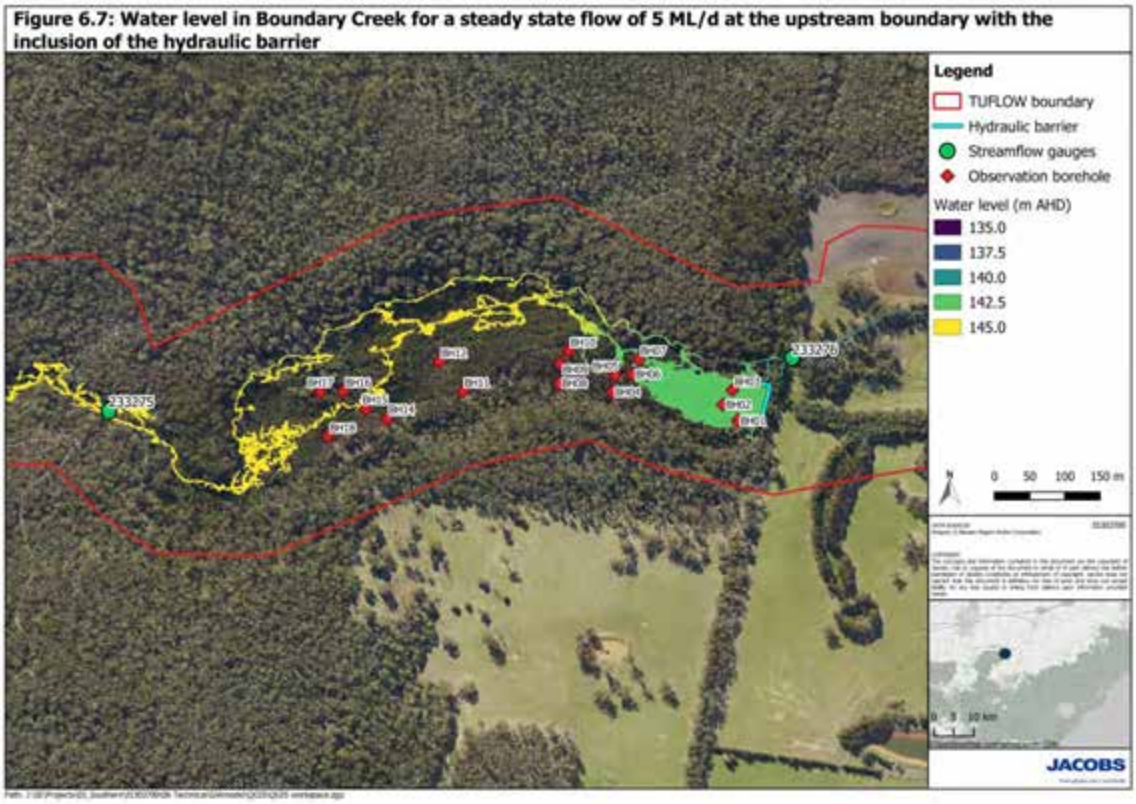


Figure 6-7: Water level in Boundary Creek for a steady state flow of 5 ML/d at the upstream boundary with the inclusion of the hydraulic barrier

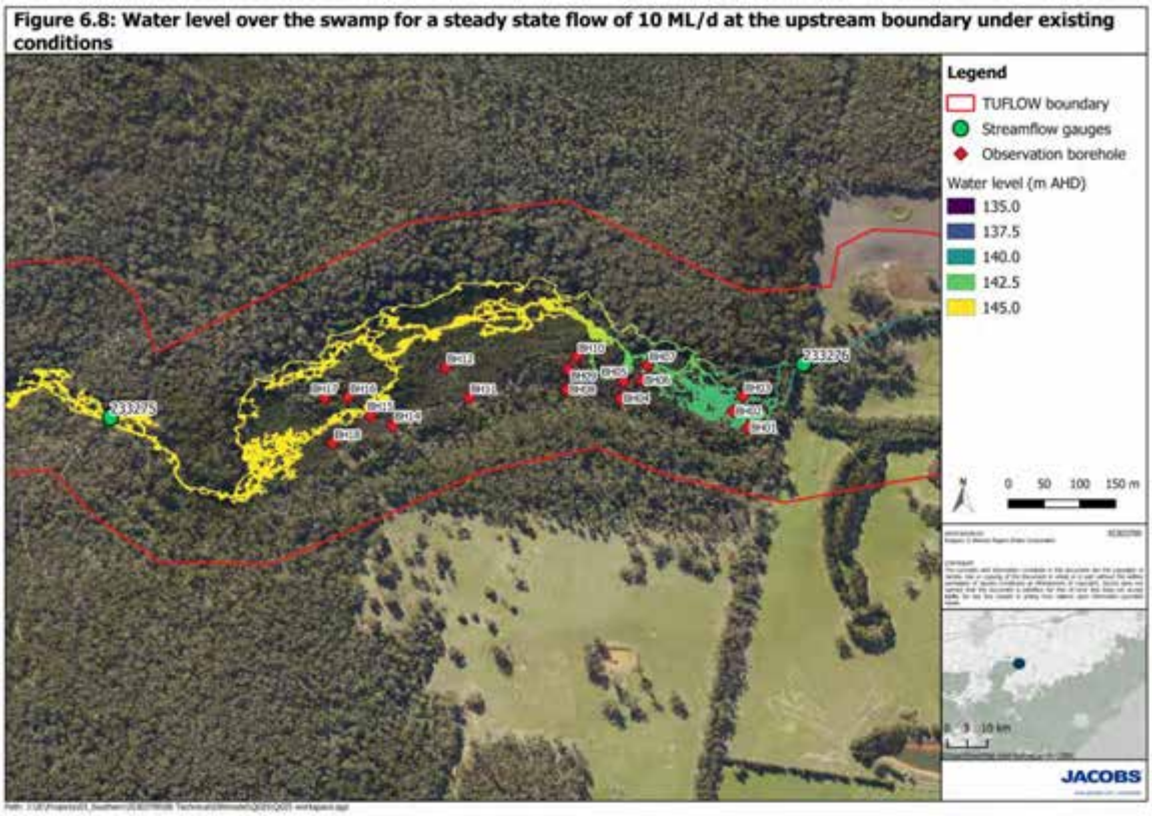


Figure 6-8: Water level over the swamp for a steady state flow of 10 ML/d at the upstream boundary under existing conditions

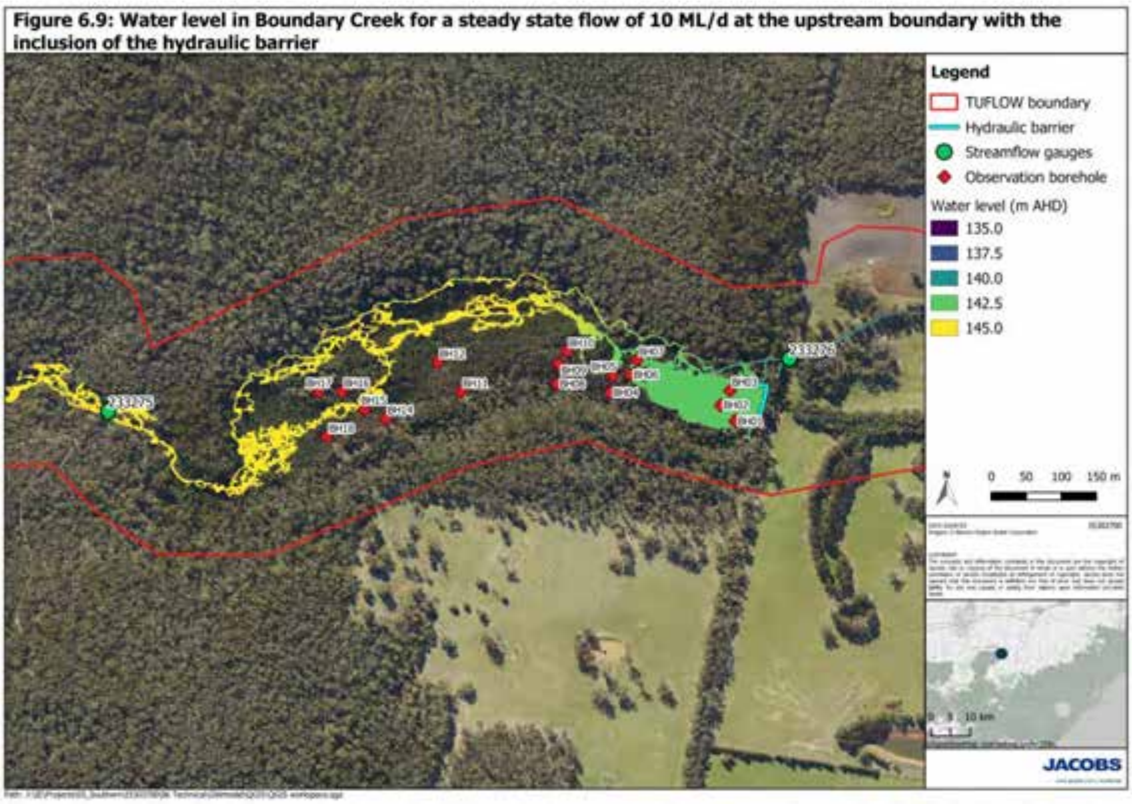


Figure 6-9: Water level in Boundary Creek for a steady state flow of 10 ML/d at the upstream boundary with the inclusion of the hydraulic barrier

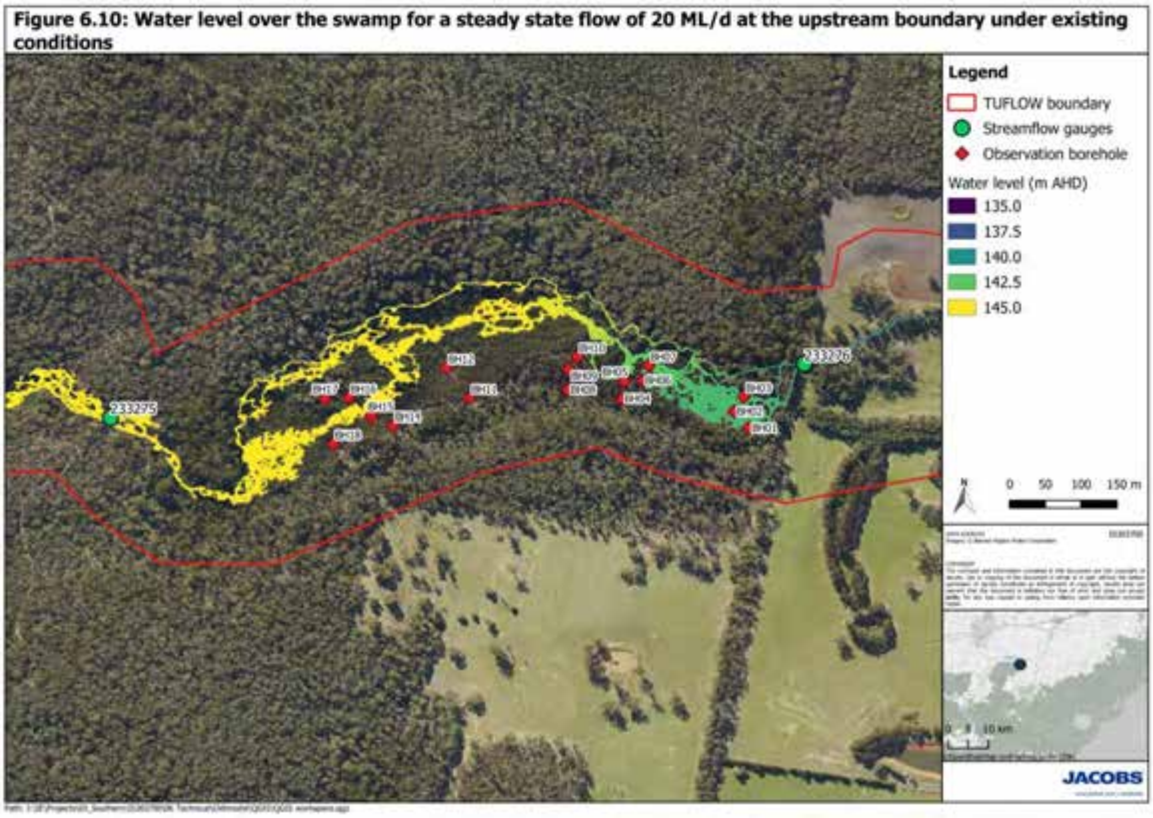


Figure 6-10: Water level over the swamp for a steady state flow of 20 ML/d at the upstream boundary under existing conditions

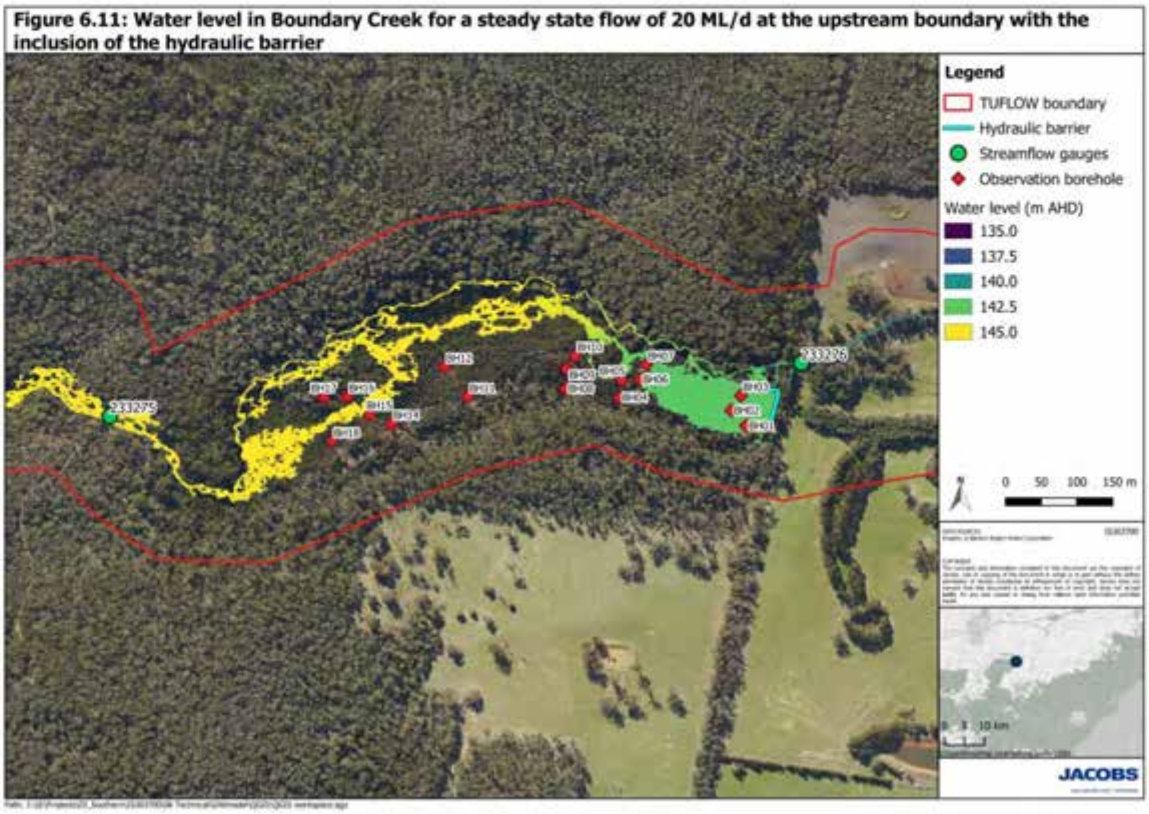


Figure 6-11: Water level in Boundary Creek for a steady state flow of 20 ML/d at the upstream boundary with the inclusion of the hydraulic barrier

7. Groundwater model

7.1 Objectives

A groundwater model has been developed to:

- Assess the potential changes in watertable elevation in the swamp that will arise from future changes in the flow through Boundary Creek including those associated with supplementary flow schemes,
- Estimate the exchange fluxes with Boundary Creek to help calibrate surface water hydraulic models of Boundary Creek,
- Assess the potential changes in groundwater heads in the swamp that may occur as a result of the construction of a hydraulic barrier at the downstream edge of the swamp (see Figure 6-5).

7.2 Confidence level classification

During discussions held as part of the project inception meeting it was agreed that the amount of data available for the development of a groundwater model would likely preclude the development of a high confidence level model. As a result, and in line with the modelling objectives, it was agreed that a Class 2 (on a scale of 1 to 3) Confidence Level Classification (Barnett *et al*, 2012) is an appropriate and realistic target for the model. While a greater level of confidence in the model is desirable and is warranted by the significance of the problem being modelled, the target level of a moderate confidence level model (Class 2) is the best that can be achieved with the available data on which the groundwater system can be conceptualised and the model calibrated.

7.3 Software code

The FEFLOW finite element modelling code has been adopted for this project. The finite element formulation allows for an efficient spatial discretisation that includes a fine mesh of calculation nodes at points of interest and a coarser mesh of nodes in areas where spatial detail is not required. FEFLOW is a widely used modelling code that is able to simulate groundwater flow in the saturated and unsaturated zones around ephemeral stream systems and includes a number of options for representing groundwater interaction with surface water and is therefore considered ideal for this project.

7.4 Model domain and spatial discretisation

The model domain covers an area of about 4 km by 4 km, centred on Boundary Creek and including Big Swamp. The mesh is refined around the creek where node spacing is set at 4 m to match every second calculation node in the surface inundation model. With a node spacing of 2 m, to match the surface inundation model calculation nodes, resulted in unacceptable model run times. Increasing the nodal spacing to 4 m has no measurable impact on the accuracy of the data transfer between the models. Element size (nodal spacing) increases to about 60 m away from the creek and swamp. The model domain and calculation mesh are shown in Figure 7-1.

7.5 Model layers and aquifer units

The model layer structure is based on the hydrostratigraphy included in the existing regional scale numerical model and is summarised in Table 7-1. The ground surface is derived from a high resolution Digital Elevation Model (DEM) as used for flood hydraulic modelling. The top model layer is one metre thick and is included to provide representation of the creek bed across the full extent of inundation under flooding. The hydraulic conductivity of the creek bed sediments can be used to regulate the surface water exchange fluxes if necessary.

Where present, the alluvial sediments are represented by layers of 1 and 2 m thickness (Layers 1 and 2 are 1 m thick and layers 3 to 6 are 2 m thick) that provide the fine vertical resolution required to model the unsaturated zone that forms near ground surface. These thin layers (Layers 1 to 6) are draped across the full model domain and where the alluvial sediments are absent they represent the upper 10 m of the outcropping geological unit as shown in Figure 7-1. Deeper model layers are designed to provide equitable subdivision of the thicker regional hydrogeological units as represented in the regional groundwater model i.e., the Lower Tertiary Aquifer, the Mid-Tertiary Aquitard (Gellibrand Marl) and the Basement. The base of the model has been set at the base of the Lower Tertiary Aquifer or at 0 mAHD where the Lower Tertiary Aquifer plunges below this elevation.

The model layer structure can be seen in Figure 7-2 and Figure 7-3 and is summarised in Table 7-1.

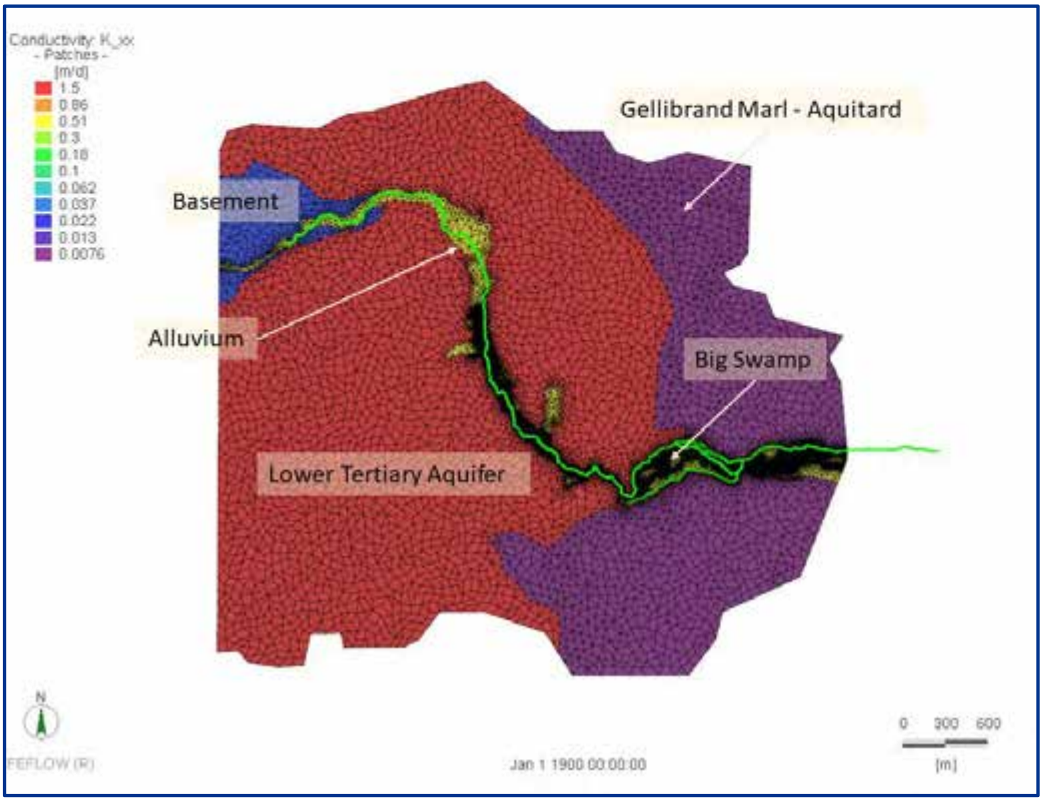


Figure 7-1 Model domain, calculation mesh and hydraulic conductivity of outcropping units

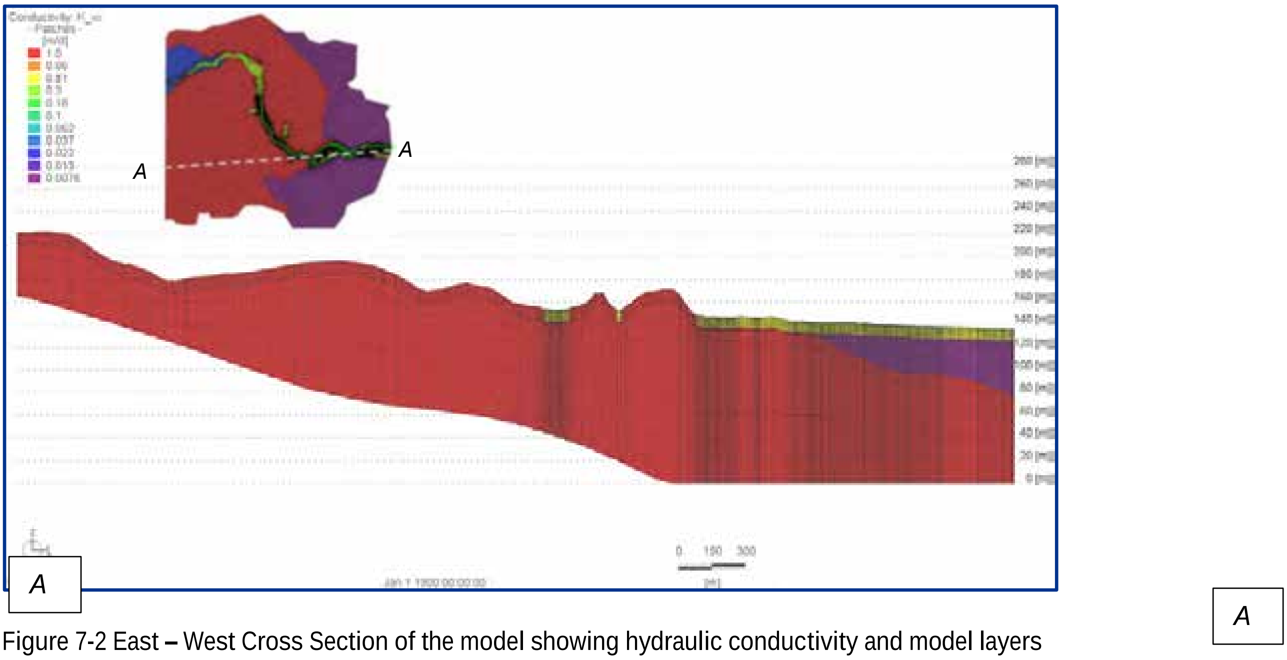


Figure 7-2 East – West Cross Section of the model showing hydraulic conductivity and model layers

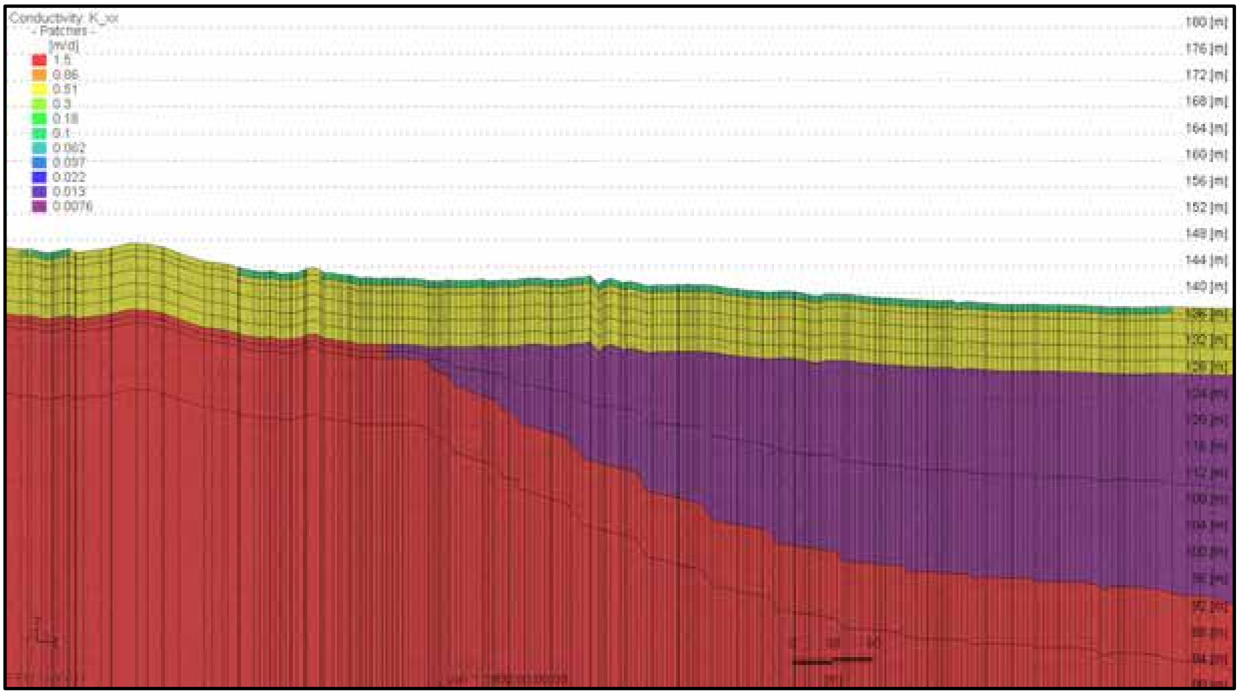


Figure 7-3 Magnified view of East – West Cross Section showing detailed layer structure.

Table 7-1: Model layer structure

Layer	Units*	Thickness
1, 2	River bed and alluvium#	1 m thick layers. River bed sediments in Layer 1 only
3 - 6	Alluvium#	2 m thick layers aimed at providing fine vertical resolution in Alluvial sediments.
7, 8	Mid-Tertiary Aquitard	Layers of equal thickness that subdivide the Marl
9	Lower Tertiary Aquifer	10 m thick layer at top of LTA
10, 11	Lower Tertiary Aquifer	Layers of equal thickness that subdivide the lower part of the LTA

* *Basement is present in all layers within the area where it outcrops.*

Where alluvium is not present these layers represent the upper 10 m of the outcropping unit

7.6 Hydrogeological properties

The hydrogeological properties assigned to the model were adjusted during model calibration. Initial estimates and ranges for each parameter are presented in Table 7.2. The PARNMME column in the table is the parameter naming convention used in the PEST automated calibration. Parameter ranges and initial estimates were obtained from the existing regional scale groundwater model and from the conceptual understanding of the alluvium within the swamp.

Table 7.2: Initial estimates of aquifer parameters

Description	Units	PARNME	Lower Bound	Upper bound	Initial Value
Alluvium Horizontal Hydraulic Conductivity	m/d	kxy_1	4.00E-02	2.00E+00	4.00E-01
MTA Horizontal Hydraulic Conductivity	m/d	kxy_2	8.64E-04	8.64E-02	8.64E-03

Description	Units	PARNME	Lower Bound	Upper bound	Initial Value
LTA Horizontal Hydraulic Conductivity	m/d	kxy_3	1.00E-02	1.50E+01	1.00E+00
Bedrock Horizontal Hydraulic Conductivity	m/d	kxy_4	1.00E-03	1.00E-01	2.00E-02
Alluvium Vertical Hydraulic Conductivity	m/d	kv_1	4.00E-03	2.00E-01	4.00E-02
MTA Vertical Hydraulic Conductivity	m/d	kv_2	8.64E-06	8.64E-04	8.64E-05
LTA Vertical Hydraulic Conductivity	m/d	kv_3	1.00E-03	1.50E+00	1.00E-01
Bedrock Vertical Hydraulic Conductivity	m/d	kv_4	2.00E-04	2.00E-02	2.00E-03
River Bed Hydraulic Conductivity	m/d	k_5	4.00E-03	2.00E-01	4.00E-02
Alluvium porosity		po_1	0.05	0.25	0.10
MTA porosity		po_2	0.01	0.2	0.05
LTA porosity		po_3	0.01	0.3	0.05
Bedrock porosity		po_4	0.01	0.1	0.05

7.7 Boundary conditions

The Feflow Type 3 Transfer Boundary Condition was assigned along the model edges in Layers 9, 10 and 11 that represent the Lower Tertiary Aquifer. The heads assigned to the boundary were obtained from the regional groundwater model from a time in mid 2018. In this manner the groundwater model heads are tuned to match those of the regional model in the Lower Tertiary Aquifer.

7.8 Rainfall recharge

Rainfall recharge was applied to the top layer across the whole model domain through the Feflow *"In/outflow on top/bottom"* material property. Recharge rates are applied in zones that correspond to the outcropping geological unit. Initial estimates and ranges assigned to PEST are defined in Table 7.3.

Table 7.3: Initial estimates and range of recharge assessed during calibration.

Description	Units	PARNME	Lower Bound	Upper bound	Initial Value
Alluvium Recharge	m/a	rc_1	1.00E-02	1.00E-01	5.00E-02
MTA Recharge	m/a	rc_2	1.00E-03	5.00E-02	1.00E-02
LTA Recharge	m/a	rc_3	1.00E-02	0.1	5.00E-02
Bedrock Recharge	m/a	rc_4	1.00E-03	5.00E-02	1.00E-02

7.9 Boundary Creek interactions

The Feflow Type 1 (Constant Head) Boundary Condition was used to simulate groundwater interaction with Boundary Creek and McDonalds Dam. The boundary condition implementation requires the definition of heads (either constant or variable with time) at each node within the river and dam. As noted, the model is being run in conjunction with a surface water hydraulic model that predicts the wetted area (flow channels) and river stage for Boundary Creek under any given flow condition. The approach adopted for this investigation is to run the hydraulic model to generate appropriate predictions of wetted area and river stage (water level) across Boundary Creek and the swamp and transfer this information to the groundwater model to inform the boundary condition used to simulate the interactions between groundwater and surface water (refer to Section 5.3).

To facilitate the exchange of data from the inundation model, the groundwater model mesh was constructed with calculation nodes on a 4 m square grid throughout the maximum wetted area for the Creek and Swamp as estimated by the inundation model. Each of the Feflow river exchange nodes aligns with a calculation node used in the inundation model thereby facilitating the direct transfer of data between the two models. The arrangement of Feflow calculation nodes in part of the swamp is presented in Figure 7-4.

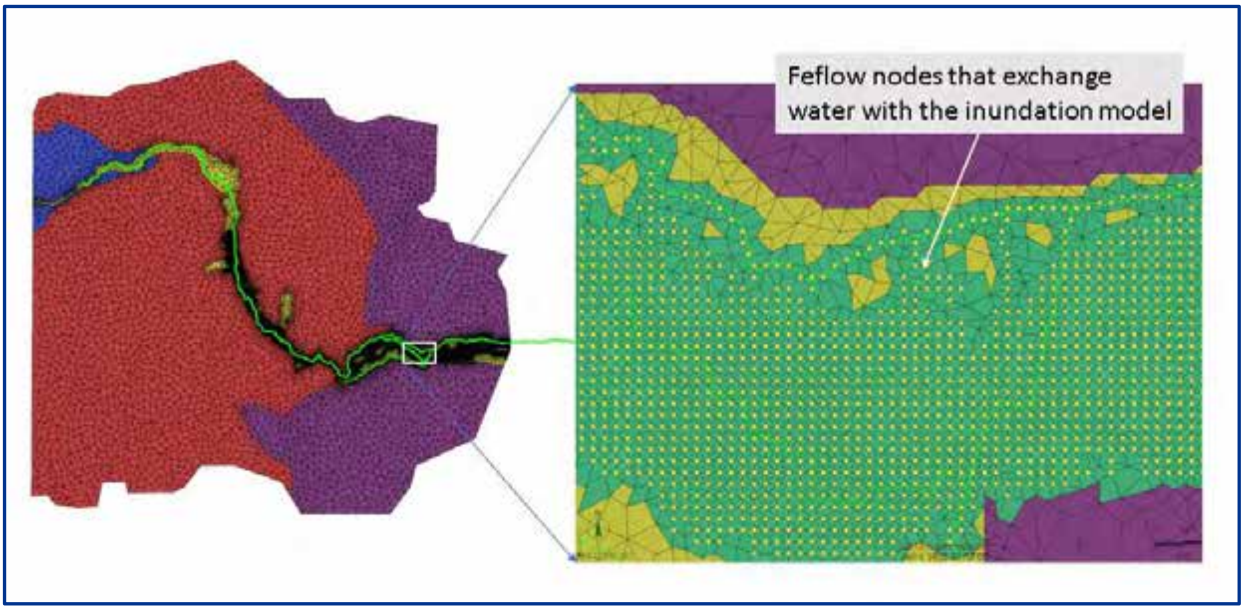


Figure 7-4: Feflow nodes used to simulation interaction with surface waters.

7.10 Calibration

7.10.1 Calibration procedure

The model calibration is hampered by a lack of local scale groundwater head data that are suitable for defining steady state heads throughout the swamp. Although there are 17 recently installed shallow wells in the swamp, data from these wells is limited to the period June to September of 2019 and do not provide a useful definition of steady state groundwater conditions. The locations of the Big Swamp observation bores are shown in Figure 7-5 and the recorded groundwater heads in all these bores are presented in Figure 7-6.

Furthermore, the explicit representation of surface water groundwater interaction over a period that would be meaningful for calibration of the groundwater model is prohibitive in terms of data transfer and computational effort. A fully transient surface water model requires short time steps (in the order of one second) and produces a unique time series of wetting and stage elevation for each of the exchange nodes in the groundwater model (about 21,000 nodes in total). The complexity of constructing a fully transient model for both the inundation and groundwater model and the high level of computational effort required to create individual time series inputs for all exchange nodes precludes the development of such a model within the available time for the project.

An alternative, less rigorous, quasi transient calibration approach was adopted. The model was formulated to simulate a 10 year period (2010 to 2019) with a synthetic sequence of river flows assumed to occur as a repeating annual sequence as shown in Figure 7-7. The flow sequence reflects observations and anecdotal evidence of creek flows over the period of calibration. It assumes no river flow through summer months, a steady flow of 2ML/day through autumn and spring and a high flow of 10 ML for winter. The groundwater model utilises steady state inundation model results (wetted area and stage at all exchange nodes see for instance Figure 6-4

Figure 6-4) for each of the nominated flows. The resultant simulation is aimed at producing groundwater heads that are similar to those observed in the monitoring bore network between June and September 2019 and at reproducing streamflow losses in the order of 1.5 ML/day during periods when the river is assumed to be flowing at 2 ML/d immediately downstream of the Dam.

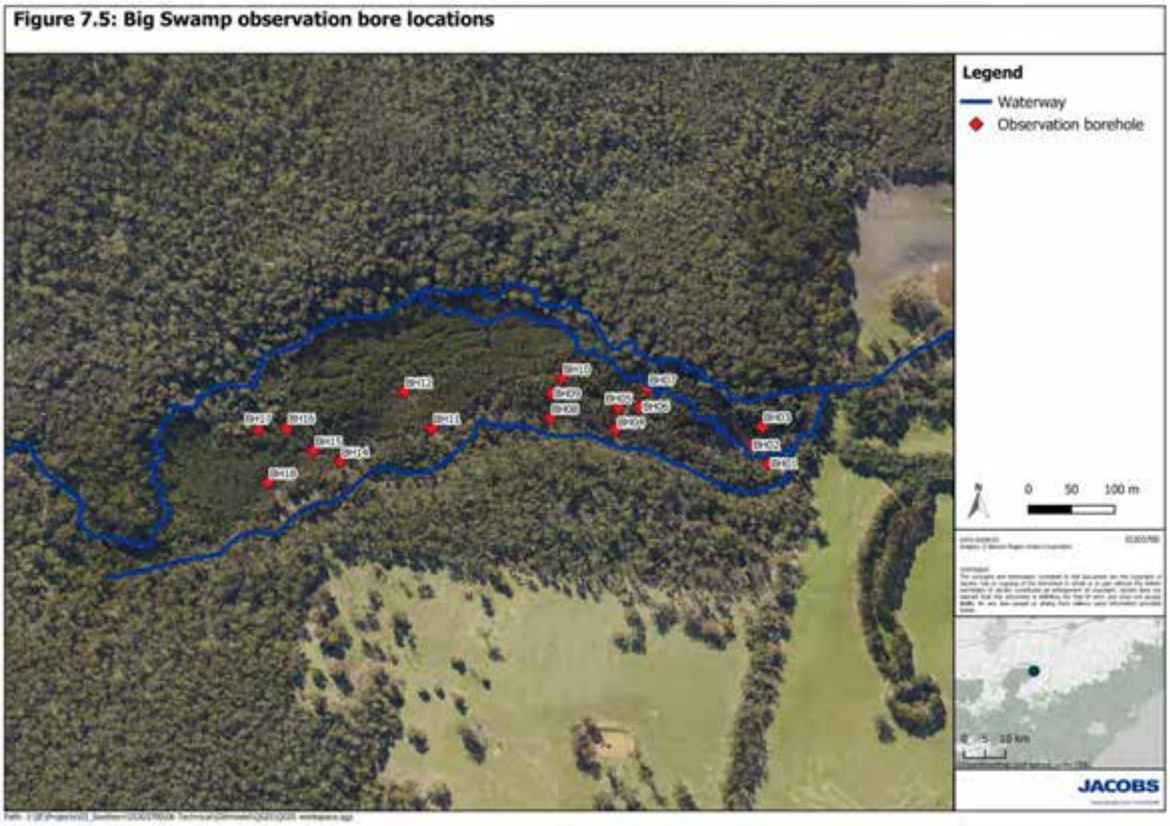


Figure 7-5: Big Swamp observation bore locations

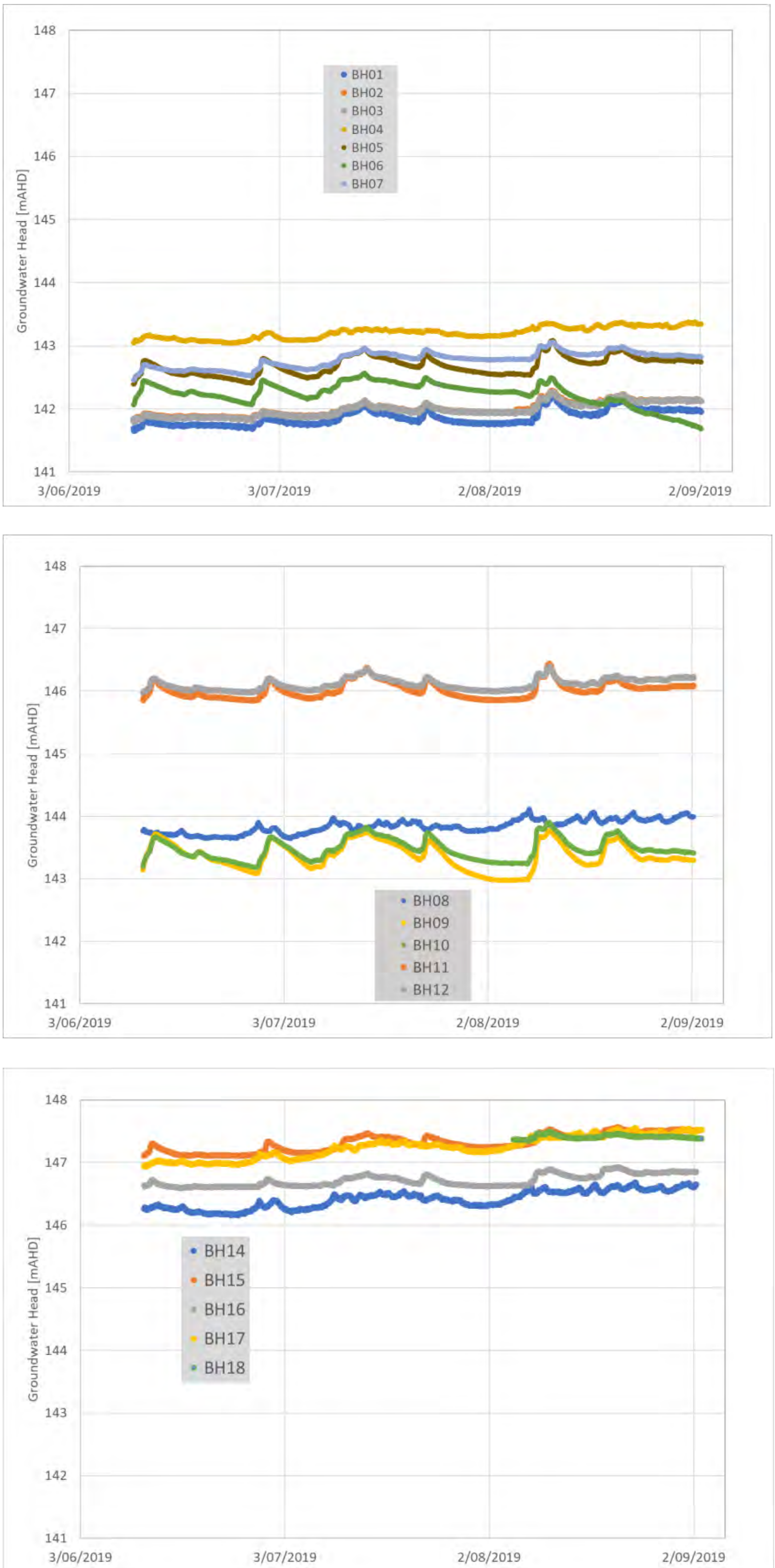


Figure 7-6: Measured hydrographs in Big Swamp observation bores.

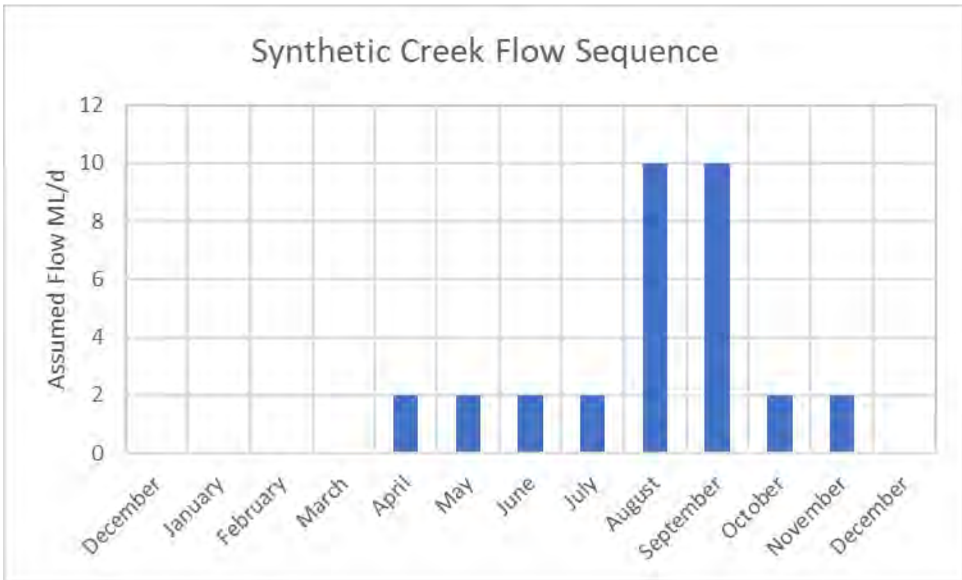


Figure 7-7: River flow sequence assumed for each year of the transient calibration model.

7.10.2 Calibration results

The calibration result is illustrated in Figure 7-8 as a comparison between the modelled and measured watertable surfaces (potentiometric surfaces) for September 2019.

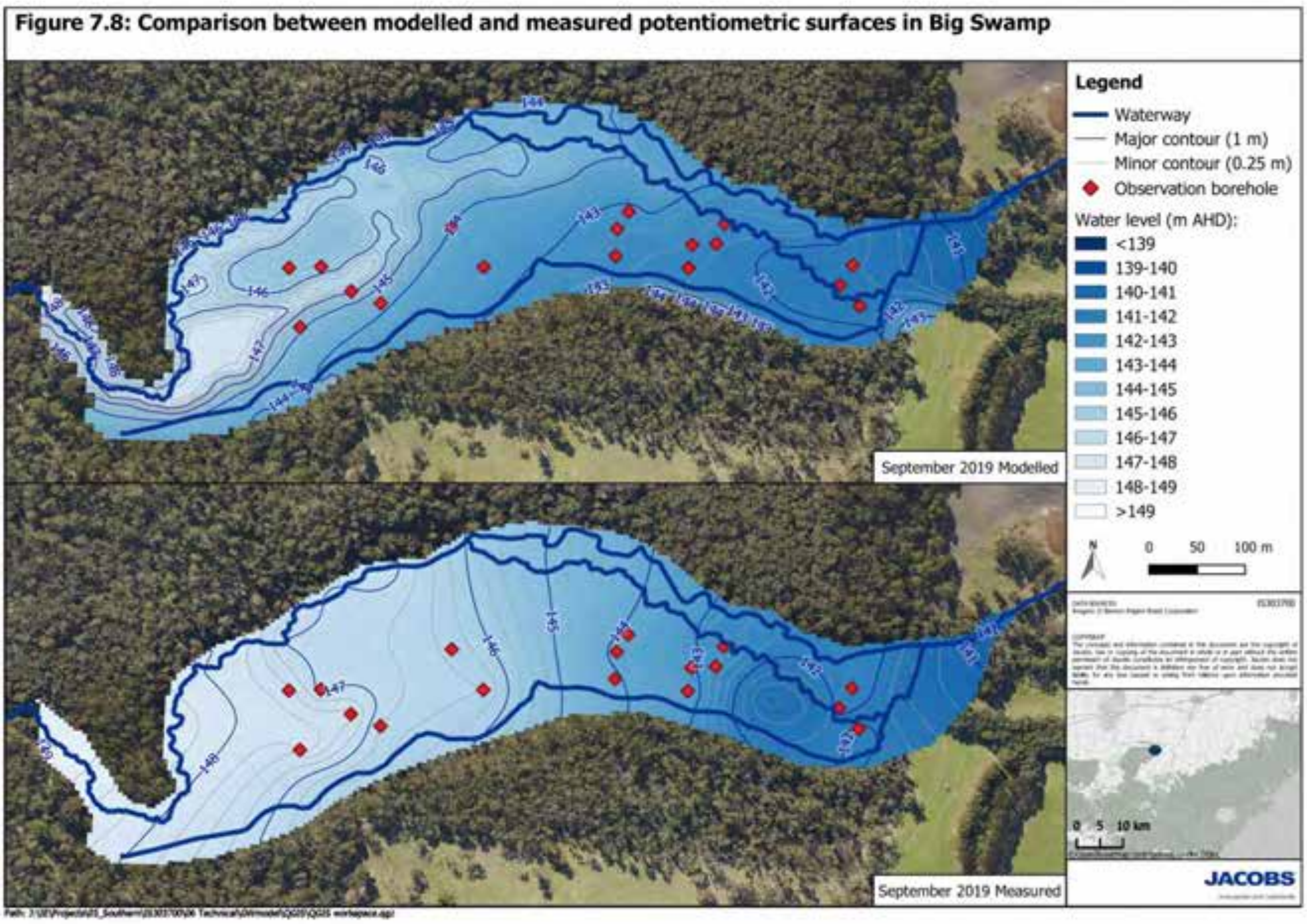


Figure 7-8: Comparison between modelled and measured potentiometric surfaces in Big Swamp.

Figure 7-9 shows a comparison between measured and predicted hydrographs in a selection of the Big Swamp monitoring bores in the period April to September 2019. The result suggests that the modelled heads are reasonably close to the observed levels at the downstream end of the swamp (for example, BH01) and that predicted heads are generally lower than measured throughout the central and upstream parts of the swamp.

The level of agreement between the modelled and observed heads is reasonable given that the calibration model is not based on a measured record of flow in the creek, rather it is based on synthetic flow data.

The modelled losses of water from Boundary Creek vary seasonally with the assumed flows in the creek. For periods when the creek flow is assumed to be 2 ML/d, the model predicts a loss of about 0.5 ML/d through Big Swamp and a loss of about 1.1 ML/d through the Damplands. The total loss of 1.6 ML/d is close to the calibration target of about 1.5 ML/d for a release of 2 ML/d.

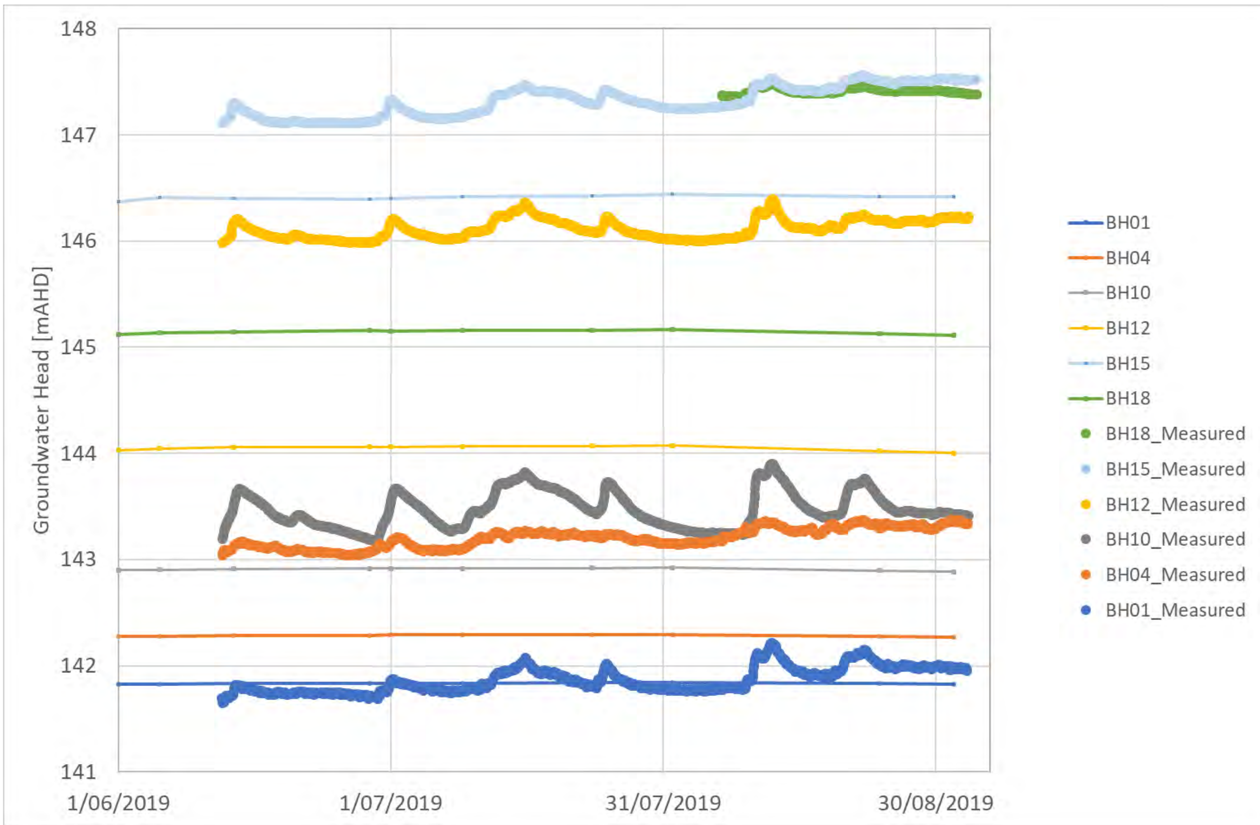


Figure 7-9: Predicted and measured groundwater levels in the Big Swamp monitoring bores.

8. Groundwater model predictive scenarios

8.1 Procedure

Six predictive scenarios have been formulated and run to assess various future flow regimes in Boundary Creek. These scenarios were designed to replicate conditions under low and high flow over short periods of time (6 months) and a longer term scenario with typical average flows. All scenarios were run with and without a hydraulic barrier at the eastern end of the swamp to determine the influence of the barrier on inundation areas and groundwater levels.

Scenario 1 to 4 are short term (150 days) simulations that assume a dry period in which the creek flow is entirely supported by supplementary flow released immediately downstream of the dam. The scenarios include an upper and lower estimate of the supplementary flow that may be required and hence provide limits within which results can be interpolated for intermediate rates of supplementary flow. The scenarios assume worst case climatic conditions in which Boundary Creek and Big Swamp do not receive any natural runoff, overland flow or baseflow.

Scenarios 1 and 3 assume that current flow conditions in the Creek and swamp while Scenarios 2 and 4 assume that a levee is constructed across the outflow channels at the downstream end of the swamp to a level of 142.5 mAHD (see Section 6.1) at the downstream limit of the swamp. These scenarios provide an indication as to changes in groundwater conditions that may occur as a result of introducing a hydraulic barrier at the downstream edge of the swamp.

Scenarios 5 and 6 are longer period simulations with an assumed seasonal fluctuation in creek flow based on the analysis presented in Section 5.3 with and without the hydraulic barrier. The head dependent boundary conditions that define the river stage and wetted area of Boundary Creek have been obtained from the hydraulic modelling scenarios including the intermediate scenarios described in Section 6.

The scenarios are defined as:

- **Scenario 1** assumes a constant release of 2 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Scenario 2** assumes a constant release of 2 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier with surface water levels from Figure 6-5.
- **Scenario 3** assumes a constant release of 20 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with no hydraulic barrier.
- **Scenario 4** assumes a constant release of 20 ML/d from McDonald's Dam with no additional contribution to streamflow from natural sources with a hydraulic barrier with surface water levels from Figure 6-11.
- **Scenario 5** is a ten year simulation that assumes an annual cycle of flows as illustrated in Figure 8-1 with no hydraulic barrier.
- **Scenario 6** is a ten year simulation that assumes an annual cycle of flows as illustrated in Figure 8-1 with a hydraulic barrier.

The flow sequence is an estimate of what could potentially be achieved with a supplementary flow of 2 ML/d providing continuous flow through summer and autumn with much higher flows occurring in wet winter months due to the flow regime (see for instance Figure 5-4).

Initial conditions for all scenarios were obtained from the calibration model at September 2019. In this case the simulations assume that flow supplementation starts in late winter when the groundwater levels in the swamp are relatively high.

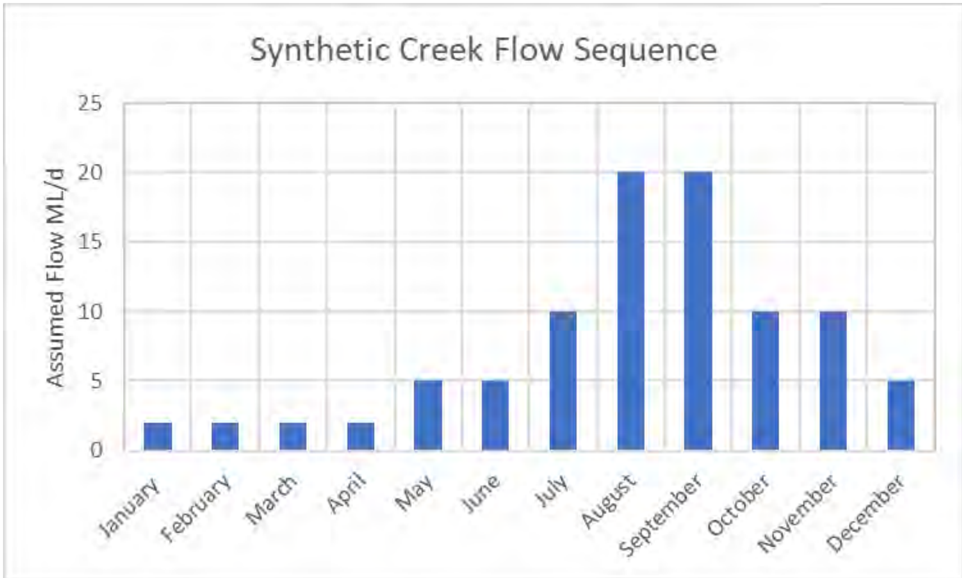
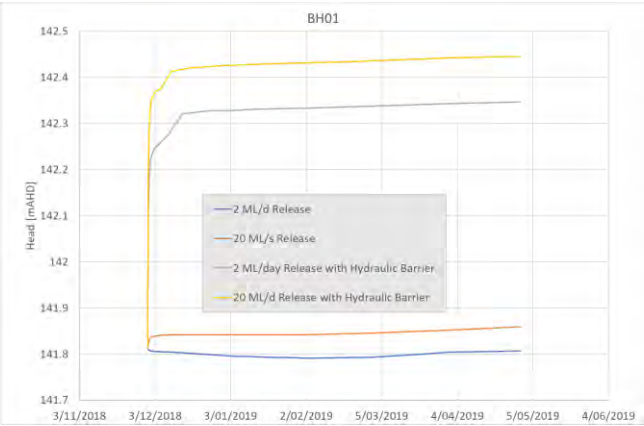


Figure 8-1: **Assumed annual cycle of flows assumed in Boundary Creek immediately downstream of McDonald's Dam for** Scenarios 5 and 6.

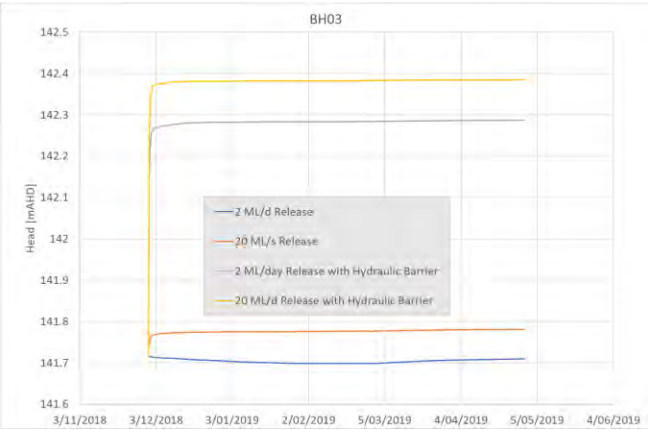
8.2 Results

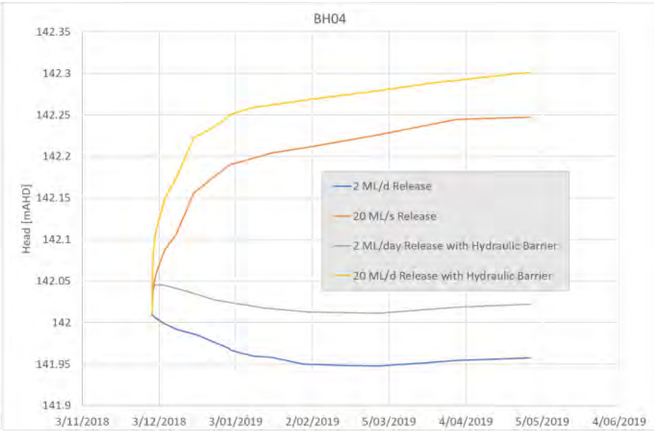
8.2.1 Changes in Groundwater Head

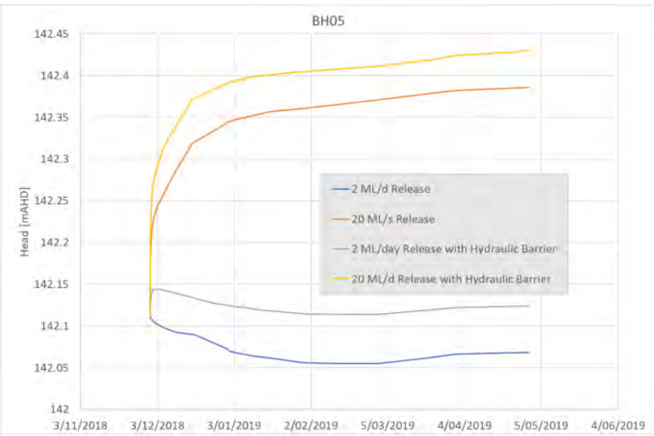
The scenarios predict changes in groundwater level in response to the applied boundary conditions in the creek and swamp. The predicted head responses in each of the swamp monitoring wells in all Scenarios 1 to 4 are presented in Figure 8-2.

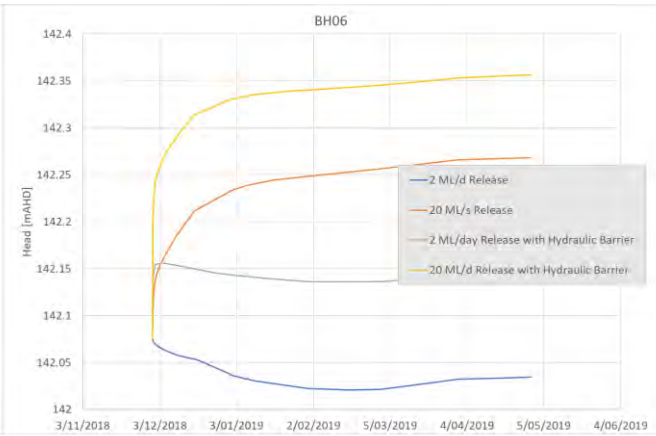

BH01
Head [mAHD]
142.5
142.4
142.3
142.2
142.1
142
141.9
141.8
141.7
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier

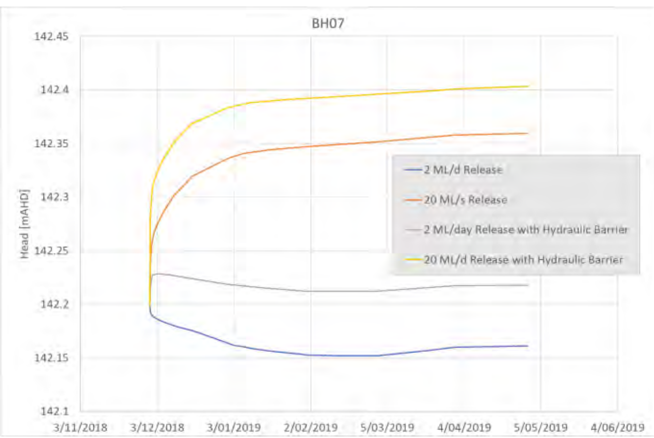

BH02
Head [mAHD]
142.5
142.4
142.3
142.2
142.1
142
141.9
141.8
141.7
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier

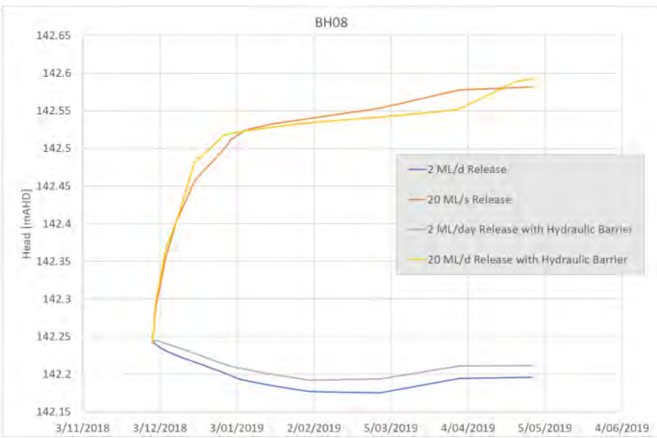

BH03
Head [mAHD]
142.5
142.4
142.3
142.2
142.1
142
141.9
141.8
141.7
141.6
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier


BH04
Head [mAHD]
142.35
142.3
142.25
142.2
142.15
142.1
142.05
142
141.95
141.9
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier


BH05
Head [mAHD]
142.45
142.4
142.35
142.3
142.25
142.2
142.15
142.1
142.05
142
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier


BH06
Head [mAHD]
142.4
142.35
142.3
142.25
142.2
142.15
142.1
142.05
142
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier


BH07
Head [mAHD]
142.45
142.4
142.35
142.3
142.25
142.2
142.15
142.1
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier


BH08
Head [mAHD]
142.65
142.6
142.55
142.5
142.45
142.4
142.35
142.3
142.25
142.2
142.15
3/11/2018
3/12/2018
3/01/2019
2/02/2019
5/03/2019
4/04/2019
5/05/2019
4/06/2019
2 ML/d Release
20 ML/s Release
2 ML/day Release with Hydraulic Barrier
20 ML/d Release with Hydraulic Barrier

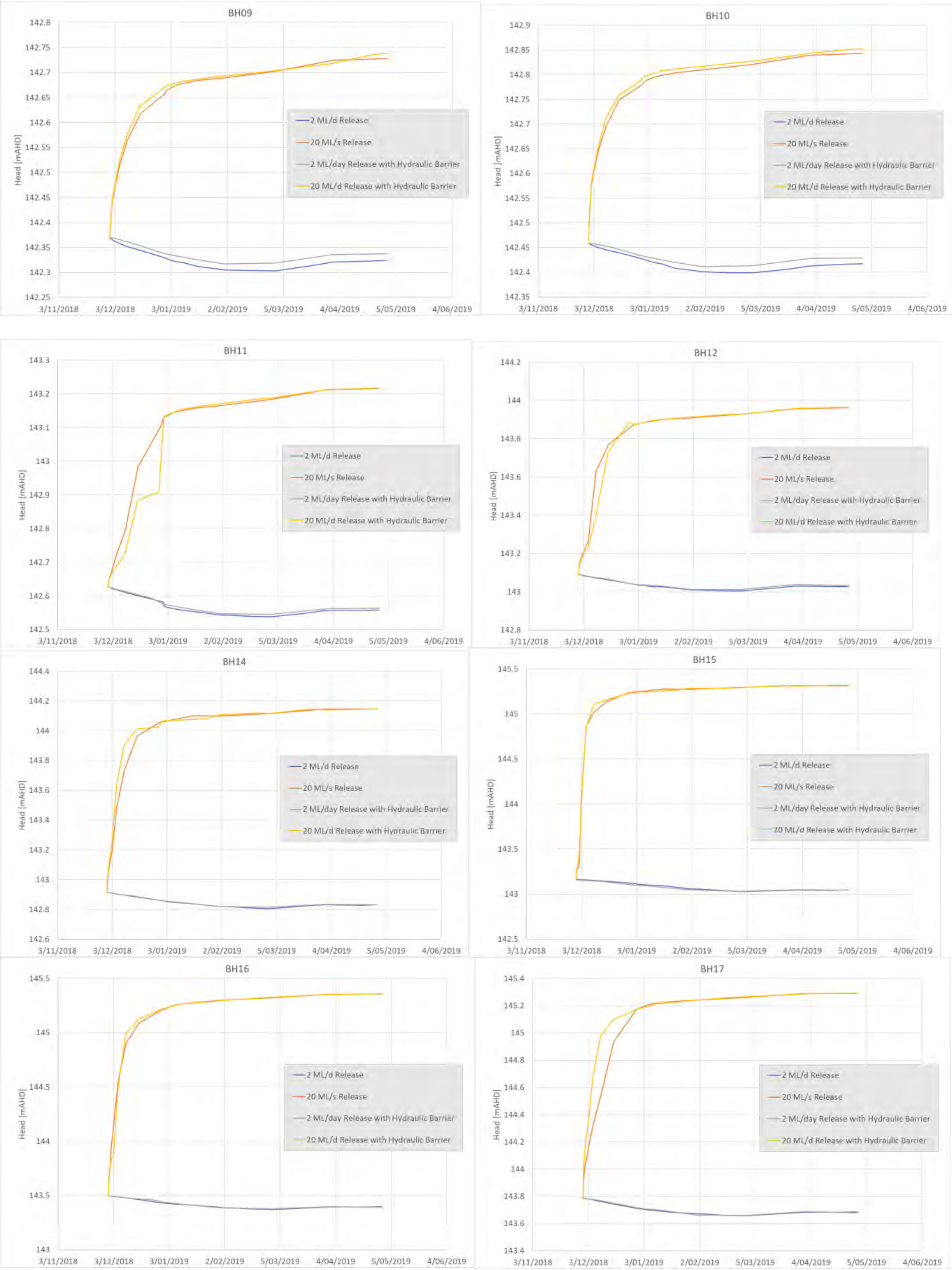
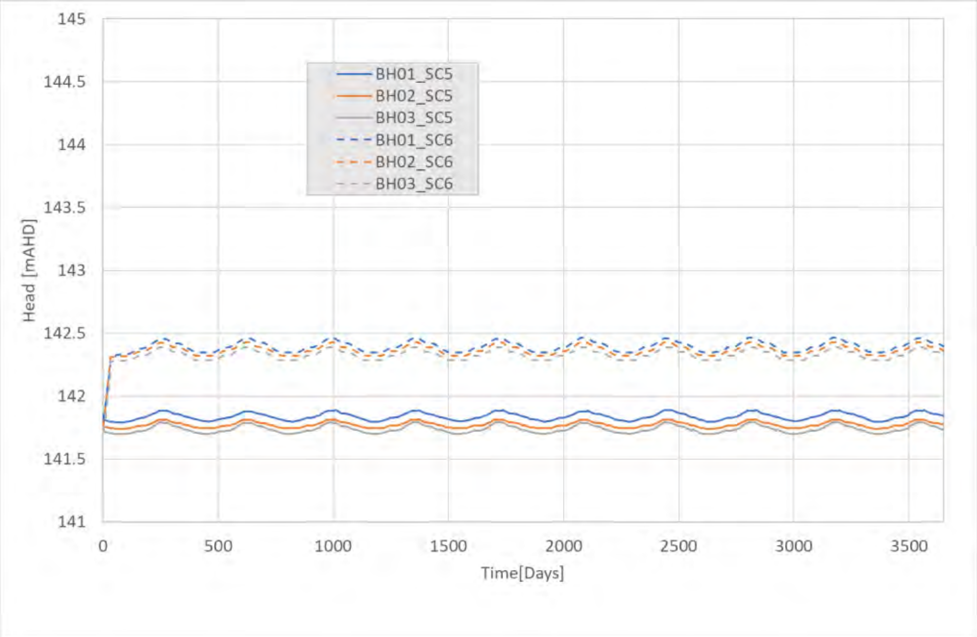
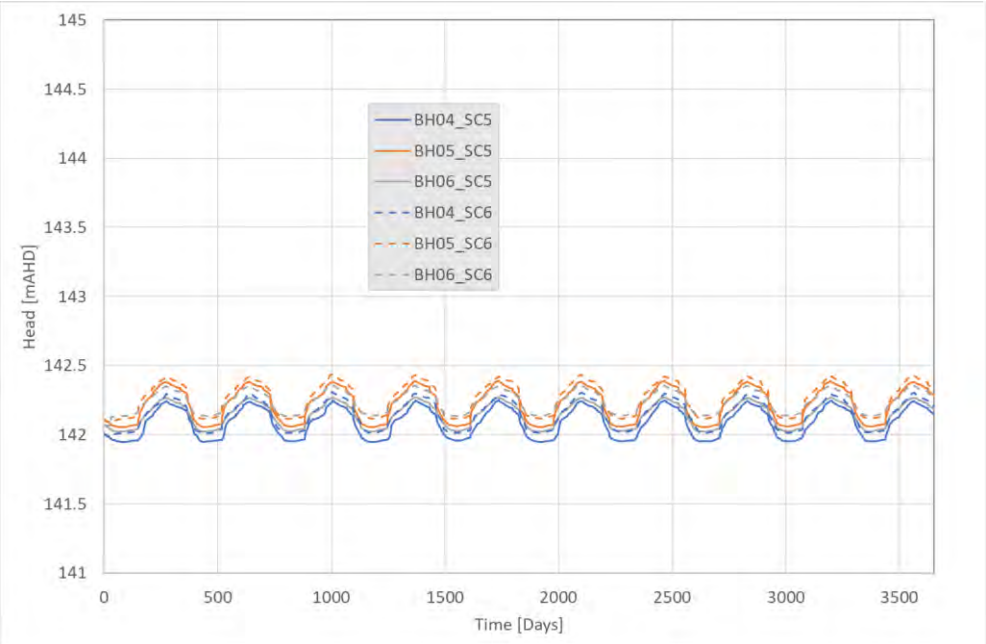


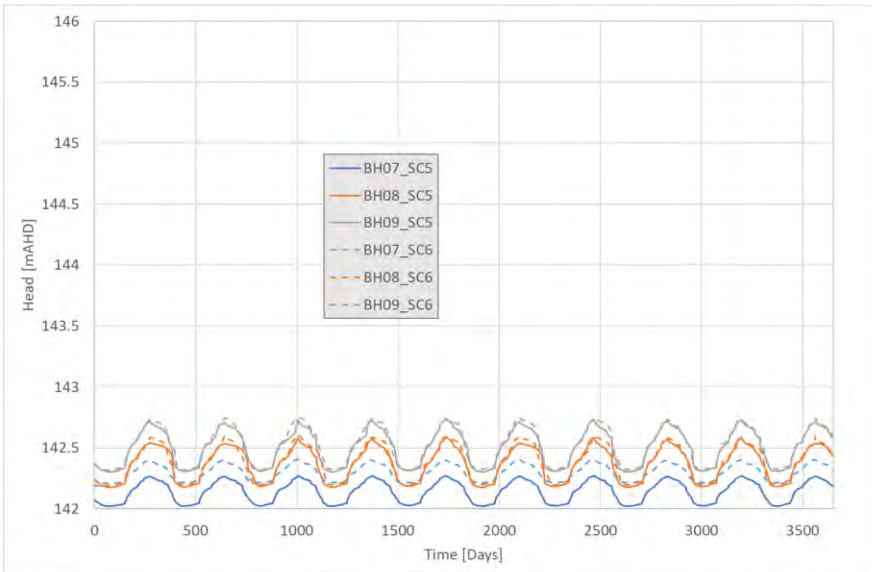
Figure 8-2: Predicted heads at all monitoring bore locations for Scenarios 1 to 4.

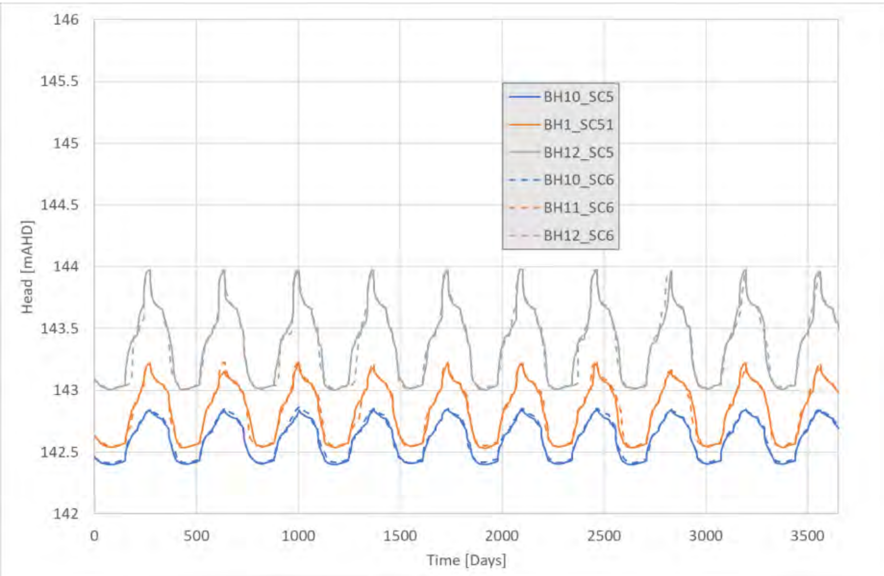
The predicted groundwater head responses at the groundwater monitoring bores in the swamp for Scenarios 5 and 6 are presented in Figure 8-3 The results indicate that long term trends in groundwater heads are not expected suggesting that the groundwater system equilibrates quite rapidly with changing flows in the creek. The predicted groundwater heads fluctuate seasonally around a long term average condition. The predicted impacts of the hydraulic barrier are constrained to the downstream part of the swamp and the increases in groundwater head caused by the barrier are not predicted to be propagated upstream of monitoring bores BH7, 8 and 9.

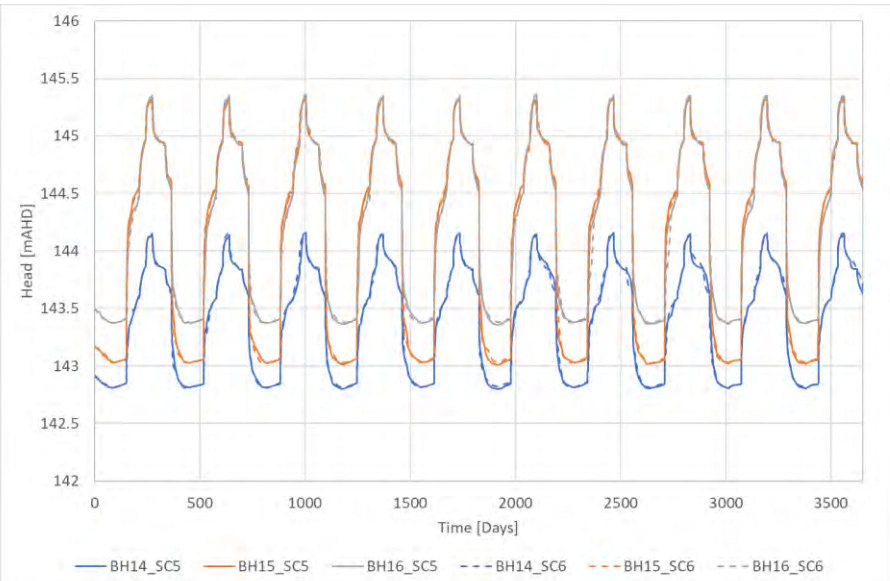
It is also of interest to note that the seasonal fluctuations in groundwater heads are predicted to be far more pronounced in areas of higher elevation in the upper parts of the Swamp, most likely due to available storage where the unsaturated zone is thicker.






Head [mAHD]
Time [Days]
BH07_SC5
BH08_SC5
BH09_SC5
BH07_SC6
BH08_SC6
BH09_SC6


Head [mAHD]
Time [Days]
BH10_SC5
BH1_SC51
BH12_SC5
BH10_SC6
BH11_SC6
BH12_SC6


Head [mAHD]
Time [Days]
BH14_SC5
BH15_SC5
BH16_SC5
BH14_SC6
BH15_SC6
BH16_SC6

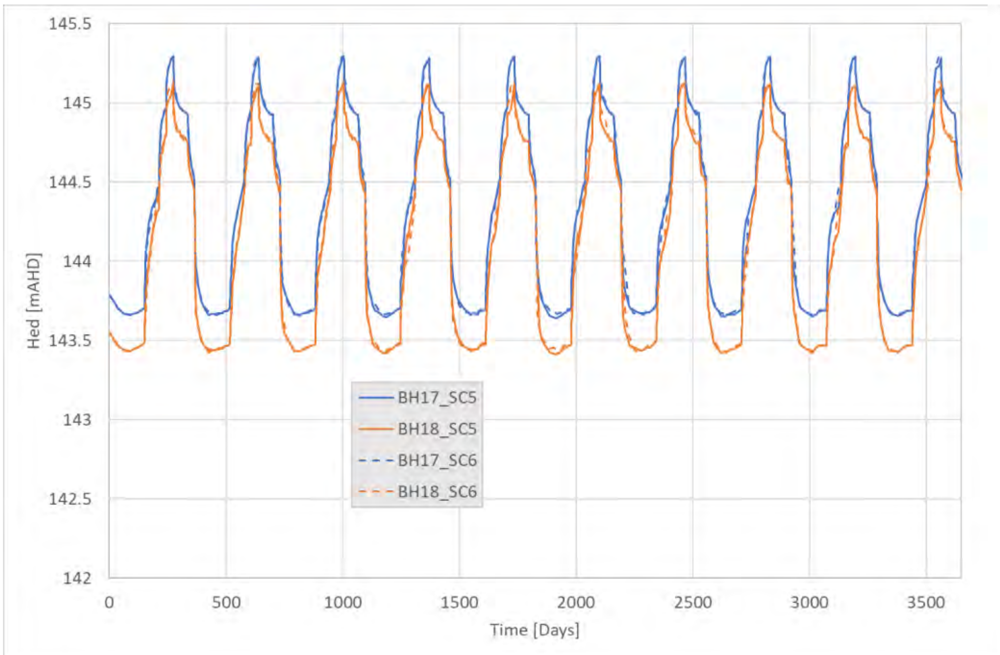


Figure 8-3: Predicted head responses in swamp monitoring bores for Scenarios 5 and 6.

Contour maps of the predicted change in head across the swamp for Scenarios 1 to 4 after 150 days of constant flow releases are presented in Figure 8-4 to Figure 8-7 respectively. In these figures the green shades represent areas where the watertable is predicted to fall with respect to the starting conditions in September 2019. The orange shading represents areas where the watertable is predicted to rise. When the flow release from the dam is set at 2 ML/day (Scenarios 1 and 2), the model predicts that heads will generally fall across the swamp. Scenario 2 (Figure 8-5) indicates that for a constant release of 2 ML/day, the construction of a hydraulic barrier at the downstream edge of the swamp is predicted to generate mounding in heads immediately upstream of the barrier.

When the flow release is assumed to increase to 20 ML/day, the model results suggest that the watertable is expected to rise over most of the swamp.

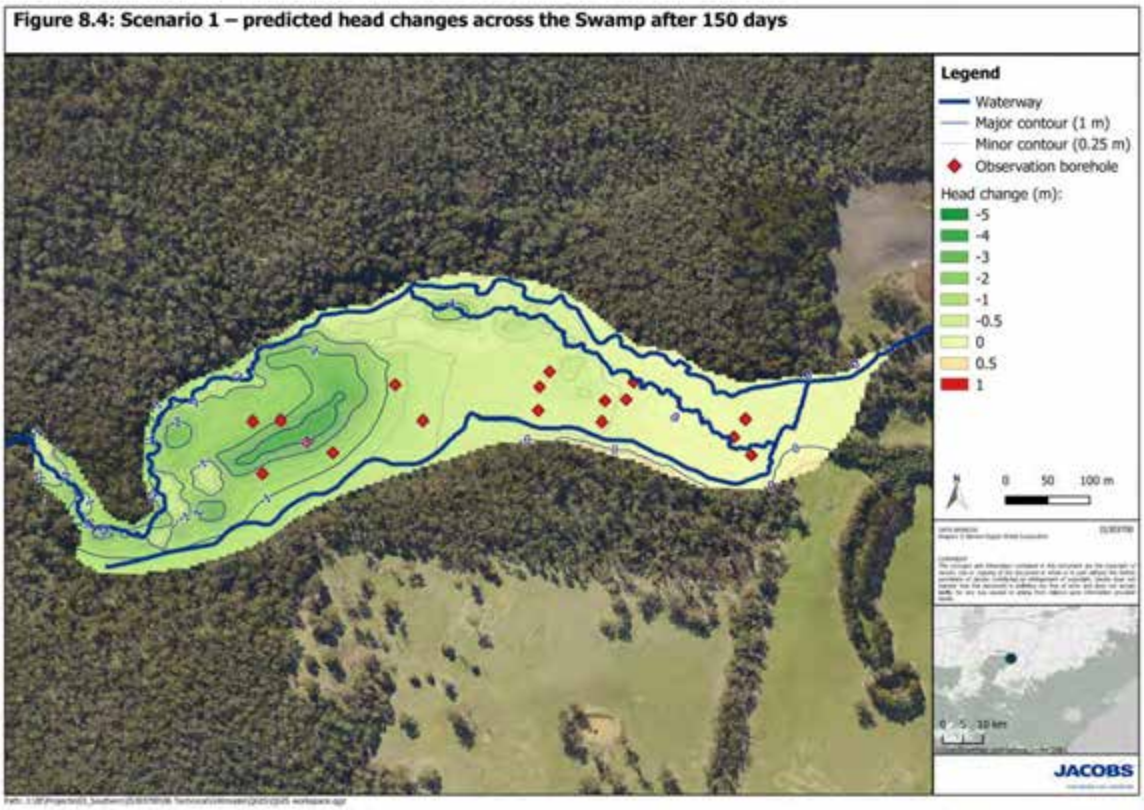


Figure 8-4: Scenario 1 – predicted head changes across the Swamp after 150 days

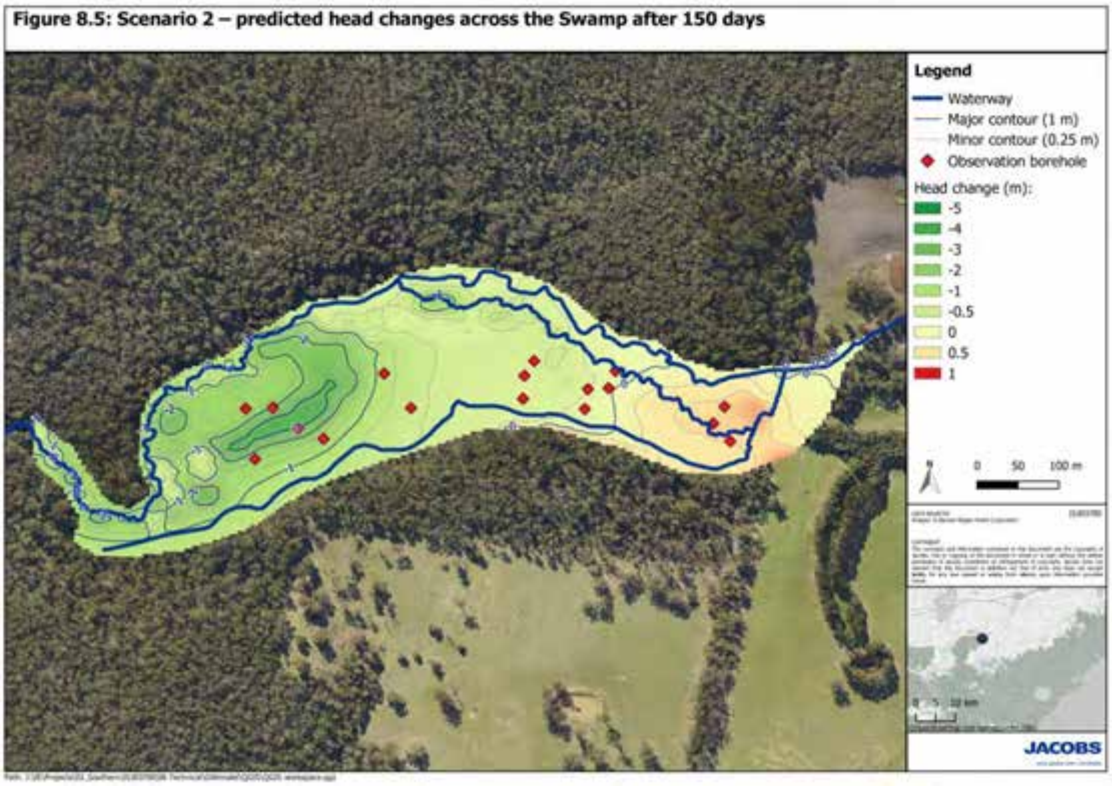


Figure 8-5: Scenario 2 – predicted head changes across the Swamp after 150 days

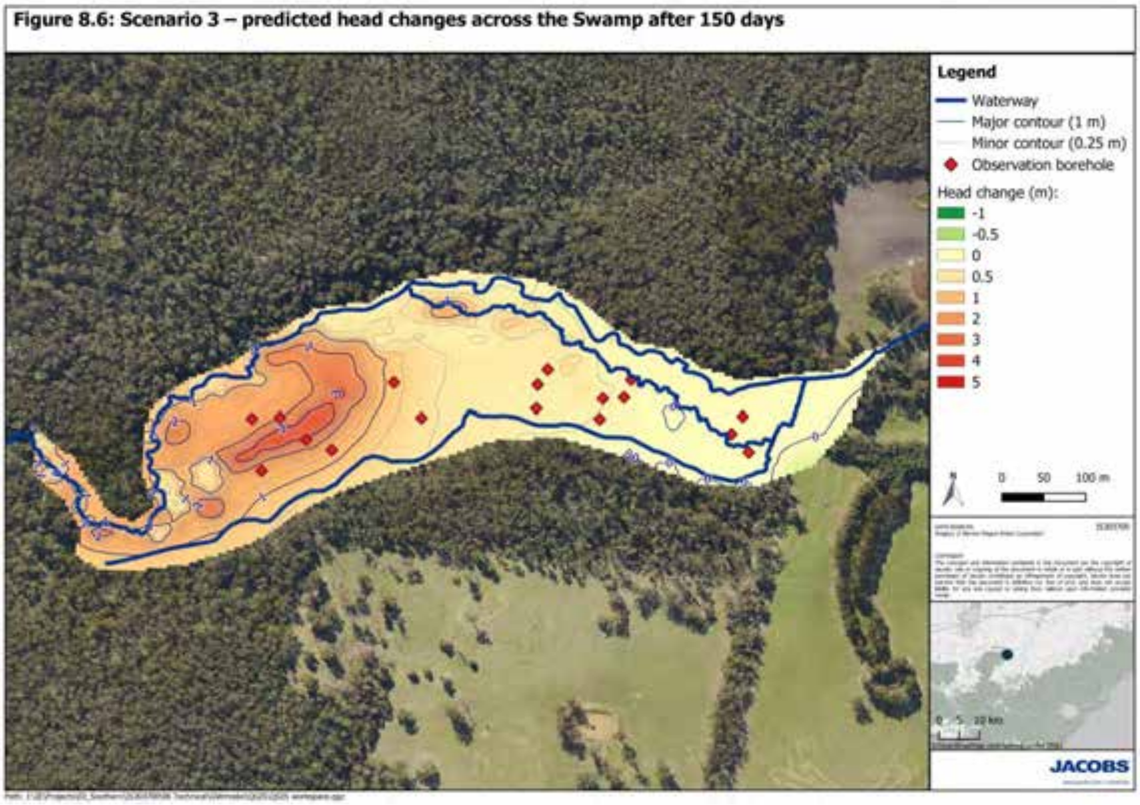


Figure 8-6: Scenario 3 – predicted head changes across the Swamp after 150 days

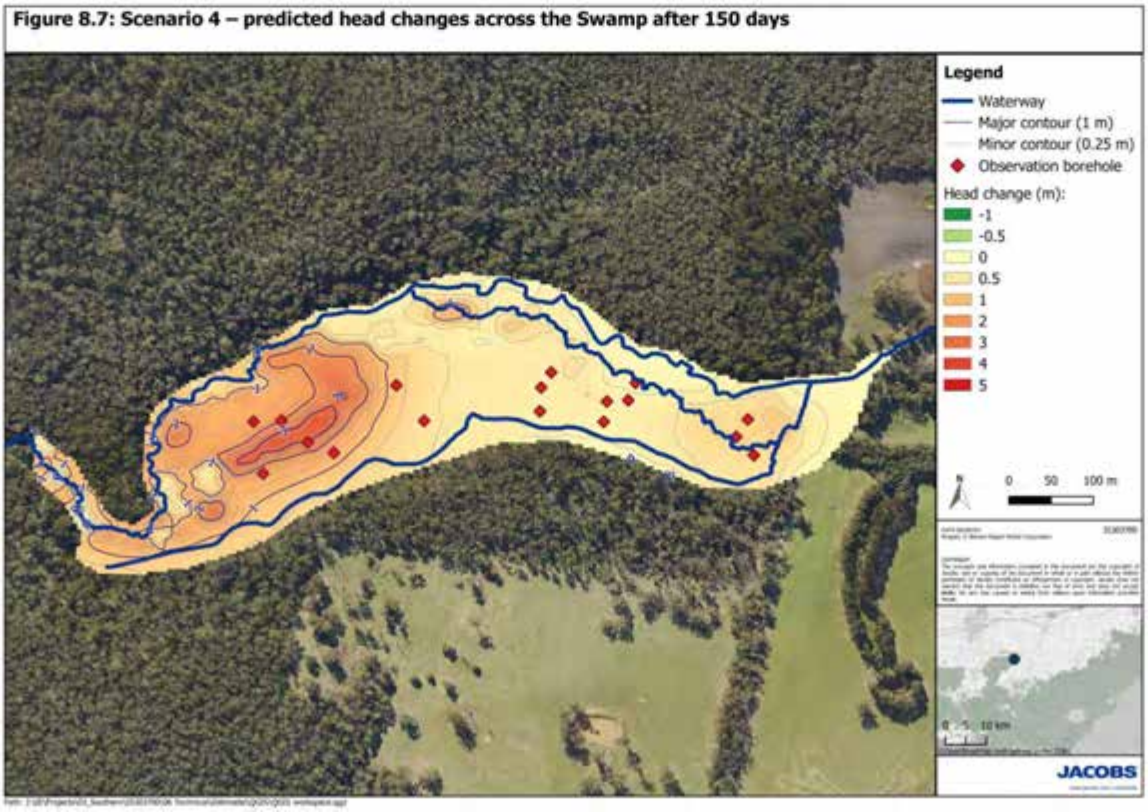


Figure 8-7: Scenario 4 – predicted head changes across the Swamp after 150 days

8.2.2 Depth to Watertable

The predicted depth to watertable contours predicted after 150 days of flow release are plotted in Figure 8-8 to Figure 8-11 for Scenarios 1 to 4 respectively. Areas of water ponding at the surface are shown in purple in these figures.

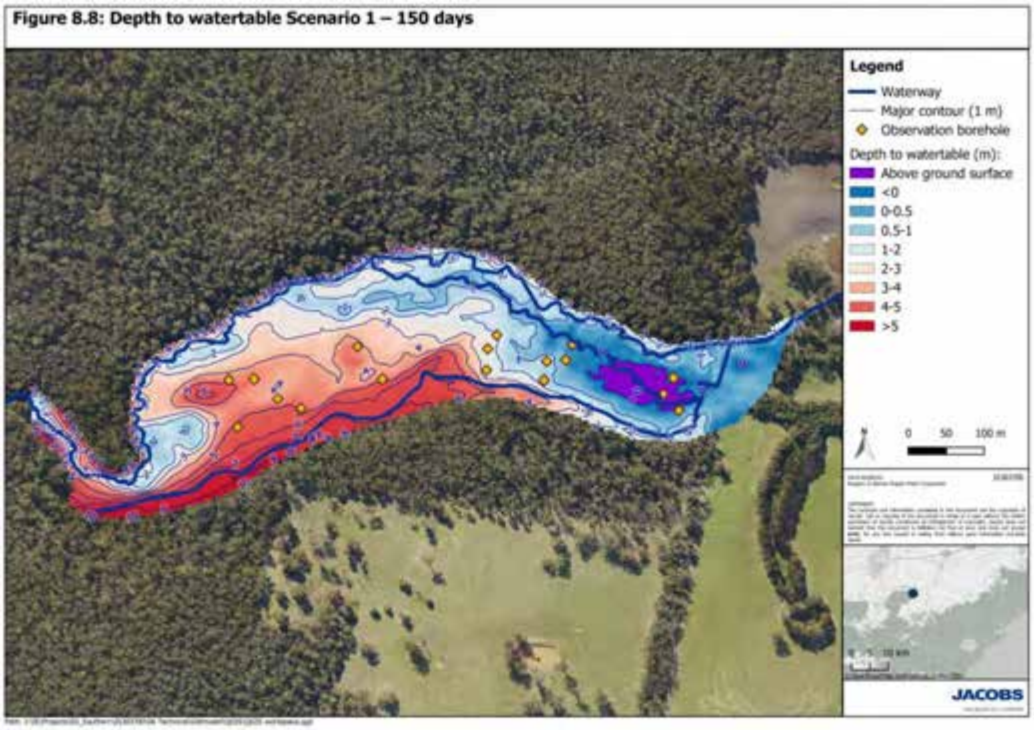


Figure 8-8: Depth to watertable Scenario 1 – 150 days

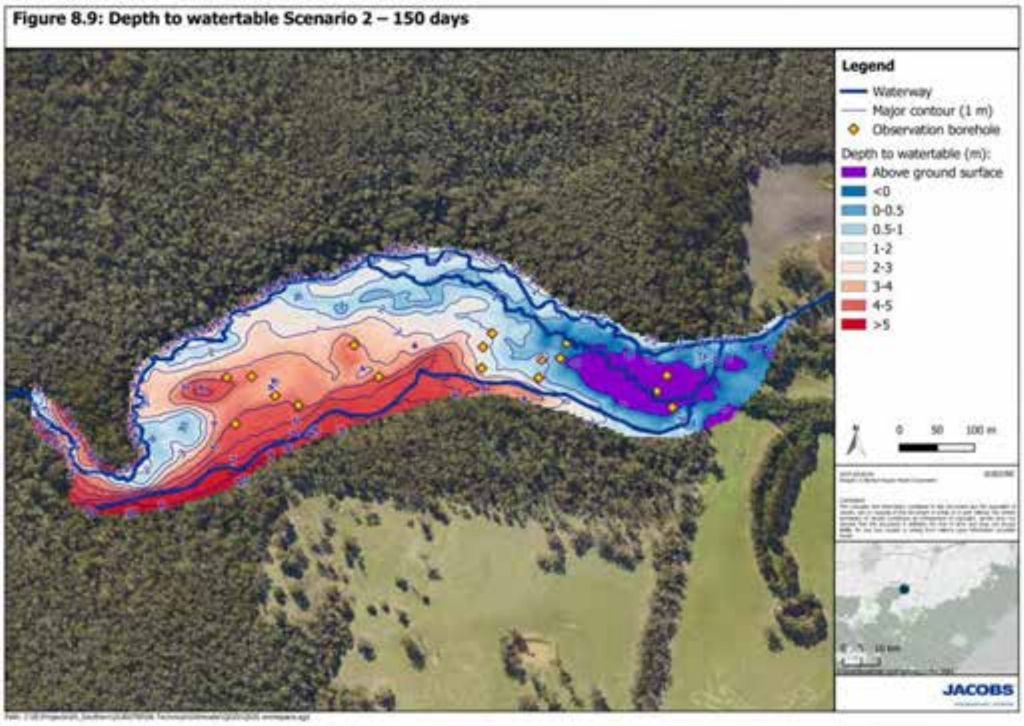


Figure 8-9: Depth to watertable Scenario 2 – 150 days

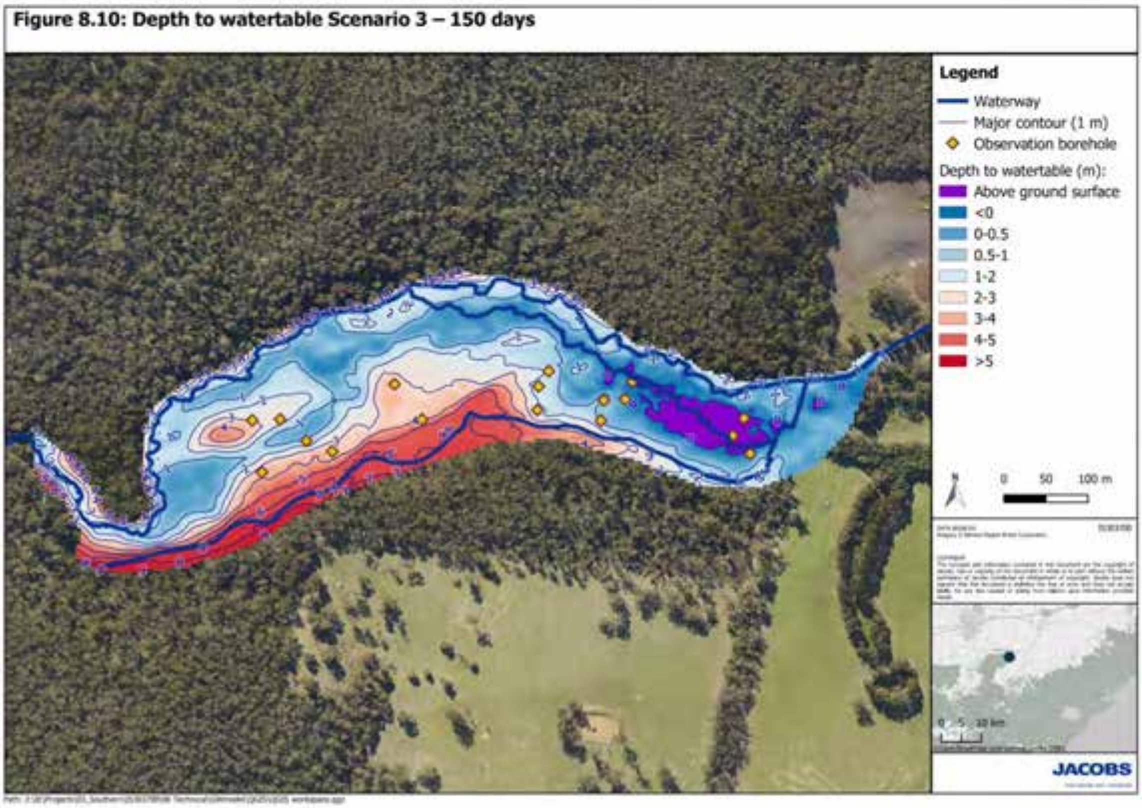


Figure 8-10: Depth to watertable Scenario 3 – 150 days

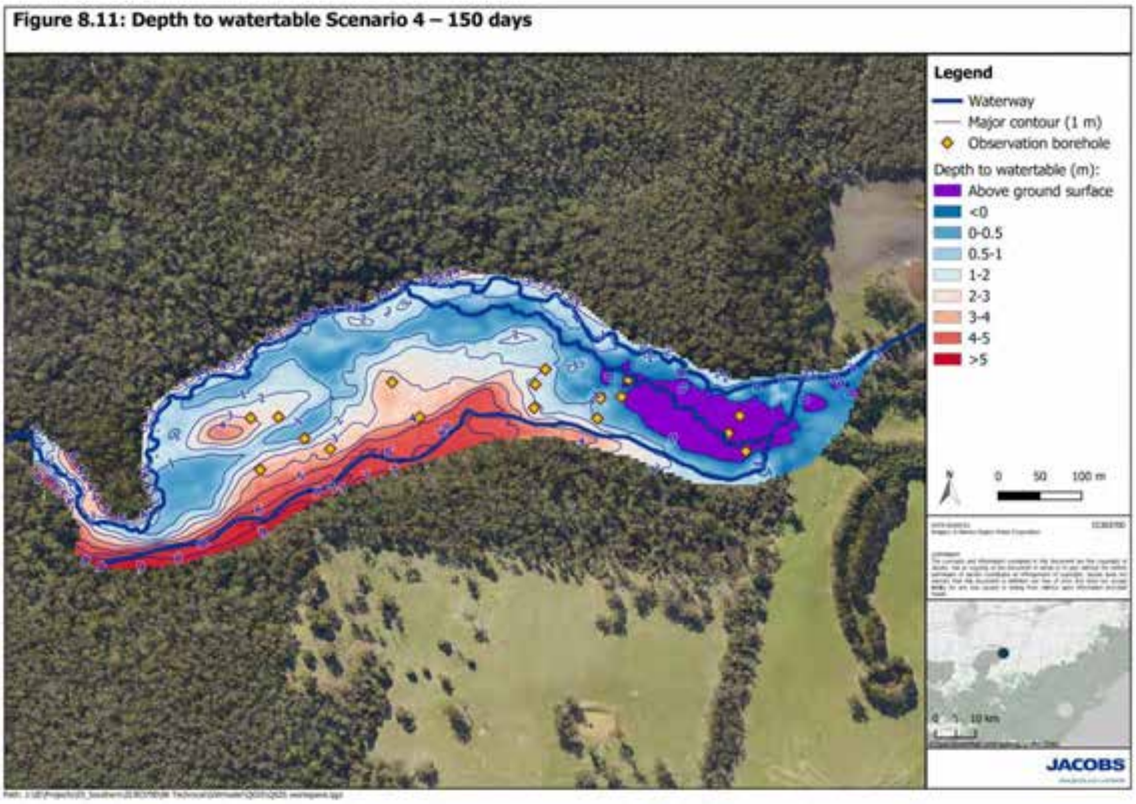


Figure 8-11: Depth to watertable Scenario 4 – 150 days

Predicted depth to watertable plots for Scenario 6 in June (low levels) and September (high levels) are presented in Figure 8-12 and Figure 8-13.

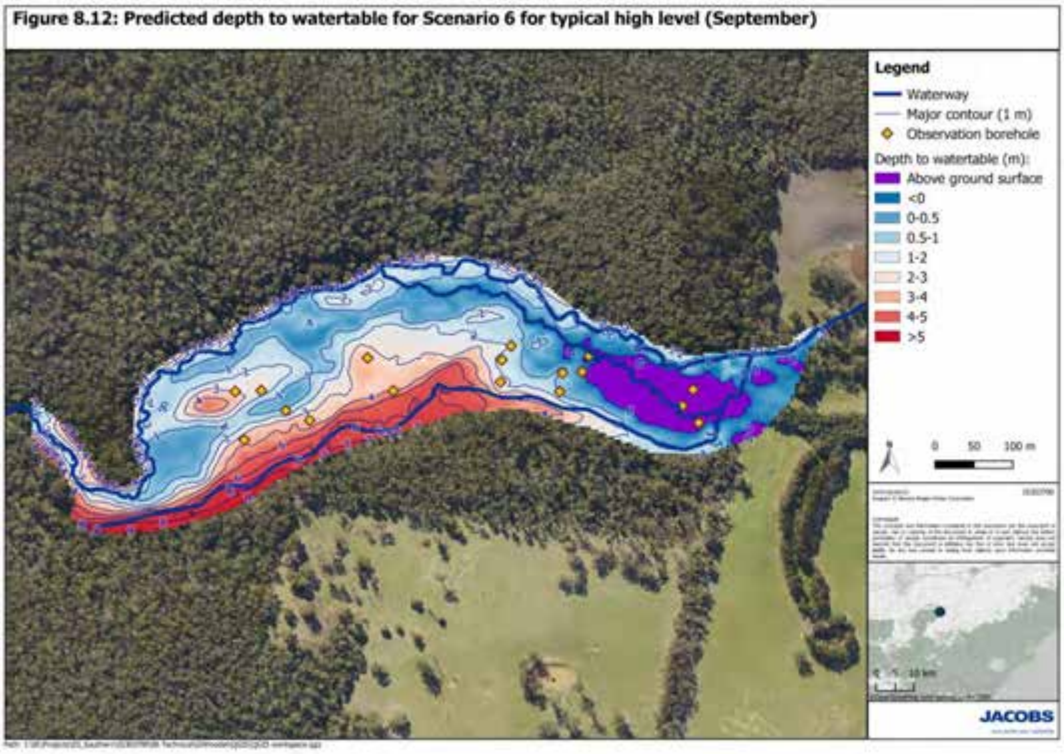


Figure 8-12: Predicted depth to watertable for Scenario 6 for typical high level (September).

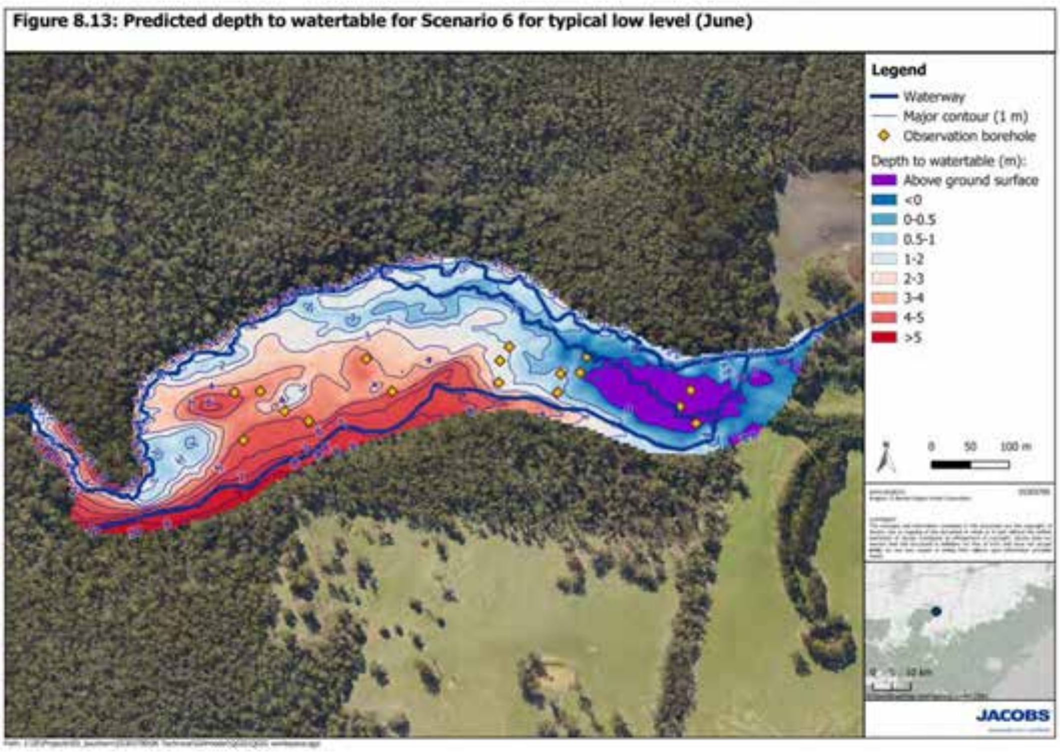


Figure 8-13:Predicted depth to watertable for Scenario 6 for typical low levels (June).

8.2.3 Surface water groundwater interaction.

Predicted groundwater exchange fluxes with Boundary Creek for Scenarios 1 to 4 are presented in Figure 8-14. The exchange fluxes are relatively constant and show very little seasonal variability. In Figure 8-14, positive fluxes represent groundwater discharge to the creek while negative fluxes correspond to predicted seepage from the creek to groundwater. The results suggest that Boundary Creek is losing to groundwater throughout the swamp and damplands and is gaining from groundwater in the region downstream of the swamp.

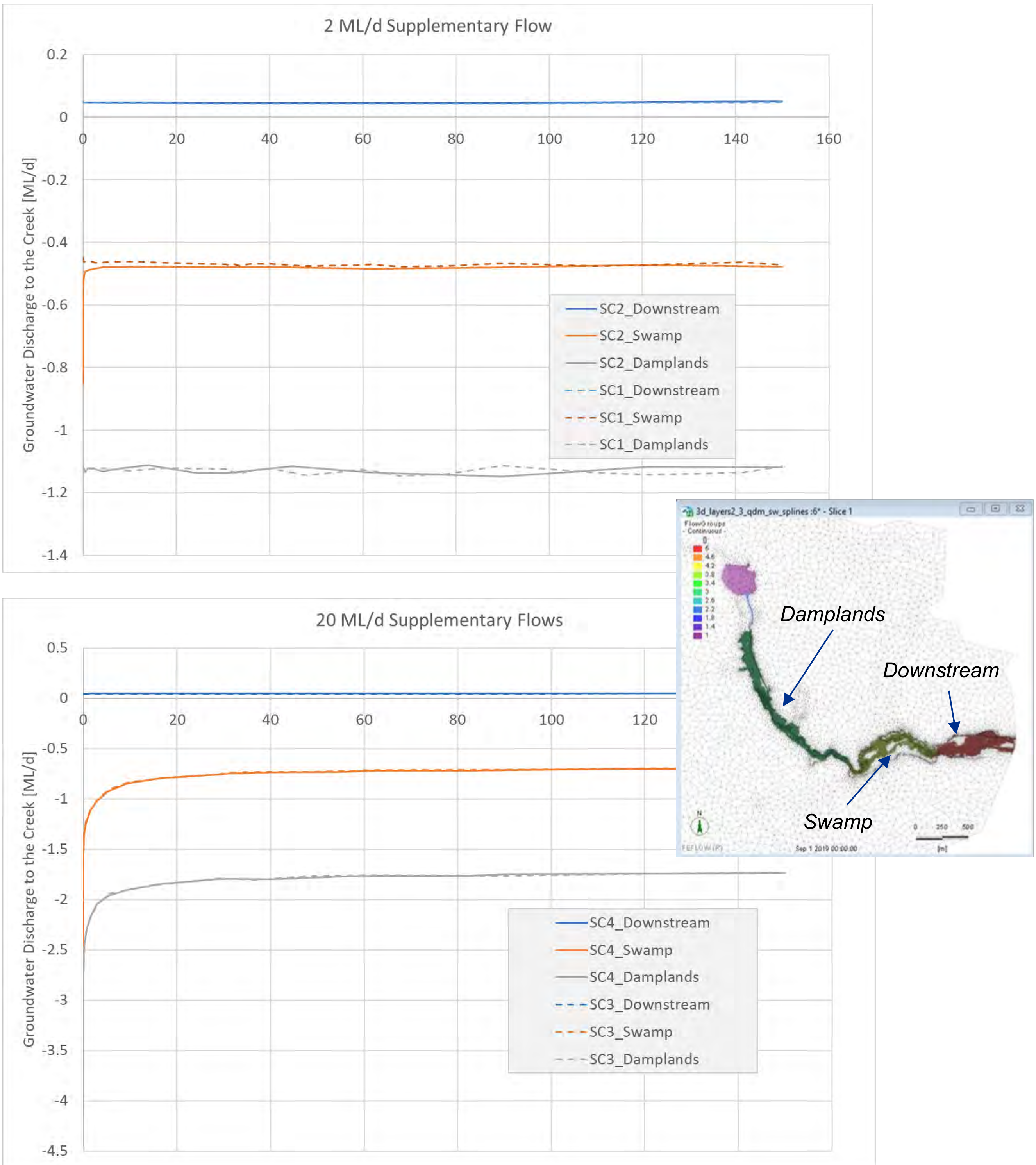


Figure 8-14: Predicted exchange fluxes for Scenarios 1 to 4.

Scenarios 5 and 6 include a level of dynamic behaviour through the assumed seasonal variation in creek flow conditions. These scenarios provide a more realistic simulation of the transient exchange fluxes between groundwater and the creek compared to the other scenarios that include constant head boundary conditions for Boundary Creek. Predicted groundwater fluxes to and from Boundary Creek in Big Swamp are shown in Figure 8-15. Note that the fluxes are predicted for the swamp only and represent about a third of the overall exchange fluxes throughout the model domain.

Figure 8-15 indicates the predicted interaction between Boundary Creek and groundwater is dominated by seepage out of the creek. The predicted losses from Boundary Creek are about ten times greater than the predicted groundwater discharge into the creek.

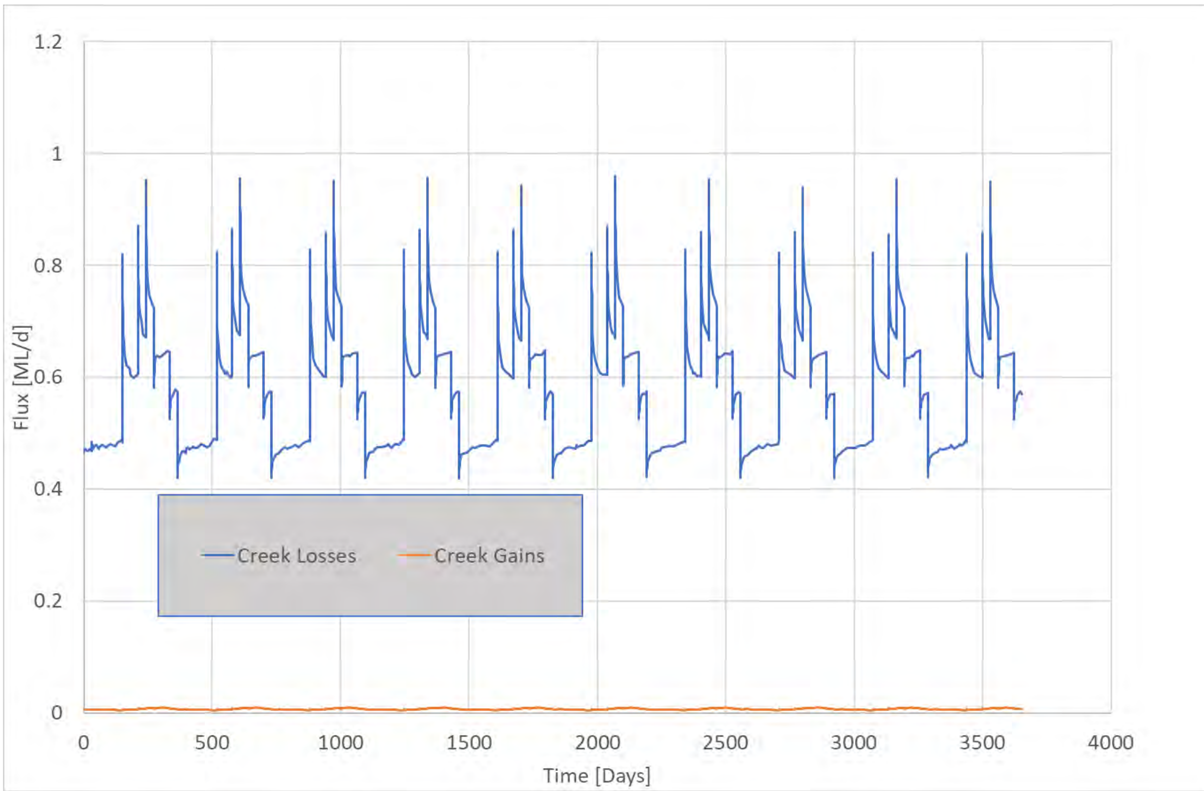


Figure 8-15: Predicted groundwater surface water exchange fluxes in Big Swamp (Scenario 5).

9. Discussion

The exchange of data between the surface water inundation model and the groundwater model provide a significant challenge for transient models. The surface water model requires a time step of about one second and produces very large data sets when the model runs for a period that is meaningful for groundwater model calibration and prediction. Typically, hydraulic models are run for individual flooding events and are not required to solve for extended periods of time. The issue can be partially solved by taking instantaneous results or averaging surface water model results over a period that is appropriate for a groundwater model stress period (days or weeks). However, the surface water model will take an excessively long time and produce extremely large output files if it is run through a transient period that would be appropriate for groundwater model calibration or prediction.

These problems have hindered the development of a fully coupled model and have led to simplifications in order to generate appropriate inputs for a groundwater model. The calibration process for the groundwater model has been simplified by applying a repeating annual flow sequence that assumes a progression of steady state surface water stage and inundation areas obtained from the hydraulic model. Predictions are similarly limited to short term simulations that assume steady state surface water flow conditions (Scenarios 1 to 4) or to a synthetic annual sequence of steady state surface water flow conditions.

Despite these simplifications, the groundwater model provides a reasonably good approximation to groundwater heads measured throughout the swamp over the period June to September 2019. The validity of the model is further reinforced by the predicted creek losses matching the conceptual or indicated losses in recent years.

Additional confidence in the groundwater model can be expected in future as additional flow and groundwater head observations are collected and through improved integration with the surface water model. In this regard the selective accumulation, averaging and saving of surface water data may generate an appropriate set of river stage and inundation areas that would be suitable for transient groundwater model runs, albeit of a restricted time period. While it may never be possible to fully couple a long-term predictive model, results obtained to date suggest that the groundwater system equilibrates quite rapidly to changes in surface flows and hence long-term predictions may not be required.

The predictive model results indicate the following:

1. The groundwater heads through the swamp are expected to fluctuate seasonally as surface water flows respond to local rainfall. The magnitude of the seasonal head fluctuations is expected to be much greater in the upper reaches of the swamp than the lower reaches.

2. If a hydraulic barrier were to be constructed at the outlet from the swamp, it would likely increase groundwater levels and lead to perennial inundation of the lower parts of the swamp. The effects of a hydraulic barrier are not predicted to propagate to the central and upstream part of the swamp.

3. The combination of providing a continuous release of water from the dam and the installation of hydraulic barriers can be expected to increase groundwater levels throughout the swamp and to maintain flow in Boundary Creek, however this would need to be confirmed with further modelling to assess appropriate heights and locations of additional barriers.

The combined groundwater surface water model results have demonstrated that:

1. Increasing supplementary flow leads to increasing inundation extent over dry conditions but less than what is typically experienced at end of winter and early spring. A supplementary flow of 20 ML/d more than doubles the area inundated by a supplementary flow of 2 ML/d.
2. The hydraulic barrier at the downstream end of the swamp increases the area of inundation immediately upstream and this inundated area is largely independent of supplementary flow i.e. there is only minor differences in the area of this pool in the four supplementary flow rates modelled. In this regard, the area of inundation is controlled by the height and location of the barrier.

3. A supplementary flow of 2 ML/d does not maintain groundwater levels at typical winter levels throughout the swamp whereas a supplementary flow 20 ML/d raises groundwater levels to varying degrees throughout the swamp.
4. The incorporation of a hydraulic barrier is effective in raising groundwater levels in the vicinity of the increased area of surface water inundation. This result can be seen in Figure 8.2 where predicted groundwater levels at BH01, BH02 and BH03 (all located within the inundated area) increase significantly for both 2 ML/d and 20 ML/d.
5. Long term trends in groundwater heads are not expected as the groundwater system equilibrates quite rapidly with changing flows in the creek.

The modelling results indicate that a supplementary flow of 2 ML/d with no other interventions is not effective in increasing the inundated area or raising groundwater levels above those typically experienced at the end of winter (nominally September) in recent years. However, the hydraulic modelling suggests that this level of flow release will ensure flows through the swamp through all seasons and hence represents an improvement in historic groundwater levels throughout the swamp. While this scenario is conservative, in that no additional flows to the system were modelled, it is not unrealistic over the summer where extended periods of low flow are normally experienced. Increasing the supplementary flow to 20 ML/d is effective in increasing both the area inundated and groundwater levels; however, the flow rates represent the average August and September flows and continuous delivery of this flow is not feasible.

The scenarios incorporating a single hydraulic barrier have demonstrated the benefit is limited to the area immediately upstream of the barrier. The surface water results of a barrier with different supplementary flows found that there were diminishing returns with higher flows.

Model results indicated that the benefit of the hydraulic barrier is localised and it is recommended that multiple sites throughout the swamp be identified where benefits may be realised from the increased inundation from a barrier. Suitable location of additional barriers may be determined from the topographic (LiDAR) data and results of modelling to determine potential impacts. In addition, the results from parallel studies including the vegetation study and the geochemical study may help locate the barriers in areas that have the highest likelihood of providing benefit to the swamp. Further, the results of the hydraulic model for a number of flow rates demonstrated that there are diminishing returns with increasing supplementary flows. Hence, a modest supplementary flow with multiple hydraulic barriers may provide the greatest benefit and limit the export of acid water. It is recommended the initial concept developed here is examined in the future with multiple barriers.

The groundwater model includes significant levels of uncertainty that arise from our inability to accurately map and characterise local scale heterogeneities that are important in controlling groundwater behaviour in the local scale. In this regard it is no different from all other groundwater models and simply reflects the fact that the model behaviour is controlled by underground features that cannot be seen, measured or even inferred from the surface. Dealing with model uncertainty is an active area of research and numerical methods are now available to help illustrate the likely error bars associated with any particular prediction. We recommend that quantitative uncertainty analysis be included in future modelling investigation of Boundary Creek and Big Swamp. Understanding the potential errors included in predictions will help clarify the level risk of associated with the use of model results that are not necessarily precise.

10. References

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Appendix A. Rainfall-runoff modelling details

In order to understand the hydrological characteristics of the catchment a rainfall-runoff model was developed. In addition to characterising the catchment in terms of hydrology, the model was used to:

- The streamflow in Boundary Creek downstream of McDonalds Dam (at streamflow gauge 233229) and at Yeodene (at streamflow gauge 233228) to infill missing gauged data;
- Catchment runoff for the intermediate catchment between McDonalds dam and Yeodene; and
- These outputs were subsequently used to inform the loss analysis and infill streamflow series inputs used as part of the hydraulic model.

A continuous daily GR4J rainfall-runoff model was created to produce an estimate of the surface runoff in response to input climate conditions (represented by a timeseries of both rainfall and potential evapotranspiration). The transformation of climate inputs into runoff is controlled by the model structure and parameters.

This section provides background on the continuous rainfall-runoff model, describes the model build and presents the results.

A.1 GR4J

GR4J (Perrin et al., 2003) is a conceptual daily timestep rainfall-runoff model which can be applied in a lumped or semi-distributed fashion. The structure of GR4J is illustrated in Figure 10-1; rainfall can be discharged to two stores (a production store (X1) and a routing store (X3)) or routed overland. Water stored in the routing store is partitioned into a quick and slow flow component which are routed by a unit hydrograph for each partition, the time base of which is controlled by X4. Water can also be exchanged (gained or lost) from a conceptual groundwater store which is represented by X2.

A description of each of the GR4J parameters is provided in Table A.1: GR4J parameters (Perrin et al., 2003), together with typical parameter ranges. Calibration of a rainfall-runoff model involves adjusting the model parameters until the output matches, as closely as possible, the observed stream flows.

Table A.1: GR4J parameters (Perrin et al., 2003)

Parameter	Description	Units	Default	Range
x1	Capacity of the production soil (SMA) store	mm	350	1 - 1500
x2	Water exchange coefficient	mm	0	-10.0 - 5.0
x3	Capacity of the routing store	mm	40	1 - 500
x4	Time parameter for unit hydrographs	days	0.5	0.5 - 4.0

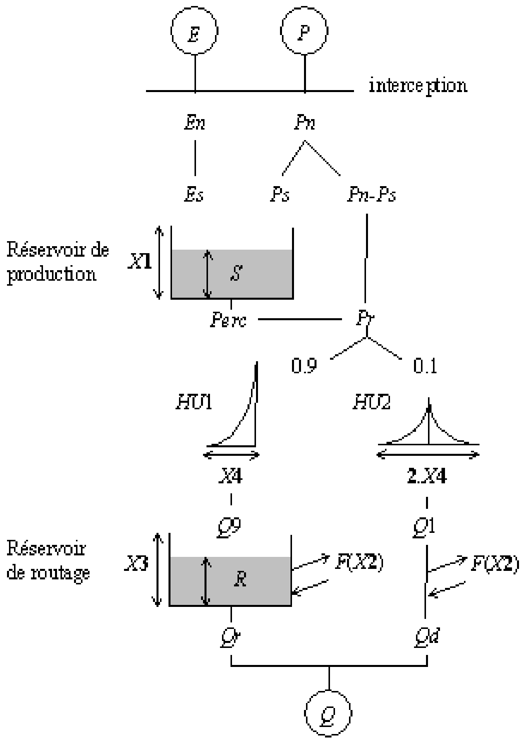

Figure 10-1: GR4J model schematic (Perrin et al, 2003)

A.1.1 Model build and catchment conceptualisation

The daily continuous GR4J rainfall-runoff model was built using the airGR software package available in the R programming language. airGR was developed by the Catchment Hydrology Research Group at Irestea (Coron, 2017) and is freely available online.

The model was conceptualised as two sub-catchments as shown in Figure 10-2 with outlets at:

- The downstream of McDonalds Dam gauge (233229); and
- The Colac-Forest Road by Yeodene gauge (233228).

Each sub-catchment required:

- Catchment area;
- A rainfall timeseries; and
- A PET timeseries.

Additionally, timeseries of observed streamflow, which may include missing data, was required for calibration and validation.

Figure 10-2: GR4J Model conceptualisation

A.1.2 Input climate data

The required climate input data for GR4J is daily rainfall and PET data over the simulation and warm-up period (see Table A.2). Catchment average rainfall and PET data which was derived from gridded SILO data was used (refer to Section 4.1). Daily PET for the missing period (July – September 2019) was infilled using the average daily PET for each month from July 1975 to June 2019. The resulting daily rainfall and PET series are presented in Figure 10-3 and Figure 10-4.

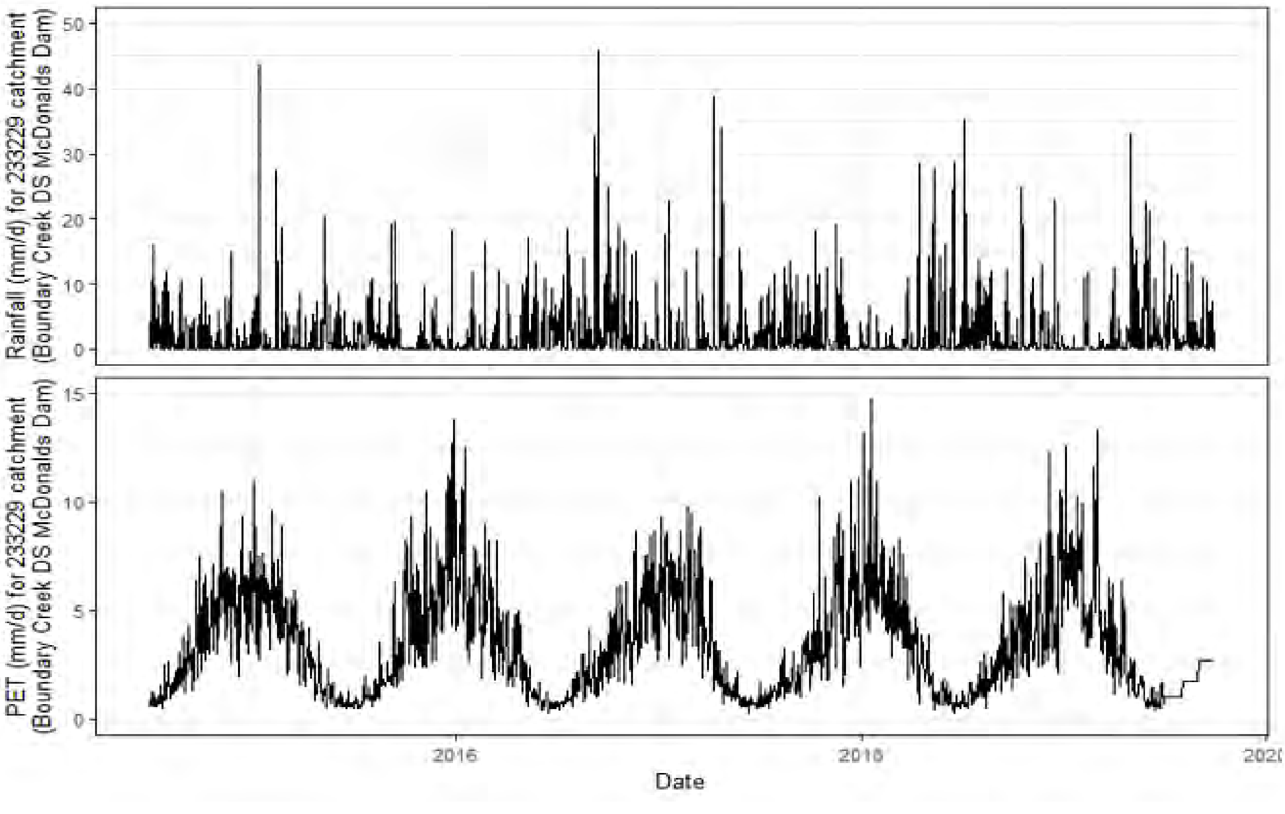

Figure 10-3: Climate inputs into the GR4J model which models the catchment upstream of streamflow gauge 233229

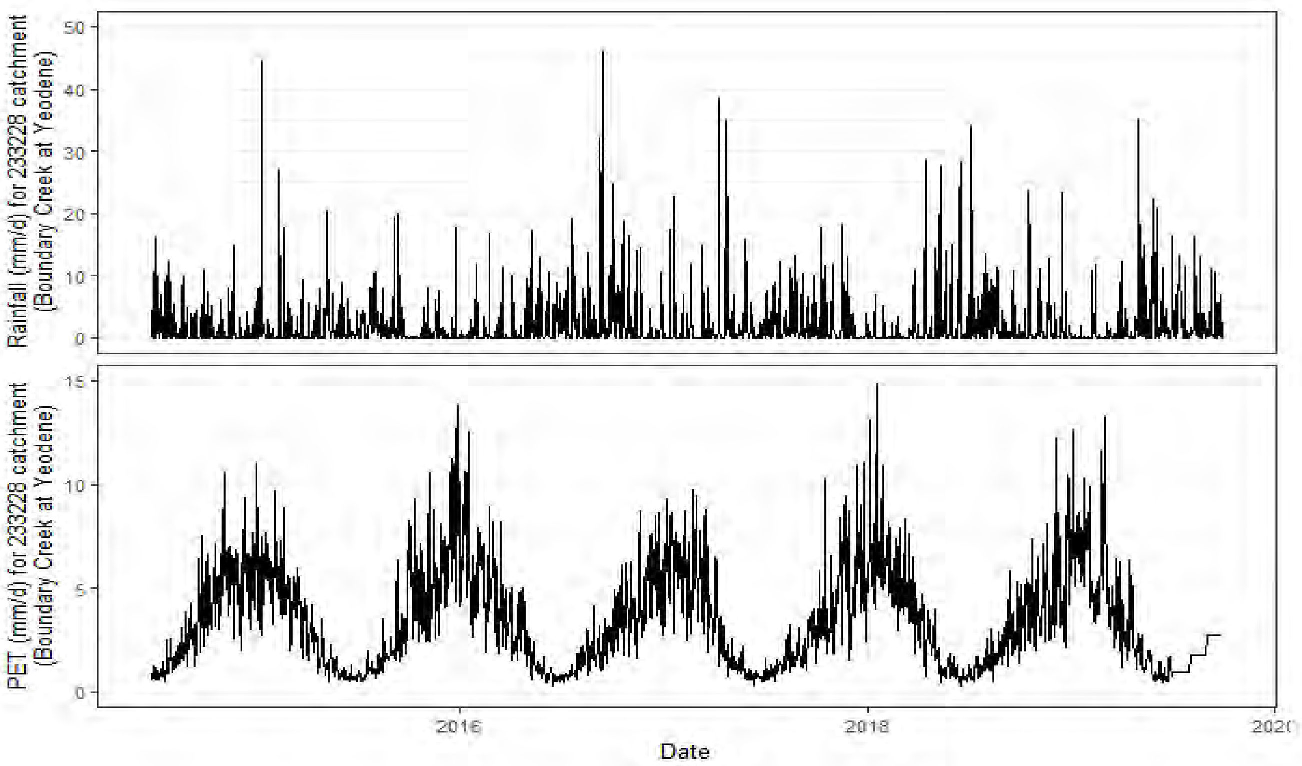

Figure 10-4: Climate inputs into the GR4J model which models the catchment upstream of streamflow gauge 233228

A.1.3 Streamflow data

Daily streamflow series are required for the calibration and verification runs so that the observed data can be compared against the simulated data to assess the goodness of fit. Observed data was sourced from the BoM Water Data Online (2019) as described in Section 4.1.

Due to the limited period of record for the two gauges immediately upstream and downstream of Big Swamp and the missing data over these periods, the streamflow gauges 233229 (Boundary Creek downstream of McDonalds Dam) and 233228 (Boundary Creek at Yeodene) were adopted as the key streamflow locations for this assessment.

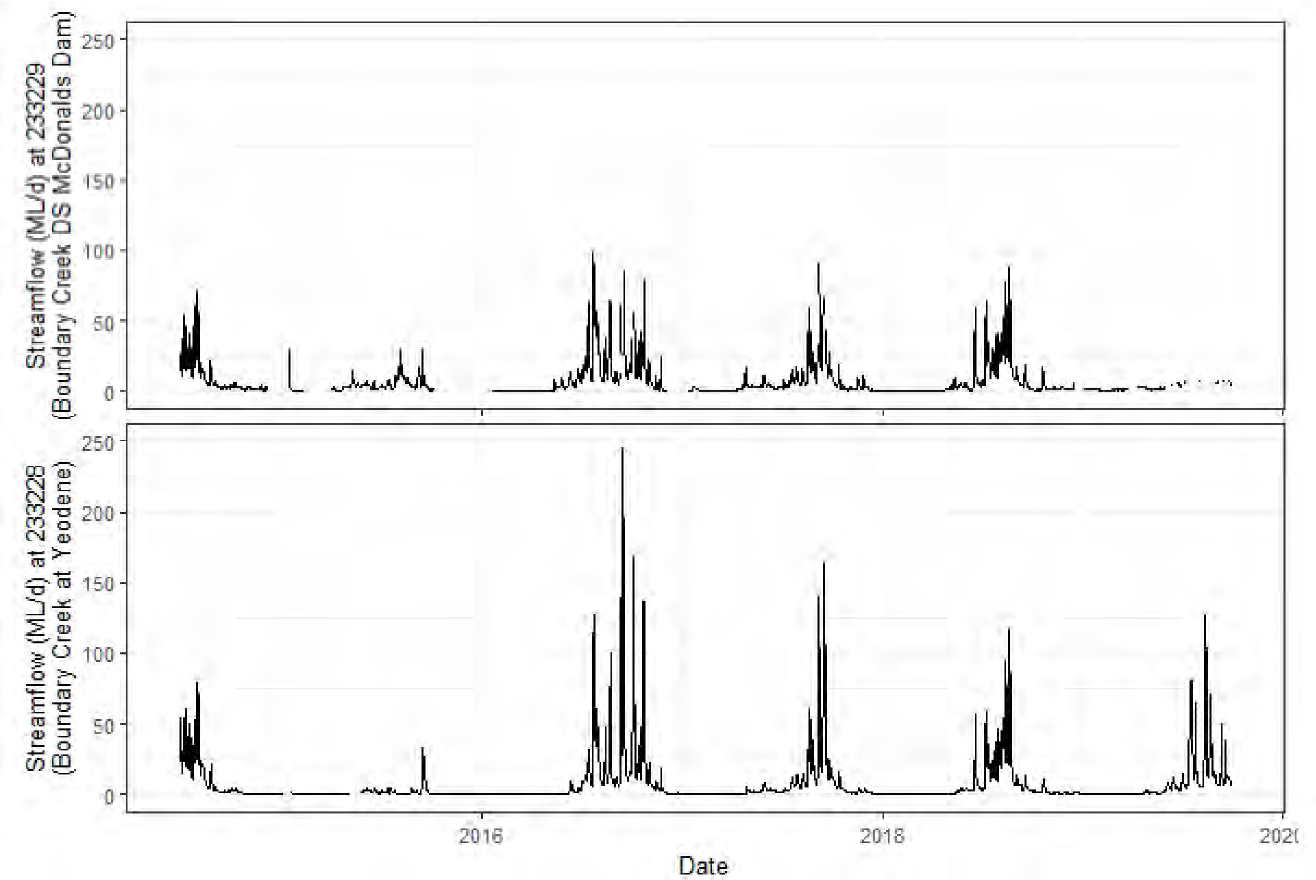

Figure 10-5: Streamflow data at the key streamflow gauges used as inputs into the GR4J model

A.1.4 Calibration / Validation

In undertaking a model calibration, a number of decisions need to be made, such as:

- What calibration method to use – manual or automatic?
- What calibration strategy to use?
- How to measure the fit of the model – what objective functions should be adopted?

These are discussed below.

Calibration method

In general, there are two options for undertaking calibration: manual calibration and automatic calibration. Manual calibration involves manually adjusting model parameters until an acceptable fit had been reached. Automatic calibration on the other hand uses computer algorithms to determine the optimal fit. In automatic calibration a model is run many times and the results compared to observed values. The best fit to the observed values is returned as the optimised parameter set.

Automatic calibration was selected as the calibration method for this assessment. Initially, the PORT optimisation routine (a gradient climbing algorithm) was used to estimate the best-fit parameters, using the parameter bounds and initial parameters as outlined in Table A.1: GR4J parameters (Perrin et al., 2003). The parameters of best fit for the GR4J model were then derived using a Bayesian Markov Chain Monte Carlo (MCMC) framework and specifically the Delayed Rejection Adaptive Metropolis (DRAM) algorithm. Three chains were used with different initial values to assess the convergence of the Markov chains. The number of iterations was fixed at 10,000 with a burning length of 10% (i.e. 1,000).

Calibration strategy

The calibration strategy refers to the way that the optimum parameter set is determined. There are a number of different strategies that can be used to calibrate a model. The most common approach is the *split sample technique* whereby the model is calibrated to a particular period and then validated against another period to assess how well the model performs outside of this period of calibration. Given the short length of available streamflow records a warm-up period of 6 months was used throughout this assessment and excluded from the goodness of fit assessment.

Table A.2: Assessment periods for calibration and validation presents the periods assessment for the split sample calibration.

Table A.2: Assessment periods for calibration and validation

Model period	Calibration	Validation
Warm-up period	01/07/2014 – 31/12/2014	1/07/2017 – 31/12/2017
Simulation period	01/01/2015 – 31/12/2017	1/01/2017 – 31/12/2018

Objective function

The objective function, in this context, aims to reduce the error between the observed and modelled flow series. In this study the daily Kling-Gupta Efficiency (KGE) (Gupta et al., 2009) was used. The KGE is a decomposition of the Nash-Sutcliffe Efficiency (NSE), which comprised different components (correlation, bias and variability) which address some of the limitation of Mean Squared Error (and hence the NSE).

A smaller KGE value is indicative of a poor fit, while a KGE of 1 indicates a perfect fit. Therefore, in order to successfully utilise KGE as the goodness of fit statistic, the automatic calibration attempts to minimise 1 – KGE.

Calibration results

To assess the performance of each GR4J catchment model a number of performance metrics were calculated as listed in Table A.3.

Table A.3: Summary flow metrics for model evaluation

Metric	Description	Range
Mean Error	Mean error between sim and obs.*	-inf to inf
Root Mean Square Error (RMSE)	Root Mean Square Error (RMSE) between sim and obs. RMSE gives the standard deviation of the model prediction error. A smaller value indicates better model performance*	0 to inf

Metric	Description	Range
Percent Bias (PBIAS)	Percent Bias between sim and obs.*	-inf to inf
Nash-Sutcliffe Efficiency (NSE)	The Nash-Sutcliffe efficiency (NSE) is a statistic describes the amount of variance explained by the model (Nash and Sutcliffe, 1970).	-inf to 1
Pearson Correlation coefficient (R)	Is a measure of the linear correlation between two variables obs and sim.	-1 to 1
Coefficient of Determination (R^2)	Describes the proportion of the variance in the sim series that is predictable from the obs series	0 to 1
Kling-Gupta Efficiency (KGE)	Is a goodness-of-fit measure developed by Gupta et al. (2009) to provide a decomposing of the NSE, facilitating the analysis of the relative important of its different components (i.e. correlation, bias and variability)	-inf to 1

A summary of the performance for each catchment is provided in Table A.4 for the goodness-of-fit statistics in Table A.4: Goodness-of-fit statistics. Diagnostic plots for two catchments are provided below to further illustrate the model performance.

Table A.4: Goodness-of-fit statistics

	RMSE	PBIAS	NSE	R	R^2	KGE
CALIBRATION						
233229	0.29	-37.70	0.57	0.79	0.62	0.51
233228	0.28	-1.70	0.66	0.83	0.69	0.83
VALIDATION						
233229	0.25	-15.80	0.75	0.87	0.76	0.74
233228	0.20	28.30	0.67	0.86	0.74	0.67

Calibration results

The MCMC analysis produced a Gelman and Rubin convergence of value of 1 which suggests an acceptable convergence. The posterior density for each parameter is presented in Figure 10-6 and the resulting parameters are presented in Table A.5. As can be observed the posterior density converges for X1 (p1), X2 (p2) and X3 (p3) close to 0 indicating little storage and exchange with groundwater.

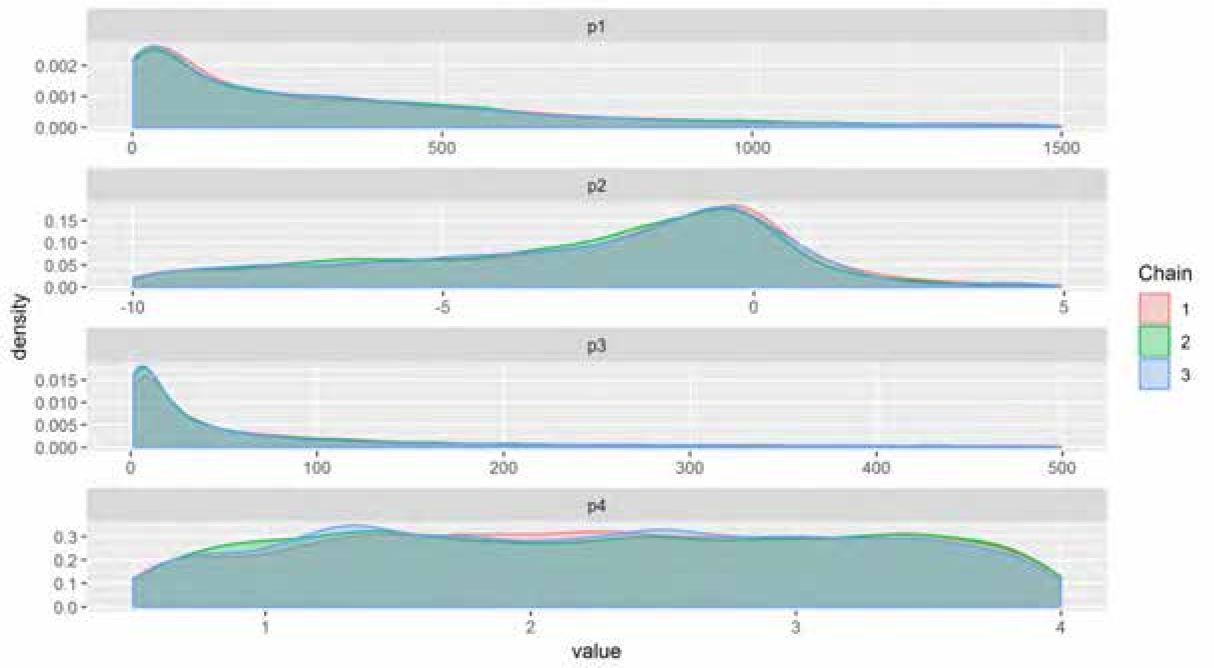

Figure 10-6: Posterior density of the GR4J parameters resulting from the MCMC calibration of the 233228 catchment. Note that p1 (x1) represents the production store capacity coefficient, p2 (x2) represents the intercatchment exchange coefficient, p3 (x3) represents the routing store capacity and p4 (x4) represents the unit hydrograph time constant.

Table A.5: GR4J calibrated parameters

X1	X2	X3	X4
418.69	-0.95	11.56	2.15

The calibration results for the upstream gauge (233229) are displayed in Figure 10-7 with the top two plots showing the observed rainfall and observed and simulated streamflow in mm/day, respectively. It can be seen in this hydrograph that the high flows and low flows occur at the same time for the simulated and observed records. The 30-day rolling mean plot (left bottom plot) indicates that the model is generally able to replicate flows throughout the year although the flows are systematically under predicted in the autumn/winter period (April to August). The flow duration curve (middle bottom plot) indicates that the model preforms better for higher flows. The final diagnostic plot indicates that the daily GR4J model highlights the systematic under prediction with points lying below the 1-1 line (right bottom plot). The goodness of fit statistics conforms these observations of the models calibration, with a KGE of 0.51 and a relatively large PBIAS of - 37%.

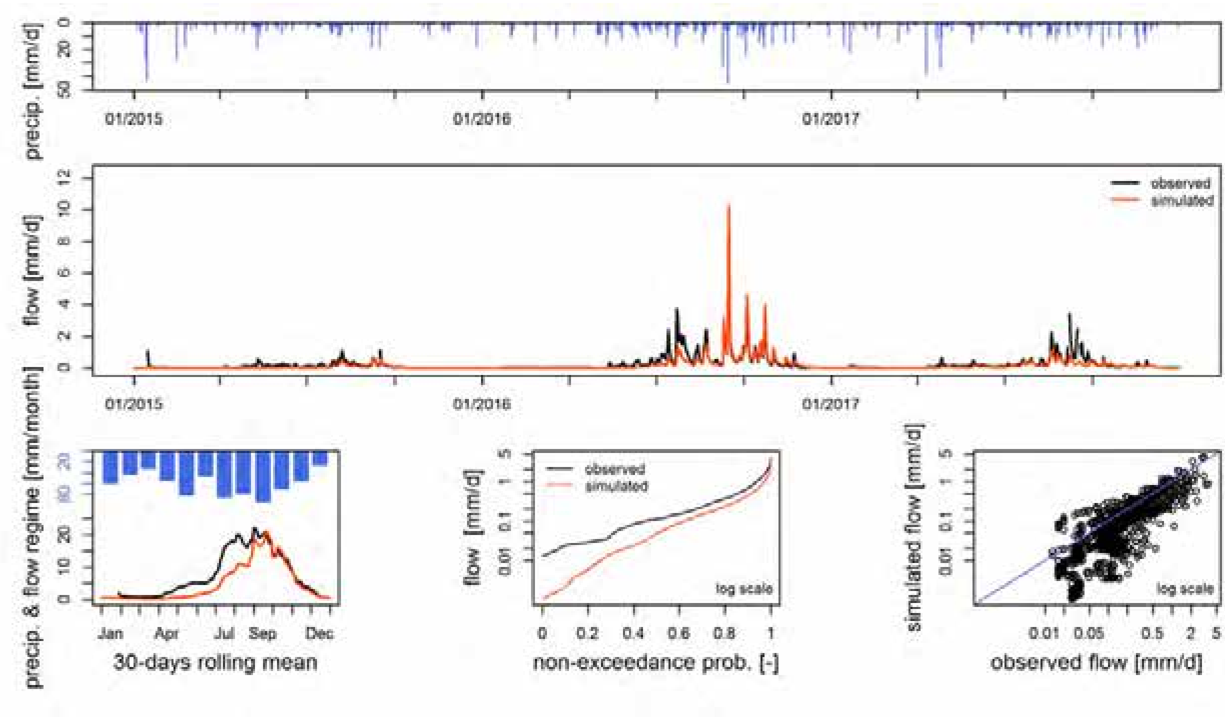

Figure 10-7: 233229 Calibration Diagnostic Plots

The calibration results for the downstream gauge (233228) are displayed in Figure 10-8 with the top two plots showing the observed rainfall and observed and simulated streamflow in mm/day, respectively. It can be seen in this hydrograph that the high flows and low flows occur at the same time for the simulated and observed records. The 30-day rolling mean plot (left bottom plot) indicates that the model is generally able to replicate flows throughout the year, whereas the flow duration curves (middle bottom plot) indicates that the model preforms well across the range of flows. The final diagnostic plot indicates that the daily GR4J model preforms well with points lying relatively close to the 1-1 line (right bottom plot). The goodness of fit statistics provides further evidence of the models ability to predict flows at 233228 over the calibration period, with a KGE of 0.83 and PBIAS within +/- 2%.

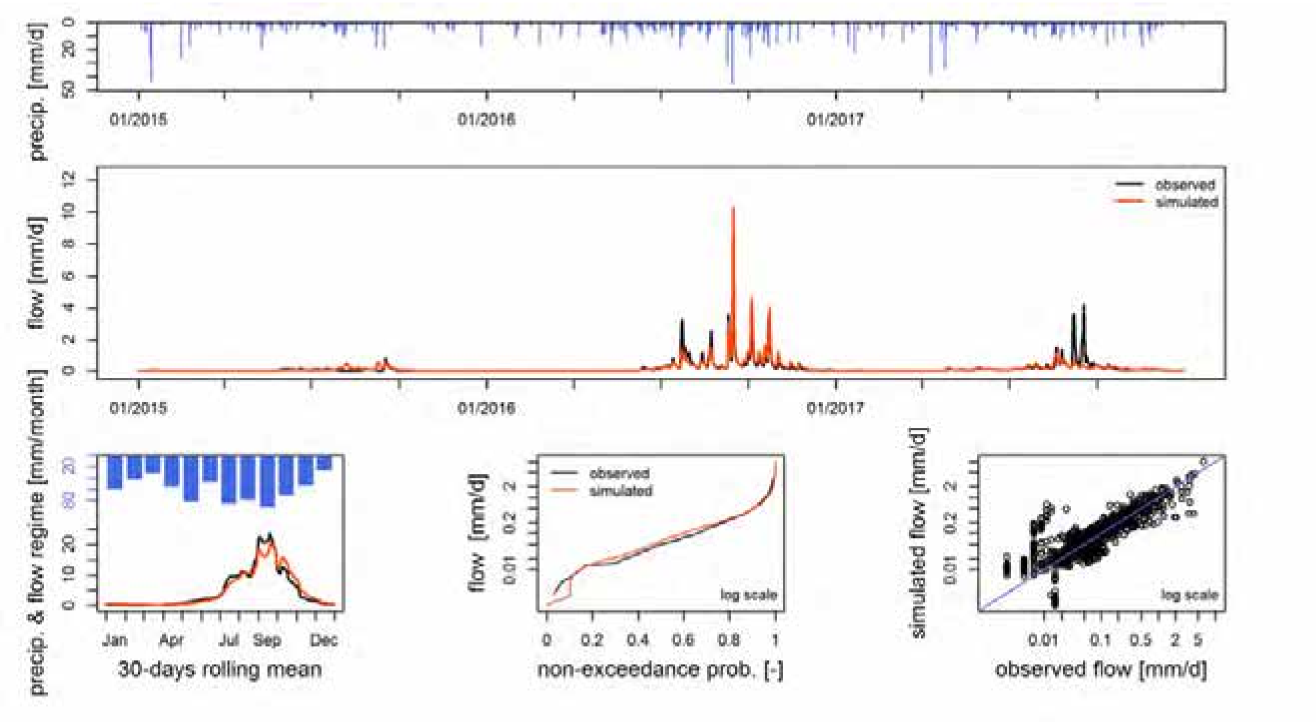

Figure 10-8: 233228 Calibration Diagnostic Plots

Validation results

Figure 10-9 and Figure 10-10 presents the diagnostic plots to assess the goodness of fit between the observed and simulated data over the validation period. In comparison to the calibration period, the model shows a better representation of streamflows at 233229 (the upstream gauge). Figure 10-9 shows that the model is better able to represent the medium and high flows, though the low flows are still underestimated.

The goodness of fit statistics for 233228 (the downstream gauge) over the calibration and validation periods is comparable. The PBIAS and KGE values indicate that the model does not perform as well over the validation period which is usually the case.

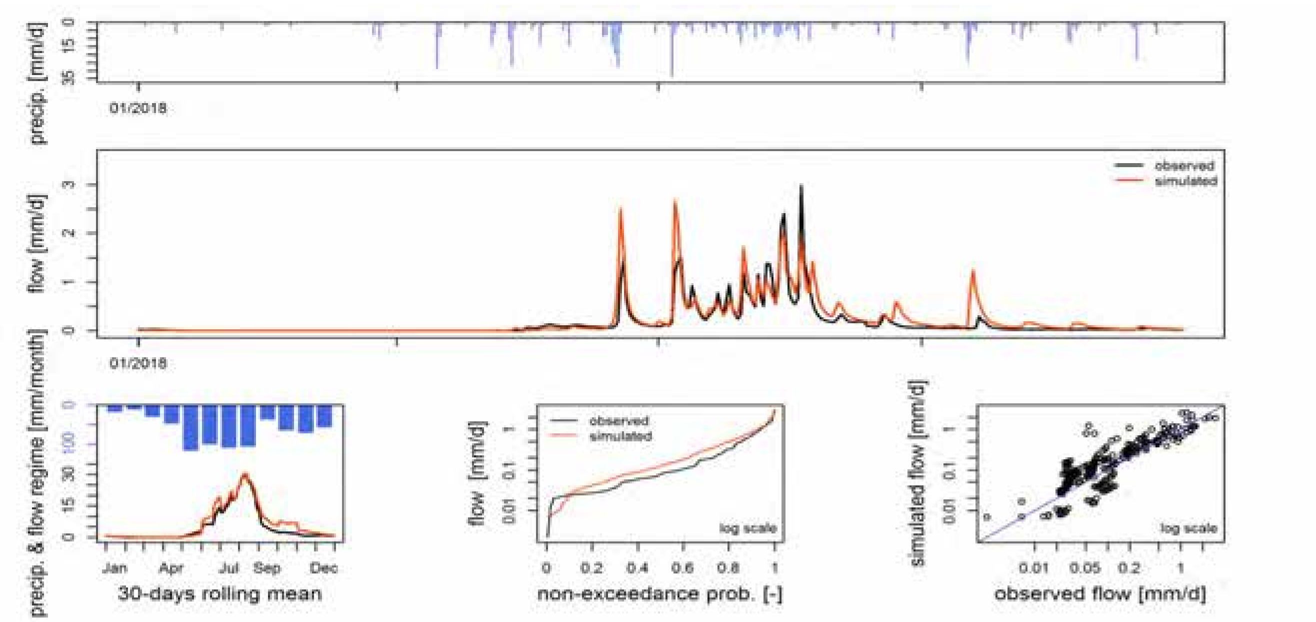

Figure 10-9: 233228 Validation Diagnostic Plots

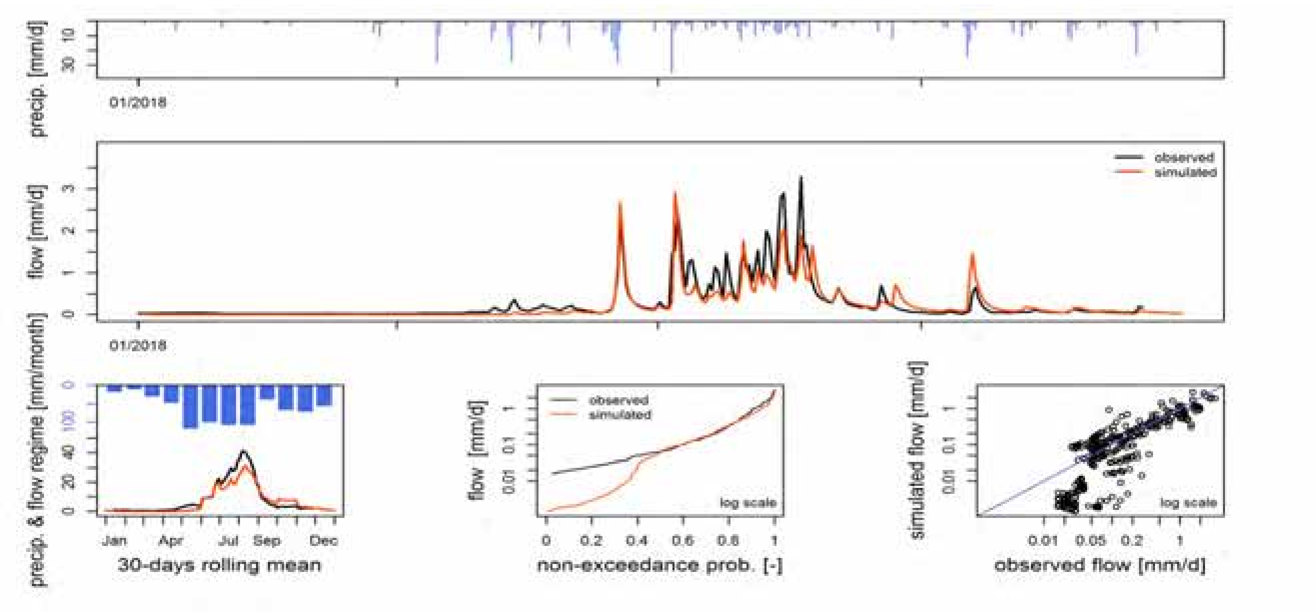

Figure 10-10: 233229 Validation Diagnostic Plots

Simulation results

After calibration and validation, the models were run over the full simulation period from 01/01/2015 – 30/09/2019, not including the 6-month warm-up period.

Figure 10-11 presents a flow duration curve of the timeseries outputs from the sub-catchment:

- Simulated flow at the gauge location 233229: Boundary Creek at Downstream McDonalds Dam
- Simulated flow at the gauge location 233228: Boundary Creek at Yeodene
- Simulated catchment runoff of the downstream gauge (which enters Boundary Creek between the two gauged locations).

A plot of average monthly flow (ML/d) is presented in Figure 10-12.

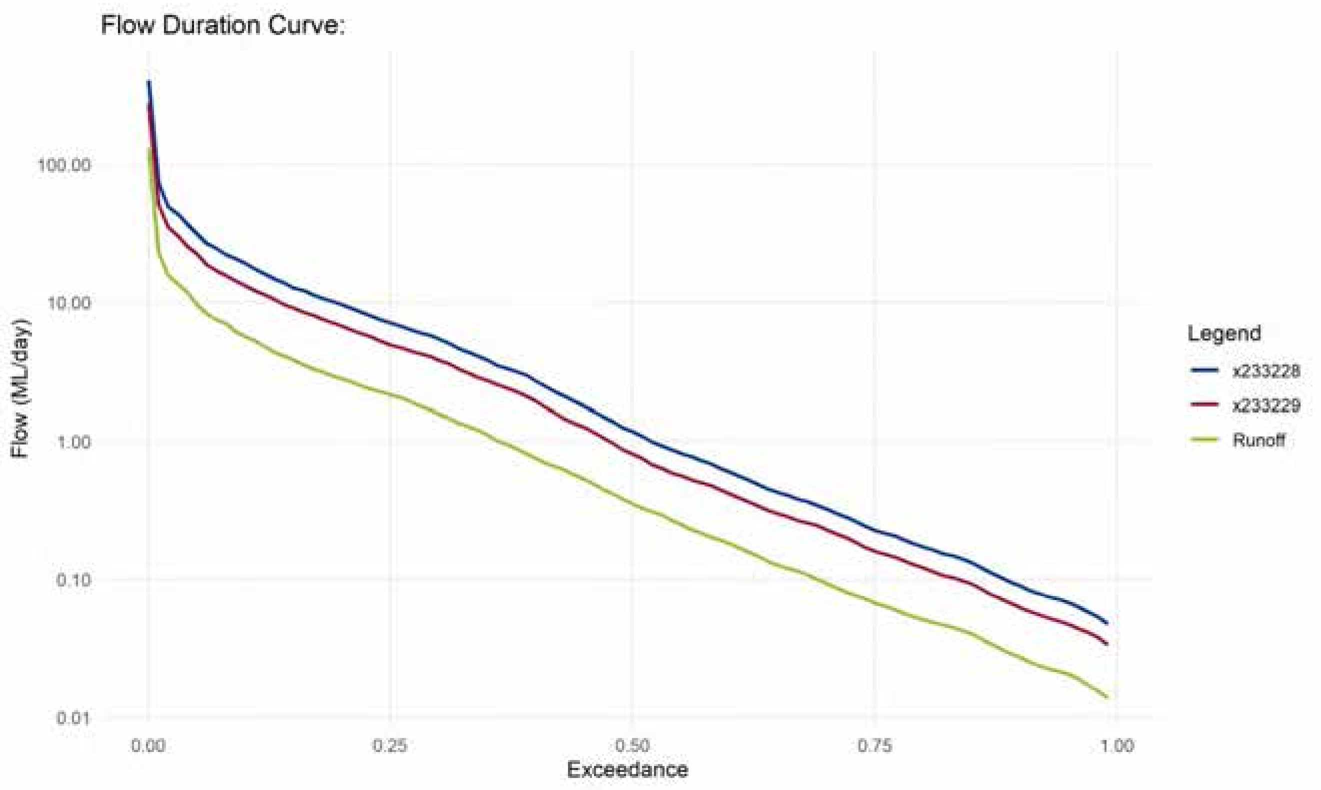

Figure 10-11: Exceedance curve of flow over the full record of simulation (1/01/2015 – 30/09/2019).

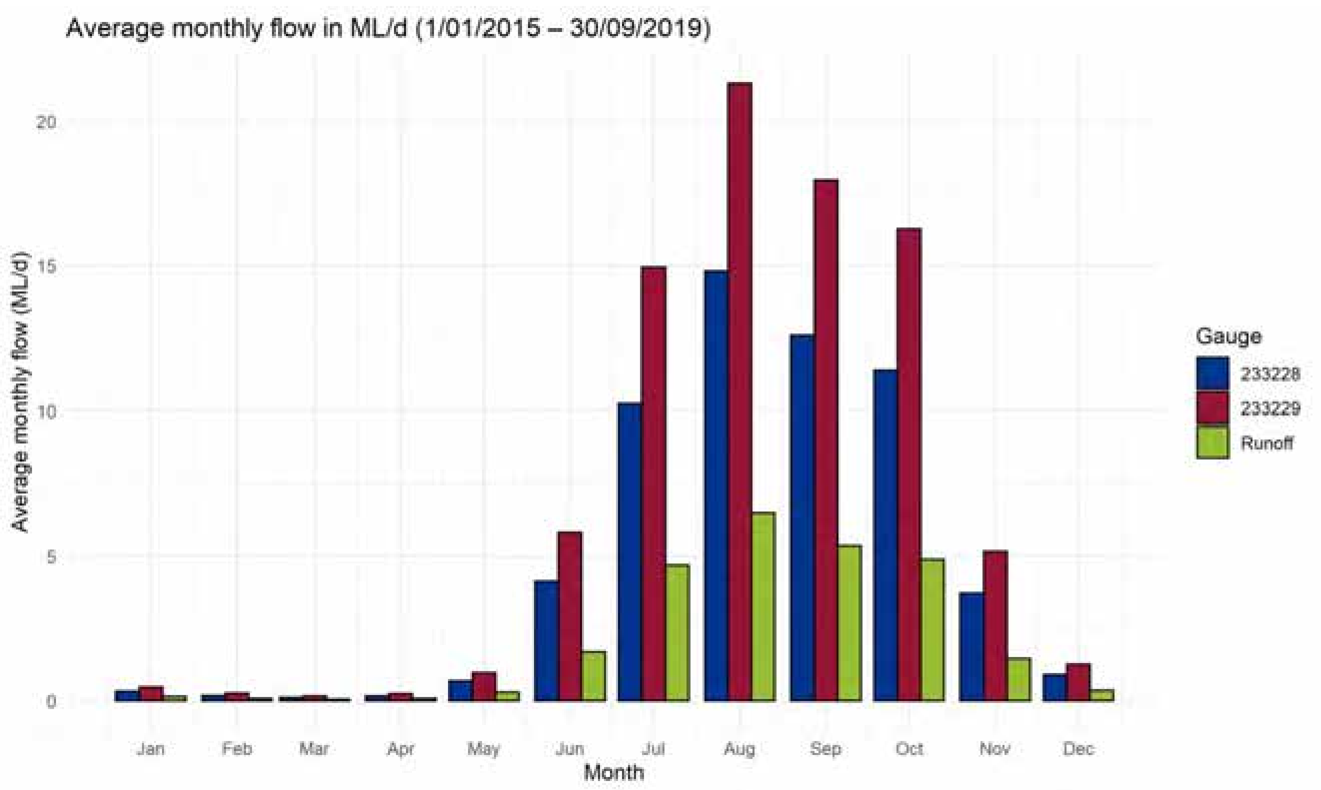

Figure 10-12: Average monthly flow (ML/d) over the full record of simulation (1/01/2015 – 30/09/2019)

Big Swamp acid sulfate soil study: Spatial extent of acid sulfate soils and potential for neutralisation of acidity upon re-flooding

Draft report

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Executive Summary

Big Swamp located in the Otway Ranges has become acidified through reduced water levels, releasing acidic water in the Barwon River. This study was initiated with two key objectives. The first was to determine the extent and nature of acid generating material within the swamp. The second objective addresses the question as to what extent acid neutralising reactions including iron and sulfate reduction are likely to occur upon re-inundation of the swamp. It was found that the swamp contains large amounts of acid generating sulfidic material heterogeneously deposited throughout the swamp. To date, only a small proportion of this material has been oxidised releasing 'actual acidity' in the surface 2 m of sediment. If the swamp undergoes further drying, there will be large and further long-term (many decades) releases of acidity upon re-wetting. It has been estimated that it will require up to ~100 000 tonnes of lime to neutralise this net acidity, but this will be technically difficult to apply given the heterogeneous nature of the sulfidic material.

It was found that the surface soils which have experienced oxidation and the generation of actual acidity had the potential to undertake iron reduction under anoxic conditions at rates sufficient to neutralise the local actual acidity in 1-2 years. This reaction, however, still produces mobile potential acidity in the form of dissolved iron (II), and any release of this from groundwater would regenerate acidity upon contact with oxygen. Longer term immobilisation of acidity also requires sulfate reduction to take place and present indications suggest this process would not occur for several years and even then, there is unlikely to be enough sulfate present in the soil to lead to the complete immobilisation of dissolved iron.

Based on these findings it is recommended that the swamp be maintained in a saturated state, and that groundwater which will have both high actual and potential acidity be prevented from leaving the swamp.

Background

Big Swamp is located to the North of the Otway ranges, just south of Colac. The swamp is fed by Boundary Creek, which has experienced reduced flows in recent years due to reduced rainfall and pumping of the Barwon Downs Borefield. This has led to a drying of the swamp and the, activation of acid sulfate soils, and the release of acidic water into the Barwon River

What causes acidity?

Reduced sulfidic material such as iron pyrite and iron monosulfides accumulate in anoxic water logged environments such as wetlands where no oxygen is present. The drying and reoxygenation of sulfidic soils and sediments leads to the release of acidity which can be summarised as the following reaction (Sullivan et al. 2018)

$$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 4H^+ + 2SO_4^{2-} \quad (1)$$

This reaction assumes the sulfidic material is present as pyrite (FeS_2) and it is complexly oxidised. The reaction produces 4 equivalents of acidity (H^+) per pyrite oxidised.

In reality, the oxidation of reduced sulfur compounds is often incomplete, resulting in the formation of minerals such as jarosite, which is also a store of acidity (referred to as retained acidity)

$$KFe_3(SO_4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3 + 2SO_4^{2-} + 3H^+ + K^+ \quad (2)$$

The net acidity of the soil can therefore be defined as:

Net acidity = Potential Sulfidic Acidity + Actual Acidity + Retained Acidity - Acid Neutralising Capacity

Potential Sulfidic Acidity is the potential for acid generation from reduced sulfur. This is represented by FeS_2 in equation 1.

Actual acidity is H^+ that has been released through oxidation of material. This is what leads to the low soil/water pH.

Retained acidity represents a store of acidity in minerals (equation 2) that can further release H^+

Acid neutralising capacity is not relevant in the context of this report because all the material being considered is less than pH 6.5 and is therefore zero and can be ignored.

Can acidification be neutralised?
Once produced, acidity can be neutralised by the addition of lime, and the amount required can be calculated based on the net acidity. Acidity can also be neutralised by the reverse reactions that led to the accumulation of reduced sulfidic materials initially. This process is driven by the oxidation of organic carbon by bacteria coupled to the reduction of iron oxide and sulfate. Effectively, these reactions are the reverse reactions that have driven the initial acidification:

Iron oxide reduction

$$4Fe(OH)_3 + CH_2O + 8H^+ \rightarrow CO_2 + 4Fe^{2+} + 11H_2O \qquad (3)$$

Sulfate reduction

$$2CH_2O + SO_4^{2-} + 4H^+ \rightarrow 2CO_2 + H_2S + 2H_2O \qquad (4)$$

In plain English, these reactions are saying that bacteria burn organic matter (CH_2O) by 'breathing in' iron oxide ($Fe(OH)_3$) and sulfate (SO_4^{2-}). In this process, they consume acidity (H^+) and produce carbon dioxide (CO_2), reduced iron and sulfur (Fe^{2+}, H_2S) and water (H_2O). These two reactions occur sequentially, with iron reduction taking place first and sulfate reduction then taking place once all the iron oxide is consumed. Once sulfate reduction commences, the H_2S produced will react with Fe^{2+} produced from iron reduction to form reduced inorganic sulfur compounds such as iron monosulfide, which then converts to pyrite over time. The overall reaction can be summarised as follows (Whitworth et al. 2014).

$$3SO_4^{2-} + 6C_{org} + 2Fe(OH)_3 \rightarrow 2FeS + S^0 + 6HCO_3^- \qquad (5)$$

The production of CO_2 (referred to here as dissolved inorganic carbon, DIC) is therefore a key measure of the rates of the above reactions and can give us some indicative timescales for the neutralisation reactions to take place. The key factors controlling the rate and extent of reactions (3-5) are the availability of degradable organic matter, sulfate (SO_4^{2-}) and iron oxide ($Fe(OH)_3$).

Objectives

1. Map the extent of acidity within Big swamp
2. Classify the soils into key groups for further study in objective 3
3. Determine the rates of acid neutralising reactions occurring within the different soil types and the timeframes and likelihood of this occurring

Study Site
Soil samples were collected at depth intervals of 0.5m (higher resolution in the surface meter where possible) from a grid of boreholes shown in Figure 1. Samples were kept on ice until return to the lab where they were frozen before later analysis and incubation.

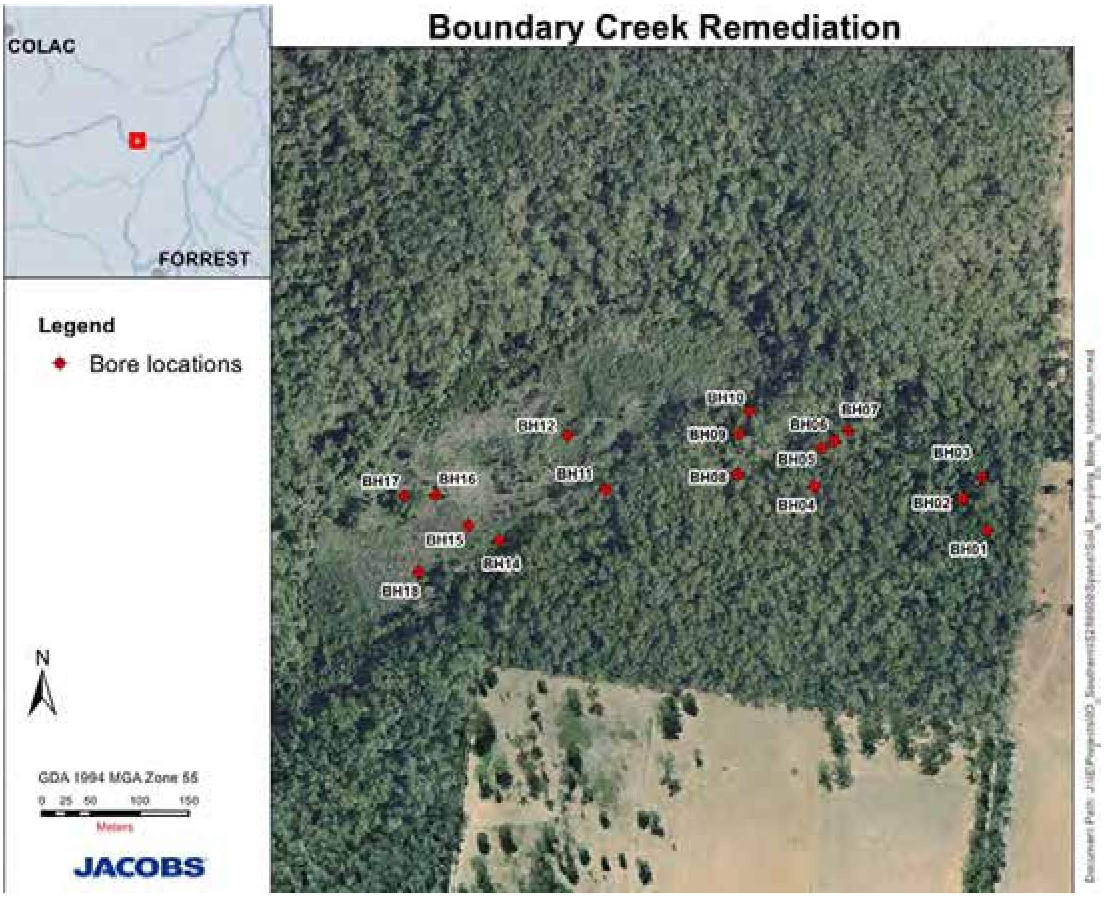

Figure 1. *The location of the sampling boreholes*

Analysis

Static testing (objective 1)

Samples were analysed for colour, texture, moisture content, density, particles size, loss on ignition, acid sulfate net acidity (sent to Southern Cross University), magnetic susceptibility and water extractable SO_4^{2-}. A selection of soil types representing, burned, unburned, wet and dry sediment were chosen for further analysis of NO_3^-, NH_4^+ and oxalate extractable Fe and Mn (Kostka and Luther III 1994). Samples were analysed using standard methods according to national acid sulfate soils identification and laboratory methods manual (Sullivan et al. 2018).

Kinetic testing (objective 3)

The soil incubations were carried out as follows

5 soil types were selected for incubation. For each soil type, the following treatments were run: Control (no additions), +alkalinity as lime (added at a rate calculated to neutralise measured net acidity), + 10 mM acetate, + 10mM acetate + lime, $+SO_4^{2-}$. Where possible, each treatment was run with three replicates of the same soil type run from 3 locations within the wetland (soil types 1 and 2). For soil types 3, 4 and 5 the availability of sample meant that incubations were conducted in duplicate on a blend of the material.

Table 1 summarises the treatments and their purpose.

Treatment	Purpose
Control	What rate of metabolism takes place in unamended sediments (a proxy for in-situ rates and pathways)?
+acetate	Does the addition of acetate (labile carbon) stimulate sulfate reduction?
+lime	Is microbial activity limited by low pH?
+acetate + lime	Is microbial activity co-limited by pH and organic matter?
$+SO_4^{2-}$	Is sulfate reduction limited by the availability of SO_4^{2-}?

The incubations were carried out in 160 mL serum vials with a 1:5 soil water (water taken from Boundary Creek) ratio (Figure 2). The vials were purged with Ar for a period of time shown to be sufficient to remove all oxygen (~1 minute) and sacrificed in a times series of 9 points over 6 months (1,2,4,8,16,32,64, 128 and 200 days). At each time point, a water sample was taken of overlying water (100 ml) for analysis of pH, alkalinity, acidity, dissolved organic carbon, SO_4^{2-}, H_2S, Fe^{2+}, Mn^{2+}, NO_3^- and NH_4^+. The headspace was sampled for CH_4 and CO_2.

Figure 2. *Images of the soil types 1-5 in serum vials undergoing kinetic incubation tests*

At the commencement and end of each incubation, the water was also be sampled for dissolved As, Cd, Cr, Cu, Pb, Ni and Zn. Similarly, sediments were analysed for for KCl extractable pH, acid neutralising capacity (depending on pH), acid volatile sulfur and chromium reducible sulfur (determined sequentially), oxalate extractable iron, and oxalate extractable manganese at the beginning and end of the experiment.

Rates were calculated using linear regression of metabolite concentrations over time and reported per mass of sediment.

Analyses were carried out using standard procedures in the Water Studies laboratory which is NATA accredited for NO_3^-, NH_4^+ and DOC. Acid sulfate soil parameters were outsourced to Southern Cross University which is NATA accredited. Metals were analysed using ICP OES. DIC was analysed using an Apollo SciTech AS-C6 DIC analyser. Gases in the headspace of the vials including CO_2 and CH_4 were analysed using an Agilent greenhouse gas analyser.

Results

All raw data from this study are available as an electronic appendix supplied with this report. For brevity and clarity, this report focuses on the data of key relevance to the management of the swamp.

Static tests

The soils sampled from Big Swamp were classified into the following 5 categories on the basis of their acidity, organic matter content and burned status.

SOIL 1 - Deep reduced, medium organic carbon (OC, most common) - medium pH (~4), high net acidity,~20% OC
SOIL 2 - Deep reduced, low OC - medium pH, %OC <5%, low net acidity
SOIL 3 - Burned surface - Red soil, %OC variable (<10%), low net acidity
SOIL 4 - Surface oxidised medium OC - Very low pH (~2), 20%OC
SOIL 5 - Surface oxidised high OC - Very low pH (~2), 40-50% OC

Soil type 1 is the most common, has a high potential to generate acidity, but has not yet done so as it has not been exposed to oxygen. Soil type 2, has a low organic matter content and is a clayey soil, with a much lower potential to generate acidity. Soil 3 represents the burned soil type, which has a relatively low potential acidity. Soil types 4 and 5 have undergone oxidation and have a very low pH (high actual acidity) but still have significant further potential to oxidise as indicated by their high potential acidity.

Table 2. *Summary of key geochemical characteristics of the different soil types*

Soil ID	% OC	St dev	pH	St dev	Potential acidity mol/tonne	St dev	Net actual acidity mol/tonne	St dev	Sulfate mol/tonne	St dev	Oxalate extractable Fe mol/tonne	St dev
Soil 1	22	6.0	4.1	0.2	3300	2700	220	100	19	27	140	160
Soil 2	2	1.5	4.1	0.3	61	100	100	70	25	12	70	70
Soil 3	4	2.5	4.3	0.5	34	36	160	80	10	4	3300	5000
Soil 4	22	5.1	2.8	0.1	1300	1800	830	360	290	230	2500	1700
Soil 5	44	7.4	2.8	0.4	3500	3800	490	230	31	27	160	15

The distributions of key soil parameters are shown in Figure 3. The distributions are quite heterogeneous, but conform to the generally expected distribution of acidity, with the highest actual acidity (that released through the oxidation of sulfides) occurring in the surface sediments (low pH areas, soil types 4 and 5). Deeper within the sediment, there is a large store of net acidity in the form of reduced sulfides (dominated by soil type 1).

The highest organic carbon content soils are present in surface soils at the top (western) end of the swamp. The lowest pH was observed in the surface soils in the middle of the swamp on the southern side, and also in the soils around 2 m depth at the top (western) end of the swamp. These pockets of low pH coincided with high concentrations of sulfate indicating they were caused by oxidation of reduced sulfides as would be expected. In addition to the actual acidity, there are pockets with a very high potential for further acidification at depths between 1~5 meters throughout the swamp as indicated by the high net acidity and liming rate required to neutralise this.

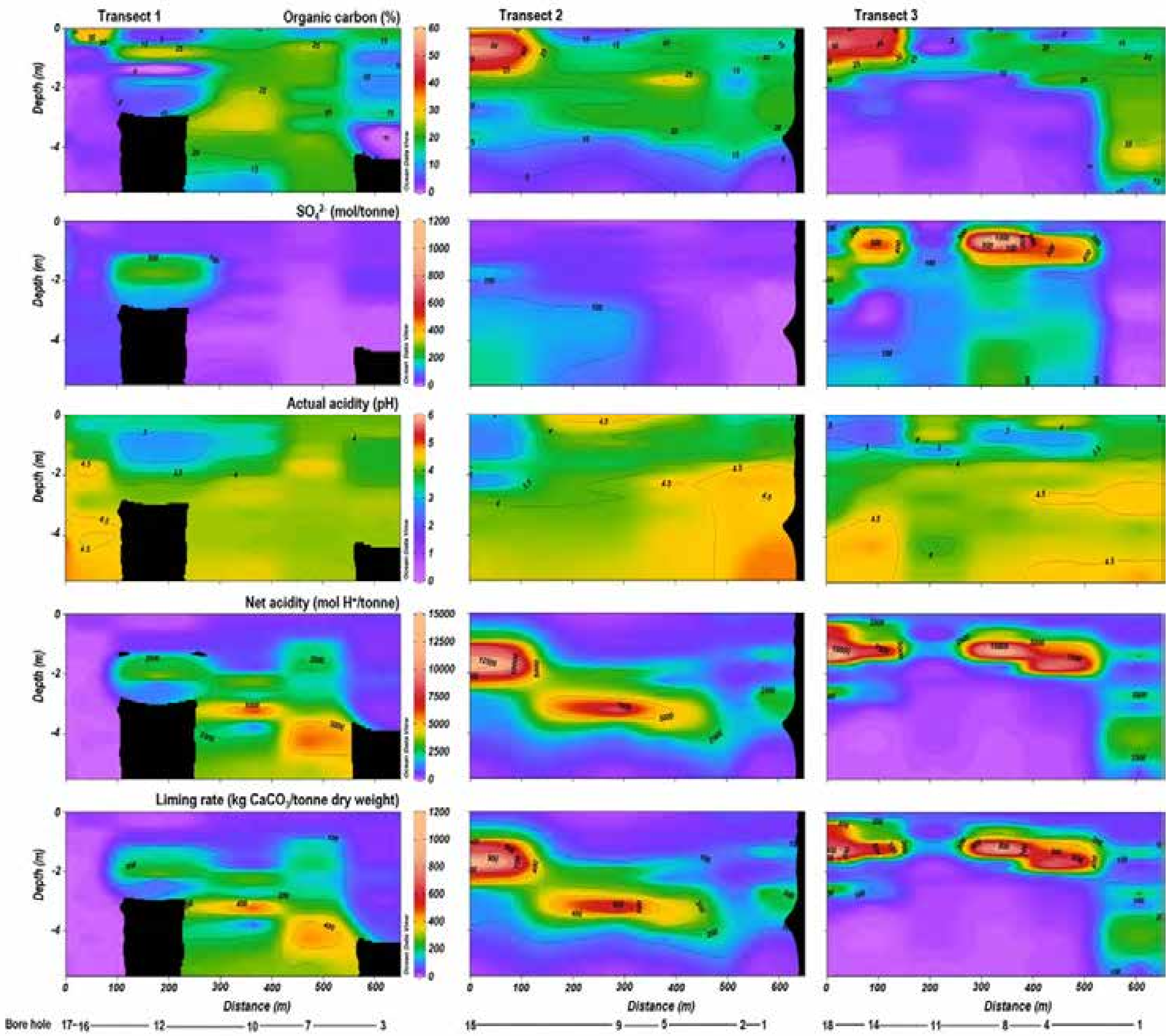

Figure 3. *The two-dimensional distribution of key soil parameters along 3 transects of key soil parameters. The borehole numbers are shown in Figure 1.*

Kinetic tests

Soil pH

Soils 1 and 2 did not show any clear trend in pH over time (Figure 4). This is consistent with their already reduced nature and one would not expect a further increase in pH under anoxic conditions. Soils 3-5 which are oxidised with varying degrees of actual acidity showed an increase in pH of 0.5-1 pH unit after 127 days. The addition of sulfate and acetate did not appreciably change the rates of pH change. The lack of stimulation by acetate is surprising as one would expect this to stimulate carbon neutralising reactions. The lack of any reactions was confirmed by the soil metabolism measurements (see below). The limed treatments showed a jump in pH to 8-10 for soils 1 and 2, and a pH of 6-7 for soils 3-5 (data not shown).

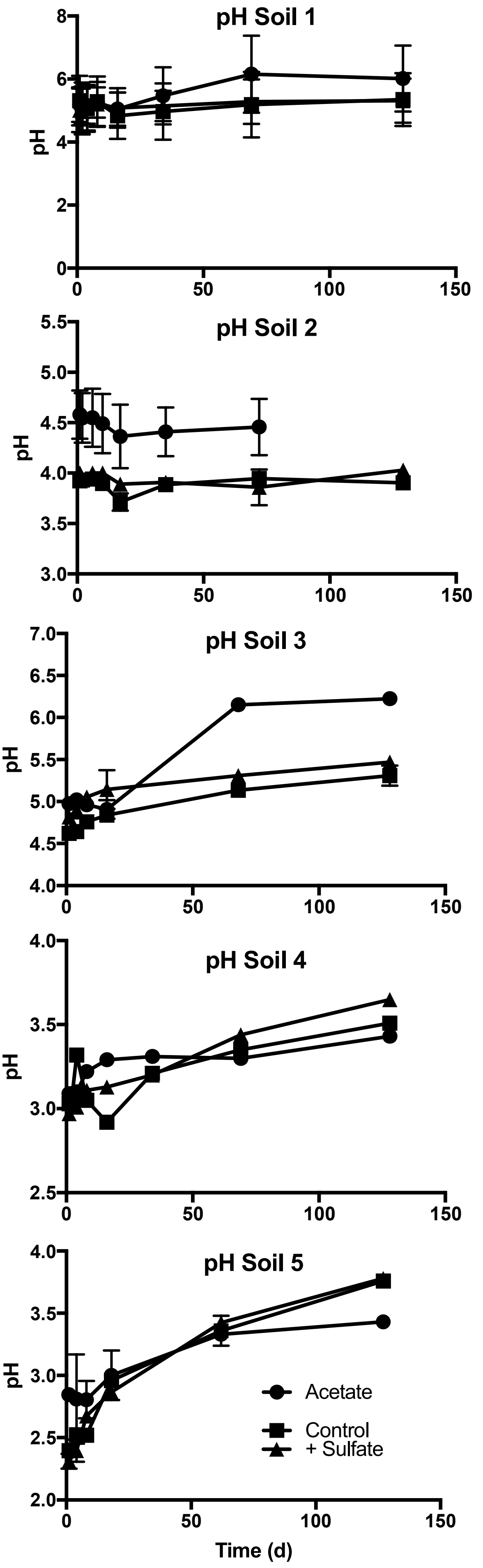

Figure 4. *Shows the pH time series for each of soil types 1-5 (top to bottom panels), for the acetate, control and sulfate treatments.*

Soil metabolism

Total metabolism (DIC production)

Soils 1 and 2 showed no clear trends in DIC production consistent with the lack of trends in the pH measurements (Figure 5). Soils 3-5 showed clear trends in DIC production which allowed us to calculate rates of metabolism. This was equivalent to 0.05, 0.2 and 0.2 mol DIC/tonne soil/day for soils 3, 4 and 5 respectively. Methane production was generally negligible except for in the acetate treatments (data not shown).

Iron and sulfate reduction

To date, no sulfide accumulation has been observed, indicating sulfate reduction is not taking place to any significant extent. For soils 1 and 2 there was generally no clear increase in dissolved Fe over time, suggesting little iron reduction was taking place, consistent with the soil metabolism measurements (Figure 6). For soils, 3-5, there was a clear increase in the dissolved iron concentrations for the control and sulfate additions, particularly at 16-32 days. These observations are also consistent with the metabolic measurements, where the fastest rates were observed in the control and +sulfate treatments. The sudden accumulation of Fe at 32 days is most likely as a consequence of metabolism taking place through other metabolic pathways, such as nitrate reduction in the early stages of the incubation, before switching to iron reduction once nitrate is exhausted.

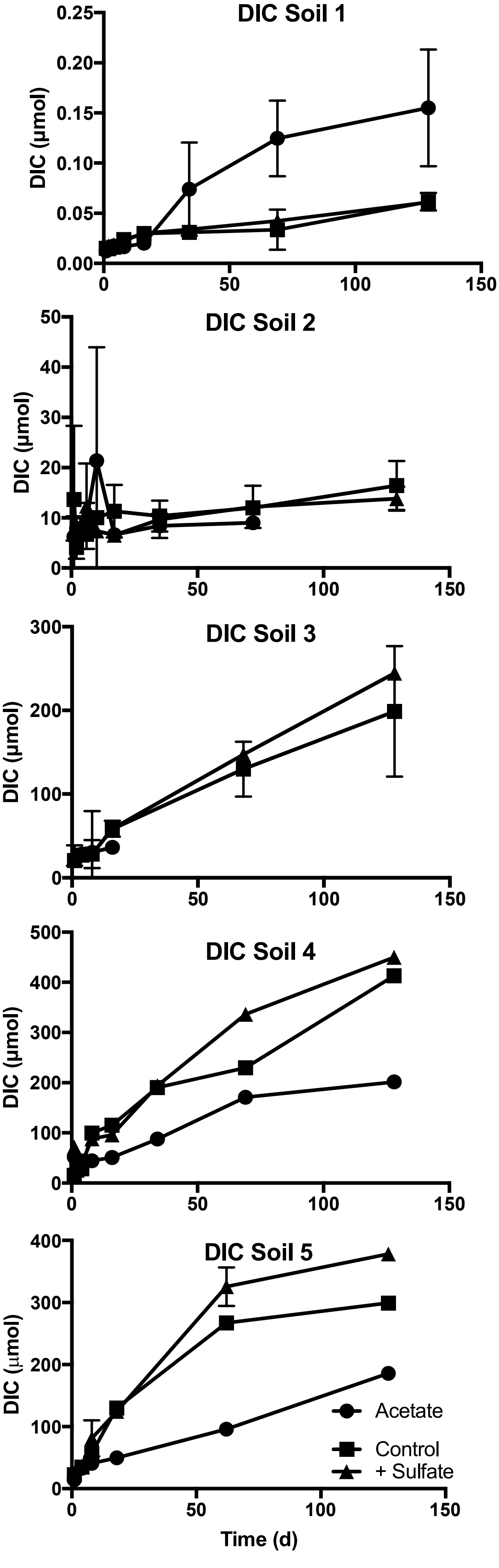

Figure 5. *Time series of dissolved inorganic carbon (DIC) production over time in each of the treatments. Note: limed is not shown as this has added a massive excess of DIC, making meaningful changes impossible to measure.*

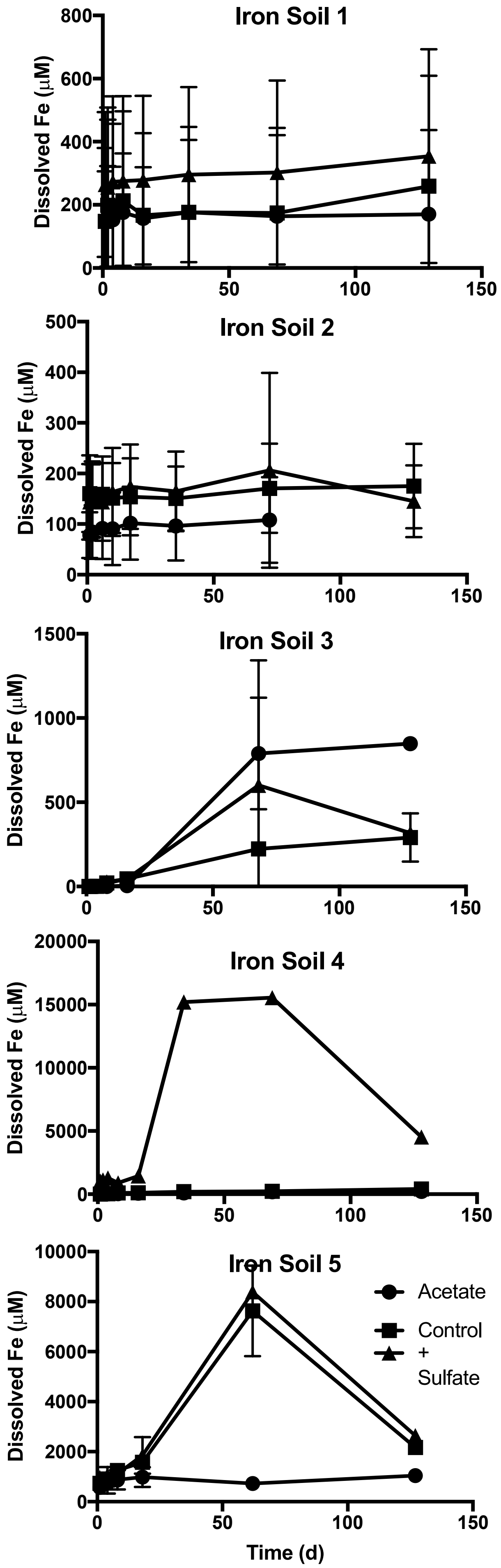

Figure 6. *Dissolved Fe accumulation in the control, acetate and sulfate treatments for the 5 soil types. Note limed data is not shown because there was little iron accumulation observed in these treatments, most likely as a consequence of the precipitation of* $FeCO_3$.

Discussion

High net and potential acidity within Big Swamp

As previously noted in a memo by Baldwin (attached as appendix), there is a substantial amount of acidity stored in Big Swamp. Based on the average net acidity of the Swamp, Baldwin estimated that 65 000 to 100 000 tonnes of lime would be required to neutralise this acidity. The highly heterogeneous nature of the acidity means that targeting the hot spot would probably be expensive and technically difficult. The most cost effective and environmentally acceptable solution to prevent the release of this net acidity is probably the maintenance of the saturated soil conditions.

Potential of anaerobic reactions to neutralise actual acidity

One of the key questions addressed in this study is the extent to which anaerobic reactions such as sulfate and iron reduction can neutralise the actual acidity present in the oxidised regions of Big Swamp represented by soil types 4 and 5. Both the kinetic and static test data from this study allow us to estimate the rate and extent of neutralisation of actual acidity. The rates of DIC production for sites 3, 4 and 5 were ~ 0.05, 0.2 and 0.2 mol DIC/tonne soil/day, respectively. Given the accumulation of dissolved iron, and the absence of sulfate reduction, it is most likely this metabolism is taking place via iron reduction as shown in equation 3 which neutralises 8 equivalents of H^+ for each mole of carbon oxidised. Therefore, the net actual acidities of 162, 833 and 493 mol/tonne (Table 1) for soils 3, 4 and 5 respectively could be neutralised within ~1-2 years assuming bioavailable iron and carbon do not become limiting. The high organic carbon content of soils 4 and 5 suggest it is quite likely that organic carbon will not become limiting, and the longer term incubation time points yet to be measured will further confirm this. We can make an estimate of the maximum size of bioavailable iron pool based on the oxalate iron extractions shown in Table 1. Based on these pools and the neutralisation stoichiometry of $4H^+$ per mole of iron reduced, then we get neutralisation capacities of ~13000, 10000 and 640 mol H^+/tonne for soil types 3, 4 and 5, respectively which is well in excess of their actual acidity. It should be noted that oxalate will extract bioavailable iron fractions such as ferrihydrite as well as more refractory forms such as magnetite (Kostka and Luther III 1994), and this neutralisation capacity should be considered an absolute maximum. It is suggested that further iron extractions be carried out using ascorbate, which is known to be a better proxy for bioavailable iron (Hyacinthe et al. 2006).

At this point it should be noted that although iron reduction will neutralise acidity through the production of dissolved Fe^{2+}, this species is mobile, and if it is released from the swamp via groundwater, acidity will be generated again at the point of release. As such, potential acidity will only be immobilised once sulfate reduction takes place leading to the precipitation of FeS (equation 5). Given the large pools of iron oxide, it seems likely that it will take several years for these to become exhausted before sulfate reduction commences. Once sulfate reduction does commence, its extent will be limited in the short term by the relatively small pool size of sulfate compared to iron which means that there will be an excess of dissolved Fe^{2+} (and mobile potential acidity). As such, any remediation option should be aimed at preventing groundwater leaving the swamp.

Updated text

Interestingly, the iron concentrations decreased substantially at day 128 in soils 3-5 in the control and + sulfate treatments. Sulfate concentrations did not decrease and the soil slurry still had a brown (as opposed to black) colour, suggesting sulfate reduction had not commenced consistent with the discussion in the previous paragraph. The decrease in iron concentrations was therefore unexpected. Another possible explanation is the formation of iron carbonates as suggested by Richard Bush. Given the pH in these slurries was less the 5, DIC would predominantly in the form of CO_2 (aq) as opposed to carbonate (CO_3^{2-}) and the formation of iron carbonate therefore seems very unlikely. At this stage the cause of the drop in dissolved iron concentration is unclear, however this requires further investigation as it has implications for the immobilisation of potential acidity within the swamp.

Recommendations

1. The swamp should be maintained in a saturated state to prevent further release of stored net acidity
2. The release of groundwater from the swamp should be minimise to prevent further release of actual and potential acidity

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Barwon Water

Basic Conceptual Geochemical Modelling for Big Swamp

December 2019

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Appendices

1. Introduction

1.1 Project objective

Groundwater extraction from the Barwon Downs Borefield, screened in the deep Lower Tertiary Aquifer (LTA) system, has impacted on groundwater baseflows to the Boundary Creek catchment and Big Swamp.

Barwon Water established the Boundary Creek remediation working group in May 2018 to design a remediation plan to address the key environmental issues at Big Swamp and Boundary Creek. Subsequently, a Section 78 notice was issued by the Minister for Water in September 2018 that required Barwon Water to develop and implement a remediation plan for Boundary Creek and Big Swamp. The Section 78 notice directed Barwon Water to:

- Discontinue groundwater extraction from the Barwon Downs Borefield while assessments were completed and remediation work under the remediation plan were completed.
- Prepare and implement a remediation and environment protection plan for Boundary Creek, Big Swamp and the surrounding area.

Barwon Water is in the process of developing options to remediate Boundary Creek and Big Swamp, and are undertaking numerous studies, workshops and stakeholder engagement to identify the most suitable remediation option. To inform the effectiveness of the remediation options assessment, development of a Basic Hydrogeochemical Model (BHM) was requested. The objective of the BHM was:

1. To develop a conceptual hydrogeochemical model for Big Swamp informed by the available hydrogeological data. This included the development of a 3D model of acidity distribution throughout the swamp.
2. Based on the conceptual hydrogeological model, develop suitable geochemical analytical models (i.e. MINTEQ) to inform the assessment of different remediation options, and their ability to achieve the remediation objectives.

1.2 Scope of works

GHD Pty Ltd (GHD) was engaged by Barwon Water to complete the basic conceptual geochemical modelling for Big Swamp remediation options and contribute to associated workshops. The scope of works is documented in GHD’s proposal dated 20 September 2019.

To meet the project objective and develop a BHM, the following key tasks were undertaken and are documented in this report:

- Compile existing hydrogeological information (i.e. soil and groundwater quality results, swamp geometry, etc.).
- Utilising the existing information, develop a Conceptual Geochemical Model (CGM) for Big Swamp, explaining the acid source and distribution, acidification process and acid fate and transport. The CGM was used as the basis for the development of the geochemical modelling, in association with a 3D model of the interpreted distribution of existing and potential acidity in the swamp.
- Attend technical workshops to discuss remediation options.

- Develop geochemical models, to incorporate the understanding of the primary acid source minerals, the primary acidification process, the speciation of the inorganics in solution and the secondary acidification processes results from the preliminary stages and include the potential effects of the management and mitigation measures under consideration to inform the assessment of effectiveness and risks of each option.

1.3 Project specific assumptions and limitations

This report is subject to the following assumptions and limitations.

1.3.1 Data assumptions and limitations

The following assumptions and limitations apply to the data utilised in the development of and conduct of the model simulation:

- The topographic, geological, geochemical, hydrological, hydrogeological, hydrogeochemical and environmental data utilised was provided by others and as such GHD does not warrant the quality of the data nor is liable for any errors, omissions and reliability of the data and any consequent errors, omission, results and outcomes of this project.
- The geological, geochemical, hydrological, hydrogeological, hydrogeochemical and environmental data is limited with respect to both spatial and temporal extent and is therefore unlikely to have captured the full range of variance and dynamics that affect these aspects. As such the project outcomes are limited with respect to capturing and simulating the full range of the variability that may occur in Big Swamp and Reach 3 of Boundary Creek.
- No data on the kinetic reaction rates for the acid formation through reduction and degradation through oxidation of the primary acid formation minerals present in Big Swamp was available. Therefore, assessment of the acid formation and attenuation realistically and at representative rates is not feasible. As such all rates and timeframes associated with this project are qualitative and subject to considerable uncertainty.
- No data on the significance of sorption processes and the kinetics for sorption of dissolved phase cations and anions was available. Therefore, assessment of the significance and rate of sorption is not possible, which limits the ability of the basic hydrogeochemical model to fully simulate all hydrogeochemical processes that may occur in Big Swamp and Reach 3 of Boundary Creek.

1.3.2 Conceptual geochemical model assumptions and limitations

The literature cited in this report formed the basis on which the opinions related to hydrogeological and hydrogeochemical properties and processes expressed in this report relied. Other literature may also be available, which could result in alteration of the opinions presented in this report.

The following assumptions and limitations apply to the Conceptual Geochemical Model (CGM) utilised in the development of and conduct of the numerical model simulation:

- That the data available is sufficient to identify and characterise, on a qualitative and semi-quantitative basis.
- That the CGM is representative of the primary geochemical processes active in Big Swamp and Reach 3 of Boundary Creek.
- That the CGM provides a sufficient basis to inform the geochemical modelling scenarios.

1.3.3 Geochemical modelling assumptions and limitations

Unless otherwise specified geochemical modelling works are subject to the limitations of the software and/or the mathematical formula adopted to conduct the modelling as well as the limitations provided herein. No assessment of variability, confidence and /or uncertainty is typically conducted as part of a geochemical modelling project. No comment on these matters is provided and the reader must make their own judgment on these issues unless it is part of the scope of work to be conducted.

Numerical modelling is based on the CGM developed from the data available at the time of the model development. Therefore, new or additional data could alter the CGM and therefore affect the validity of the numerical model.

The reader needs to be aware that more than one approach is generally possible for numerical modelling simulations, with all approaches potentially producing equally valid results.

The following assumptions and limitations apply to the Geochemical Modelling utilised in the development of and conduct of the model simulation:

- That the equilibrium assumption is sufficiently representative of the geochemical processes that occur in Big Swamp and Reach 3 of Boundary Creek.
- That the omission of sorption from the model due to a lack of representative and reliable data does not significantly adversely affect the representativeness of the model in simulating the actual geochemical processes that occur in Big Swamp and Reach 3 of Boundary Creek.
- That the thermodynamic data in the model database is representative of the thermodynamic energies of the geochemical reactions occurring in the swamp.

2. Remediation options workshop

A key objective of the BHM is to support the development of an effective remediation strategy to improve the environmental values of Big Swamp and Reach 3 of Boundary Creek using reasonable and practical remediation methods. The BHM was developed in parallel with the Remediation Options Assessment (ROA) and GHD's project team participated in a series of workshops that formed part of the remediation option evaluation.

During the project a series of workshops were held to evaluate potential management and remediation options that could be applied to Big Swamp and Reach 3 of Boundary Creek. Initially 18 options were considered, which following preliminary evaluation resulted in the adoption of 9 options for more detailed consideration. The remediation options considered are listed in Table 1, with the option not considered beyond the preliminary evaluation stage shown in the grey table fields.

Table 1 Summary of management or remediation options considered

ID	Technology	Description
O1	True 'do nothing'	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs. 2008). During the first technical workshop, it was agreed that a true 'do nothing' approach should reflect historical conditions and management practices at the site, which include the following: • Supplementary flow not passed entirely through McDonalds Dam • Continued presence of existing drainage channels across Big Swamp • Water users along Reach 3 of Boundary Creek unable to access water allocation during periods of 'no flow' Unlikely recovery of groundwater levels in the LTA aquifer to pre-pumping conditions in the short term (i.e. 5 years)
O2	Implementation of contingency measures	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs. 2008). During the first technical workshop, it was recognised that a range of contingency measures have been identified to ameliorate some of the issues associated with historical conditions at the site. These contingency measures include: • Minimum supplementary flow of 2 ML/d passed entirely at McDonalds Dam (already implemented) • Infilling of existing drainage channels across Big Swamp (potentially applicable) • Construction of a water pipeline to provide water to users along Reach 3 of Boundary Creek (to be implemented) No interim pumping from the LTA until a new licence from SRW is obtained
O3	Direct treatment of soils with neutralising agents (watershed liming)	This option was included in the Yeodene Swamp Study (Jacobs, 2008) and envisages spreading of agricultural lime (or other suitable neutralising agent) over all or a part of Big Swamp to neutralise acidity of the upper soil profile as wells as increasing pH and alkalinity of the water leaving Big Swamp and discharging into Boundary Creek. Once the areas requiring treatment and the treatment rate (expressed as mass of neutralising agent per unit area) have been evaluated, a variety of implementation methods are possible, including terrestrial applications and aerial methods.

ID	Technology	Description
O4	Oxic (aerobic) limestone drain (OLD)	This option was included in the Yeodene Swamp Study (Jacobs, 2008) and envisages construction of an open drain channel filled with limestone (or other suitable material) downstream of Big Swamp to improve quality of Boundary Creek water (i.e. increase pH/alkalinity and decrease dissolved metals concentration). Key design parameters of OLDs are mass and size of the limestone aggregate, slope of the drain and water residence time (in the range of several hours). The slope of the drain is inversely proportional to residence time, however higher slopes increase OLDs' efficiencies by limiting the potential for metal precipitation on the surface of the aggregate (armouring). Armouring reduces limestone pore space and surface area, decreasing the limestone dissolution rate and acid neutralising capacity.
O5	Dilution of acidic discharge	This option was included in the Yeodene Swamp Study (Jacobs, 2008) and envisages provision of additional water volumes (i.e. in addition to the supplementary flow of 2 ML/d released upstream of McDonalds Dam as part of the contingency measures) to improve water quality in Boundary Creek. Implementation of this option will require construction of a dedicated water infrastructure and identification of a sustainable source to supply water in the long term (this option does not address generation of acidity in Big Swamp, which will continue). The Yeodene Swamp Study (Jacobs, 2008) seems to indicate that the additional water volumes will be delivered through McDonalds Dam. However, to increase effectiveness and minimise potential side effects to natural environments downstream of the release point, the additional water volumes could also be delivered downstream of Big Swamp (i.e. in the upper reaches of Reach 3 of Boundary Creek). While not mentioned in the Yeodene Swamp Study (Jacobs, 2008), the additional water may also be amended with neutralising agent to increase pH/alkalinity and therefore volumetric requirements.
O6	Water flow diversion and Big Swamp isolation	This option was included in the Yeodene Swamp Study (Jacobs, 2008) and envisages isolation of Big Swamp (source of acidity) and diversion of Boundary Creek flow so that the swamp is by-passed and transport of acid drainage to Reach 3 of Boundary Creek is minimised. Implementation of this option would require building a channel so that water flowing into Boundary Creek does not disperse into Big Swamp, as well as construction of a series of impermeable structures to prevent groundwater within the alluvial swamp sediment to discharge into Reach 3 of Boundary Creek. Additional water retention structures may be also required to minimise risks of acid flushes from Big Swamp into Reach 3 of Boundary Creek.

ID	Technology	Description
O7	Flooding of Big Swamp (natural anaerobic wetland)	This option was included in the Yeodene Swamp Study (Jacobs, 2008) and envisages flooding of Big Swamp to create permanently waterlogged areas where microbially mediated iron reducing and sulfate reducing reactions have the potential to increase alkalinity, raise pH and remove dissolved metals by precipitation. For sulfate reduction reactions to occur, the following conditions must be realised in the re-flooded portions of Big Swamp: • A permanent water coverage having enough depth to maintain generally anaerobic conditions within the water column • Presence of a bioavailable organic carbon source (electron donor) • pH between 5 and 8 • Presence of sulfate and low concentration of competing electron acceptors such as nitrate (NO_3^-), manganese (Mn^{4+}) and ferric iron (Fe^{3+}). Implementation of this option envisages the following steps: • construction of water retention structures (likely to be located at the downstream side of Big Swamp) to realise a permanent water coverage across a significant portion of Big Swamp • infilling of existing drainage channels across Big Swamp to assist with water retention • supply of additional water volumes to achieve the required permanent water coverage • supply of additional organic carbon source (and potentially sulfate) in case of deficiencies of these elements in the natural environment. In addition to promoting favourable geochemical conditions, this option has the additional benefit of maintaining the sulfidic sediments in Big Swamp below water, preventing further oxidation associated release of acidification products in the environment.
O8	Managed groundwater levels within Big Swamp	This is a slightly modified version of the original ‘Inundating Yeodene Swamp’ option presented in the Yeodene Swamp Study (Jacobs, 2008) developed during the RWG workshop, which accounts for the potential risks associated with re-flooding of the acidified swamp. This option, named ‘managed groundwater levels’ envisages the following steps: • construction of water retention structures (likely to be located at the downstream side of Big Swamp) to maintain minimum groundwater levels in the Big Swamp alluvium aquifer above the layer of the unoxidised sediments (PASS). • infilling of existing drainage channels across Big Swamp. • supply of additional water volumes to achieve the required minimum groundwater levels. The benefit of this option is to prevent further oxidation of potential ASS within the swamp and associated increase of acidification products released in the environment.
O9	Soil excavation/treatment and rehabilitation	This option involves excavation and removal of the oxidised ASS sediments within Big Swamp which are treated (or disposed) according to EPA Victoria ASS management guidelines. Construction of access tracks and significant removal of vegetation will be required to implement this option. The excavation is likely to be progressed as separate cells to minimise potential exposure of non-oxidised sediments to oxygen. Following removal of the oxidised sediments, lime would be added at the base of the excavations to neutralise potential future acidity generation and then the excavation would be backfilled with suitable imported fill material. After remediation and backfilling, the site would be landscaped and revegetated to resemble the original character of Big Swamp.

ID	Technology	Description
O10	Deep soil mixing	This option involves the use of a large diameter (one to three metres) hollow-flight auger fitted with special mixing 'paddles' to achieve mixing of a neutralising agent with the oxidised sediments in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require to be rehabilitated through landscaping and planting of vegetation.
O11	Alkaline slurry injection	This option involves injection of a slurry composed of alkaline and impermeable materials to minimise oxygen infiltration and neutralise acidity. Depth of application would be typically to the top of the unoxidised ASS in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require to be rehabilitated through landscaping and planting of vegetation.
O12	In-stream limestone sand	This option involves placement of limestone sand (or other suitable neutralising agent) directly in the streambed of Boundary Creek. The sand is carried into the stream during high flow periods where it dissolves releasing alkalinity and increasing pH.
O13	In-stream active treatment system	This option involves installation of an active treatment system to treat water quality in Reach 3 of Boundary Creek. The system would be installed at the downstream end of Big Swamp and will comprise a range of equipment (i.e. tanks, mixers, pumps) to dose dry or liquid chemicals in the Boundary Creek water to increase alkalinity/pH and remove metals (by precipitation and settling). Depending on system configuration and design parameters, precipitation of metals could be achieved in a settling pond or above ground clarifiers.
O14	Limestone diversion wells	This option envisages that a portion of the flow in Boundary Creek downstream of Big Swamp is diverted into a series of limestone-filled wells to increase alkalinity/pH and precipitate metals. Following treatment, the flow is diverted back into Boundary Creek.
O15	Anoxic limestone drains (ALD) and settling pond	This option envisages construction of a buried drain lined with impermeable material, filled with limestone (or other suitable neutralising agent) and covered by impermeable materials. The water seeping downstream of Big Swamp is diverted into the limestone (to maintain saturated conditions and anoxic conditions) where dissolution of the limestone increases alkalinity and pH. Low oxygen conditions in the ALD would prevent precipitation of metals and armouring issues. The water leaving the ALD is then directed into an aerobic settling stage where metals are precipitated and removed from the water. Removal of metal precipitates (sludges) is required at periodic intervals.
O16	Constructed aerobic wetland	Construction of an aerobic wetland to remove metals by oxidation and hydrolysis.
O17	Constructed vertical flow anaerobic wetland (organic layer, limestone layer and drainage system)	Construction of an anaerobic wetland to increase alkalinity, raise pH and remove metals by precipitation of insoluble hydroxides, carbonates and sulfides. The anaerobic wetland comprises an organic rich substrate at the top, a layer of limestone at the bottom and a drainage system. The wetland is constructed within a watertight basin and water flowing from the top across the organic layer and the limestone layer is collected by the drainage system and released into an aerobic settling pond. Alkalinity is generated by microbial process in the organic layer (if sulfate is available) and through dissolution of the limestone. An aeration and settling stage may be required prior to discharge to increase oxygen and promote precipitation of residual dissolved metals.

ID	Technology	Description
O18	Permeable reactive barrier	Construction of permeable reactive barriers in Big Swamp (perpendicular to groundwater flow direction) to intercept and treat acidic groundwater.

3. Hydrogeological characterisation

It is noted that the hydrogeological characterisation of the Barwon Downs bore field and the Boundary Creek catchment has been described in detail by Jacobs, 2018, and other reports used to support the groundwater licence application, and therefore a summary has been provided in this document.

3.1 Regional hydrogeological setting and the Barwon Downs Borefield

In most years, Barwon Water's water supply is sourced exclusively from surface water resources. However during the Millennium Drought and historically since the 1980's, groundwater was sourced from the Barwon Downs Borefield to supplement the Geelong region water supply. Barwon Downs was relied upon to provide more than 70% of Geelong's daily water requirements during the peak of the Millennium drought period.

The Barwon Downs Borefield is located approximately 70 km south-west of Geelong in the foothills of the Otway Ranges. The borefield extracts from the Lower Tertiary Aquifer (LTA) through six production bores at depths of 600 m. At the borefield location the LTA is a confined aquifer system, overlain by the low permeability marls. However, the LTA outcrops at the surface predominately in an area known as Barongarook High, where the aquifer has its main recharge zone and interacts with the surface water hydrological system (refer Figure 1 and Figure 2)

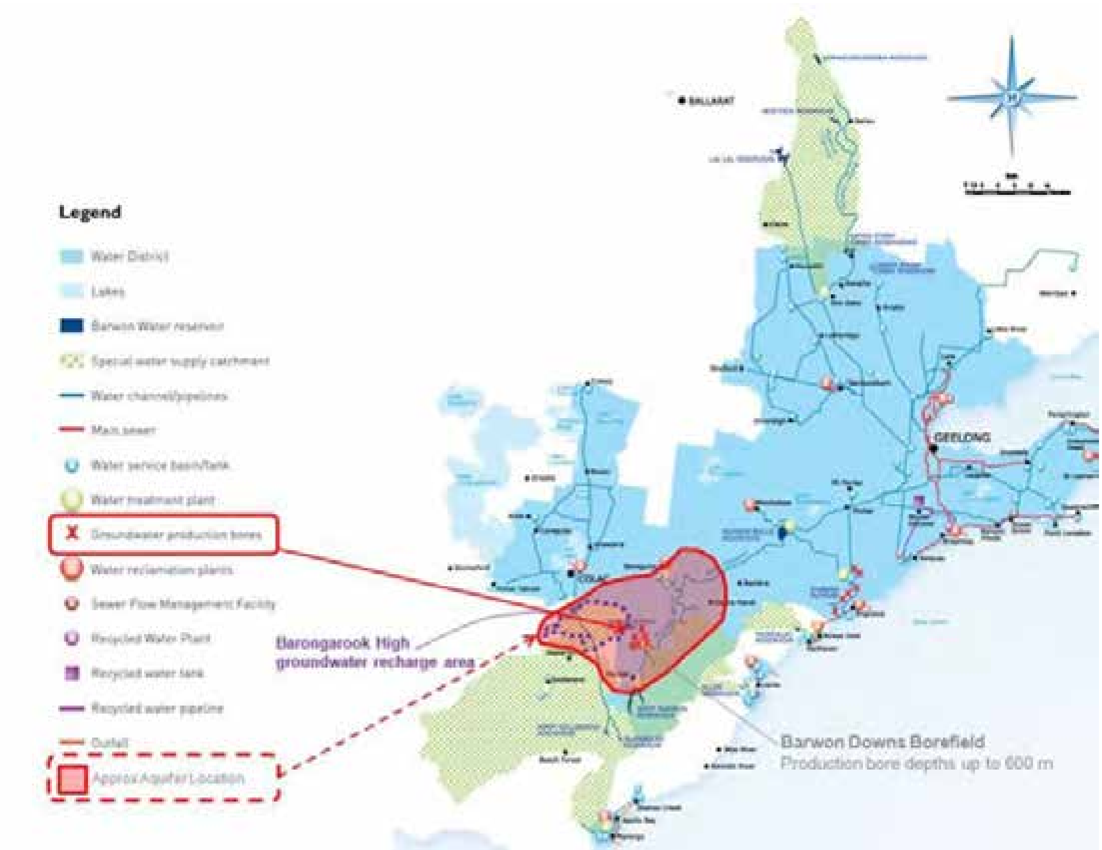


Figure 1 Borefield location, aquifer extent and recharge area (Jacobs, 2018)

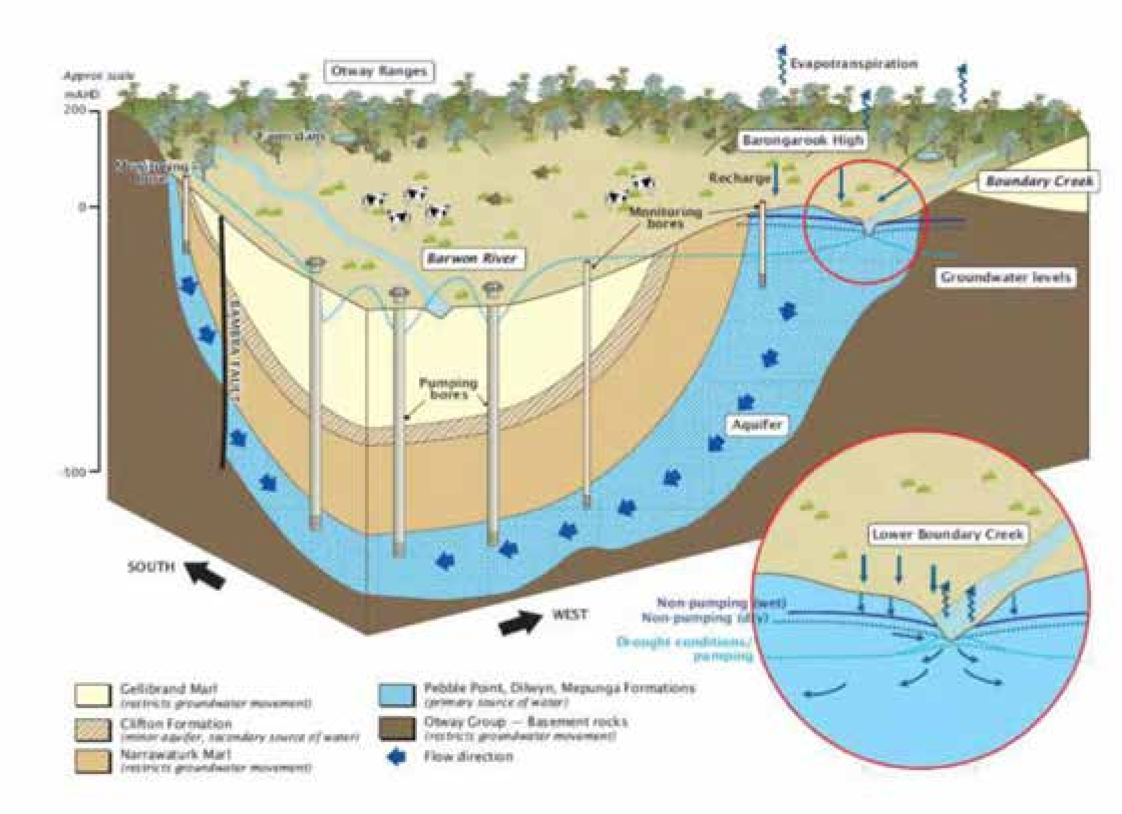


Figure 2 Schematic of LTA Aquifer, borefield and outcrop area (Jacobs, 2018)

3.2 Impacts of groundwater extraction

Extraction from the deep confined borefield causes the development of a drawdown in the aquifer system, and this drawdown can extend to the outcrop area at the Barongarook High. It is in this recharge zone area, where the LTA is outcropping or subcropping, that the induced groundwater drawdown has the potential to impacts on the groundwater level in the shallow watertable aquifer system, and subsequently the potential to reduce groundwater baseflows, impact on surface water flows/levels or groundwater dependent ecosystems , such as swamplands.

Extensive studies have been completed by Barwon Water to investigate the hydrogeological setting of the Boundary Creek Catchment which flows east across the Barongarook High aquifer recharge area, and joins the Barwon River a couple of kilometres downstream around Yeodene. These extensive investigations have indicated that Boundary Creek flows through 3 distinct hydrogeological settings, classified as Reach 1, 2 and 3 (Jacobs 2017) and are shown in Figure 3 below:

- Reach 1: This is the upper reach of Boundary Creek which predominately flows over outcropping bedrock which is characterised by Palaeozoic sandstone, siltstone and mudstone.
- Reach 2: The central reach of the creek flows over the outcropping regional aquifer (the LTA), which is characterised by permeable sands of the Mepunga, Dillwyn and Pebble point formations. The Yeodene (Big) Swamp is located at the downstream end of Reach 2 on boundary between the regional aquifer and the aquitard. McDonalds Dam, a privately owned dam and is subject to licensing conditions which includes passing flows, is located at the upstream end of Reach 2.

- Reach 3: The lower reach of Boundary Creek flows over an aquitard (the Mid-Tertiary Aquitard or MTD) and is characterised by silty clays of the Gellibrand Marl.

It is noted that shallow Quaternary alluvium occurs locally along the flow path and overlies most of these regional formations. This includes swamp deposits and acid sulfate soils that occur throughout the Yeodene Swamp (Jacobs, 2018).

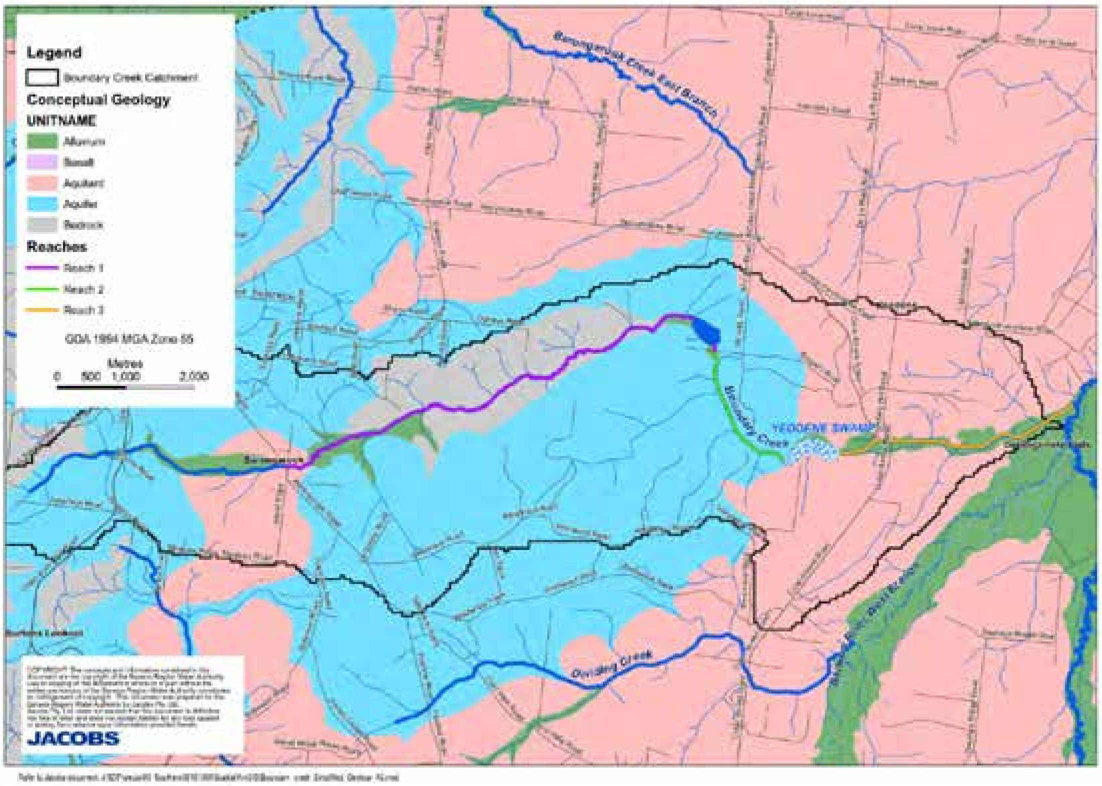


Figure 3 Simplified geology of the Boundary Creek Catchment (Jacobs, 2018)

The current conceptual understanding of groundwater- surface water interaction along these Reaches is shown in Figure 4 (Jacobs, 2018). With groundwater seepage occurring from the surface water system to the perched water table aquifer in the shallow alluvials, and subsequently there is a downward hydraulic gradient for groundwater flows from the perched water table aquifer towards the regional LTA system. This downward hydraulic gradient has developed due to the drawdown in the LTA associated with Barwon Water extraction. The groundwater levels are shown in Figure 5 (Jacobs, 2018) , which indicate that prior to 1997 there was a general upward hydraulic gradient from the regional aquifer to Boundary Creek, and the surface water system would have been gaining groundwater baseflow. However, due to the borefield extraction, the hydraulic gradient has been reversed, and Boundary Creek in Reach 2 has generally become a losing feature, the water losses being dependent on numerous factors, such as the stream bed hydraulic conductivity, the hydraulic gradient and the time of the year (i.e. depending on surface water levels, re-wetting of the aquifer etc.).

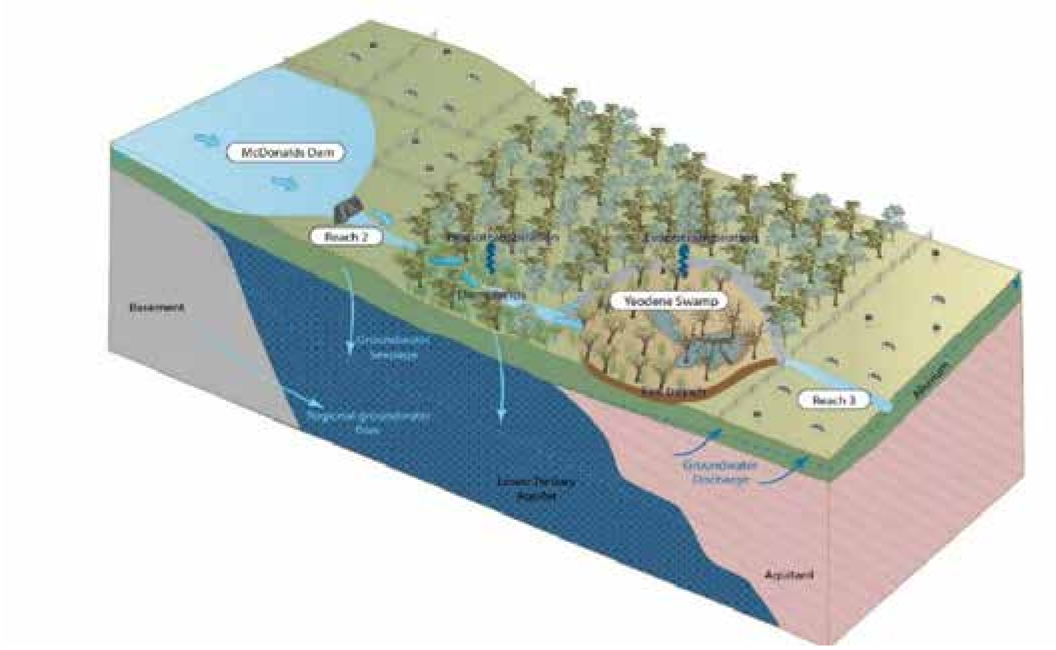


Figure 4 Conceptual groundwater-surface water interaction along the Boundary Creek (Jacobs, 2018)

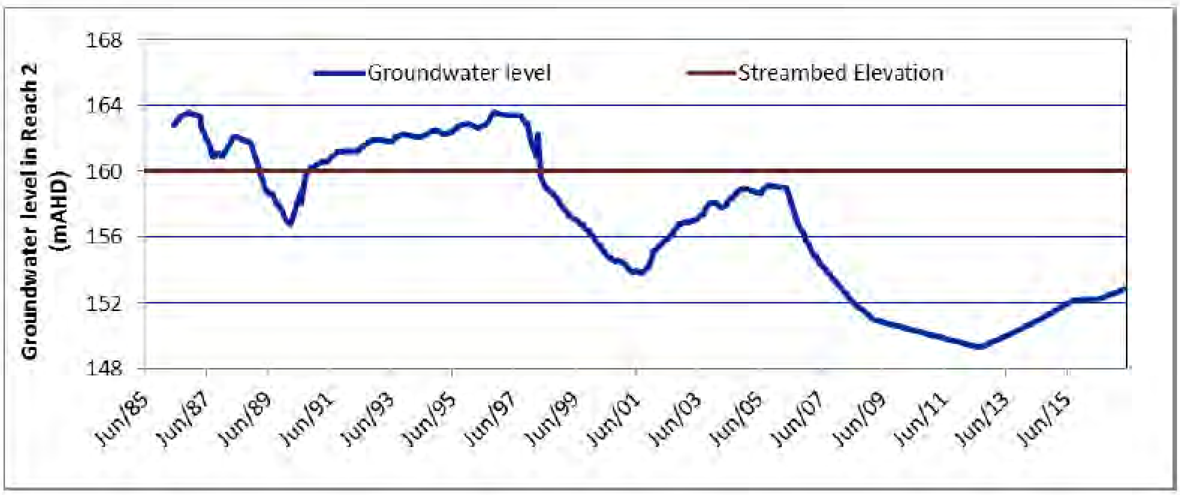


Figure 5 Historical monitoring of regional aquifer in Reach 2 (Jacobs, 2018)

Jacobs, 2018 estimated that streamflow declined approximately 3 ML/day through the Damplands and Yeodene Swamp, as a result of evapotranspiration and recharge to the shallow groundwater (i.e. baseflow losses). Barwon Water currently provided 2 ML/day additional flow to Boundary Creek to assist in making up for these baseflow losses.

The impact of the loss of baseflow to Boundary Creek in Reach 2, associated with the borefield extraction and dry climatic conditions, are:

- Reduced stream flow in Boundary Creek.

As shown in Figure 6 (Yeodene gauge), surface water flows were generally higher prior to 1999, with the creek rarely ceasing to flow, however post 1999 surface water flows are significantly lower and more cease to flow days occurred (also refer Figure 7 and Graph 23).

- Reduced Stream flows into Big (Yeodene) Swamp.

This swampland is supported by a perched water table aquifer in alluvial sediments, which are expected to overlie both the LTA aquifer at the upper end and the MTD aquifer at the lower end.

The reduction in surface water flows into the swamp have resulted in:

- Lower groundwater levels in the alluvial watertable aquifer, and more storage in the aquifer system in drier months.
- Lower groundwater levels have exposed potential acid sulfate soils, causing oxidisation of the naturally occurring acid sulphate soils in the swamp and the release of acidic water (i.e. pH <4) and high concentrations of metals downstream, when flows do occur during wet period (refer Figure 7).
- The additional storage capacity in the alluvial aquifer system means that when surface flows upstream occur, it takes longer/higher volumes of water to saturate the alluvial aquifer system before surface water flows out of the swamp. This further contributes to the increase in no flow days at the Yeodene Swamp gauge (Figure 7).

The lower groundwater levels and drier conditions in Big Swamp impact on the terrestrial ecology of the swampland (i.e. flora and fauna), and will result a higher risk of peat fires (which have occurred in the past).

The reduced surface water flows and quality downstream of Big Swamp have subsequent impacts on the following key receptors:

- Downstream stock water users.
- Aquatic ecology, fish kills have occurred downstream and in the Barwon River associated with low pH surface water flush events.

The potential impacts associated with the groundwater extraction from the Barwon Downs borefield on the Boundary Creek catchment, are conceptualised in Figure 8 (Barwon Water, 2019).

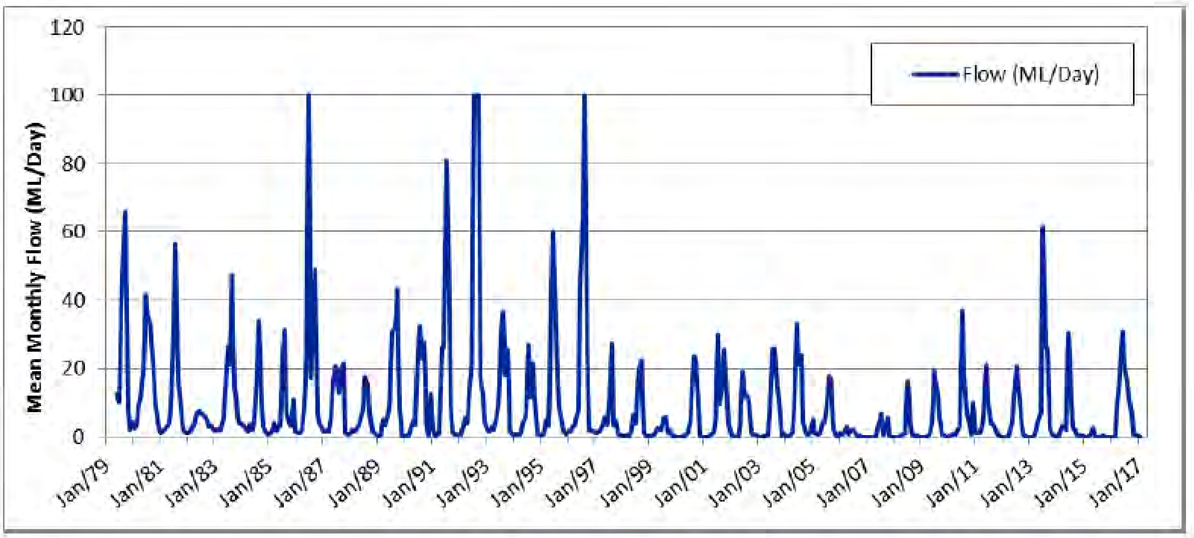


Figure 6 Average monthly flow in Boundary Creek at Yeodene (Jacobs, 2018)

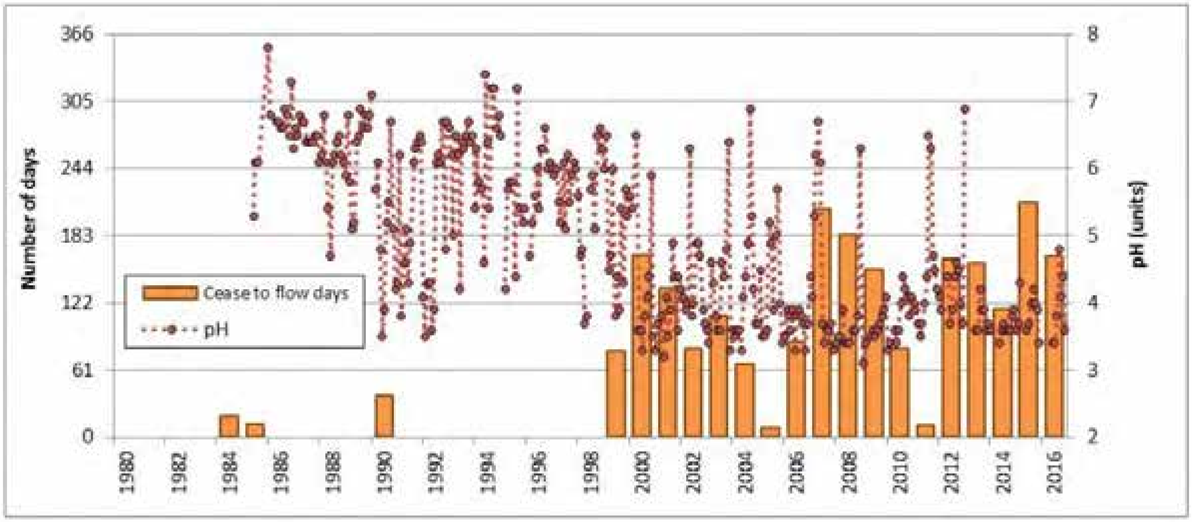


Figure 7 Number of cease to flow days in Boundary Creek at Yeodene Vs monthly pH at Yeodene.

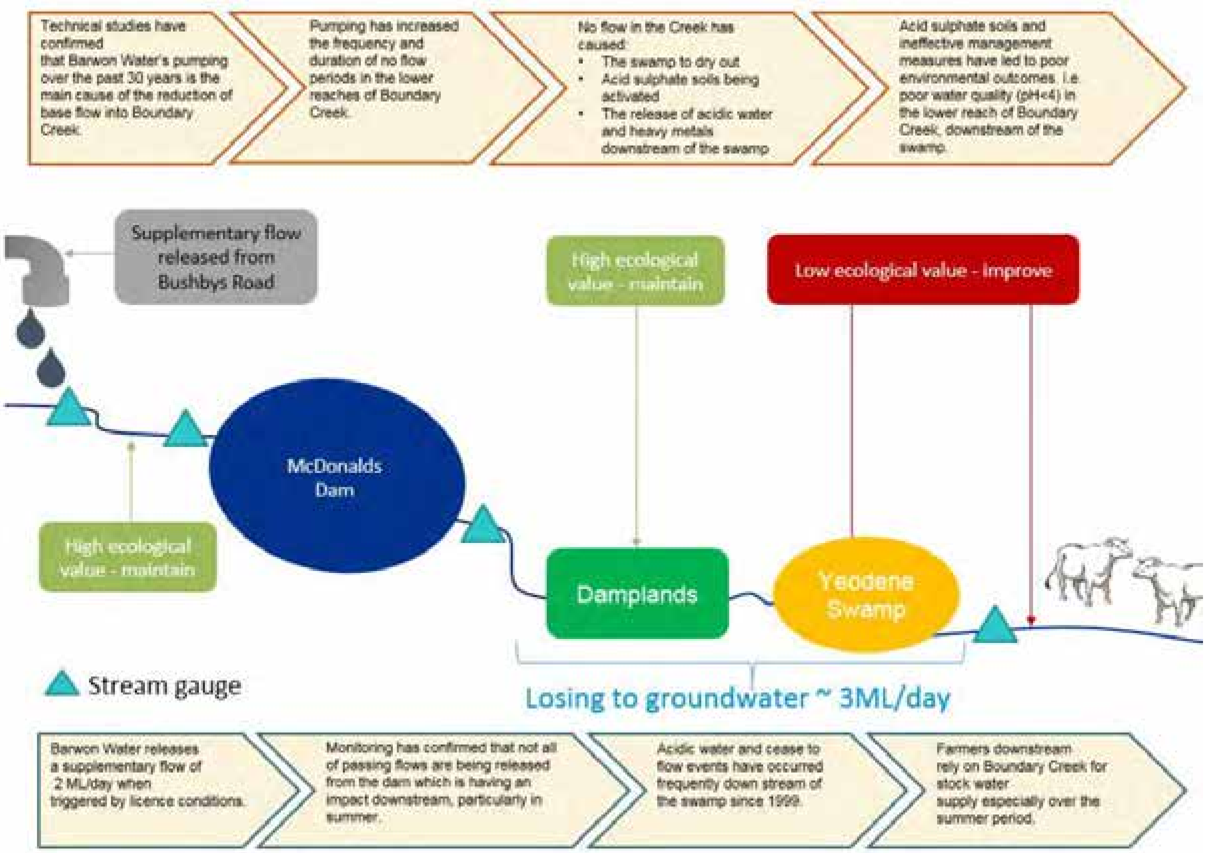


Figure 8 Boundary Creek Catchment conceptualisation

4. Conceptual geochemical model

This section sets out the Conceptual Geochemical Model (CGM) developed for the acid source, acidification process, acid flux and acid fate and transport for Big Swamp and Reach 3 of Boundary Creek as they are relevant to the project objectives.

This section includes a discussion to the general processes as they apply to Inland Acid Sulphate Soils and then assessment of the available data to evaluate the relevance and significance of these processes with respect to Big Swamp and Reach 3 of Boundary Creek.

Following data evaluation a CGM was developed. The CGM was used as the basis for the development of the geochemical modelling and its primary purpose was to support the remediation solution design and inform the BHM.

4.1 Primary acid source assessment for Big Swamp

The primary acid source in Big Swamp is associated with the organic carbon rich sediments that have accumulated in the saturated part of the swamp, where over time primary acid forming minerals generally comprising sulfide minerals have accumulated over recent geological time.

Based on the limited geological and acid formation testing data available, a three dimensional model was developed that mapped the mass of net acid present in Big Swamp. This model is associated with an appreciable amount of uncertainty as a result of the limited lateral and vertical extent of the geological investigation locations completed to date and the consequently limited amount of net acid data available. As such, the results of the three dimensional model should be utilised with an appropriate amount of caution and should be regarded as semi-quantitative. The bore locations from which the geochemical data was used for the 3D model is shown in Figure 9.

4.1.1 Three dimensional geological model

The existing topographical and acidification data was used to develop the three dimensional model of the distribution of retained, actual and potential acidity under current hydrological and hydrogeological conditions and those predicted under future flow conditions and water table elevations. For the purpose of this assessment the three dimensional model considered two flow scenarios:

1. Maintenance of an additional 2 ML of flow, with the following conditions considered:
   i) No barrier to restrict flow at the down-stream end of the swamp.
   ii) Installation of a barrier to restrict flow at the down-stream end of the swamp.
2. Maintenance of an additional 20 ML of flow, with the following conditions considered:
   i) No barrier to restrict flow at the down-stream end of the swamp.
   ii) Installation of a barrier to restrict flow at the down-stream end of the swamp.

The three dimensional model was used to provide volumes of swamp sediments that would remain unsaturated and therefore able to generate acid into the future (refer Section 5.5).

Figure 10 and Figure 11 shows the 3D model with the net acidity interpreted between each bore location. The spatial relationship of the net acidity between bore locations was checked using a variogram prior to constructing the 3D contour.

Figure 12 and Figure 13 shows the actual groundwater level in dark blue (July 2019), 20 ML/day modelled groundwater levels (without the head barrier) in red and the 2 ML/day modelled groundwater levels (without the head barrier) in light grey.

Based on the results of the three dimensional model analysis, there appear to be around 600,000 to 700,000 cubic metres of sediments that contain potential primary acid producing minerals based on the available net acidity data.

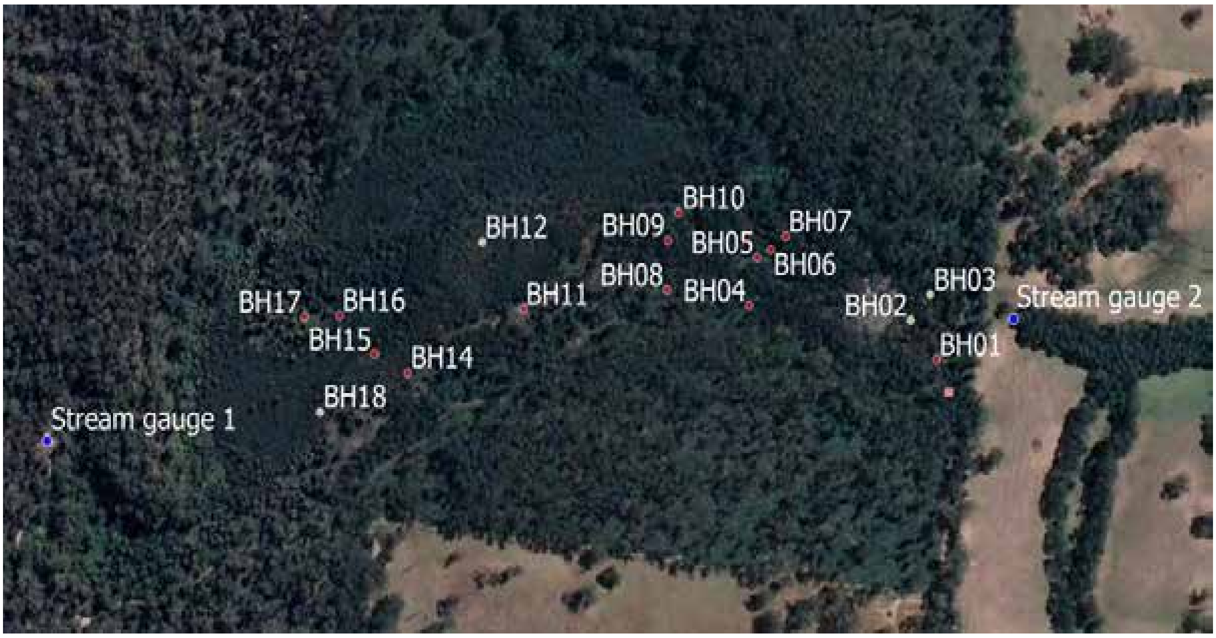


Figure 9 Bore locations (Jacobs, 2018)

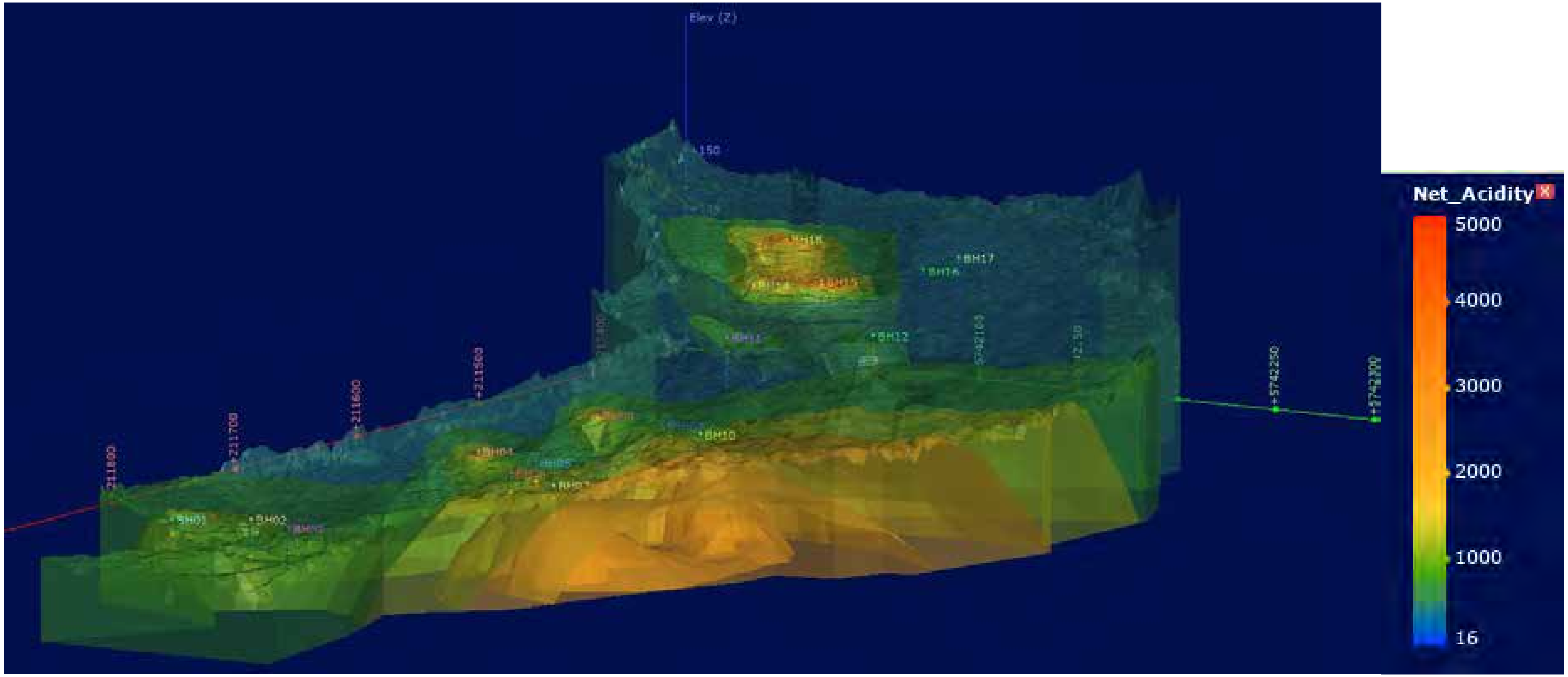


Figure 10 3D model - net acidity

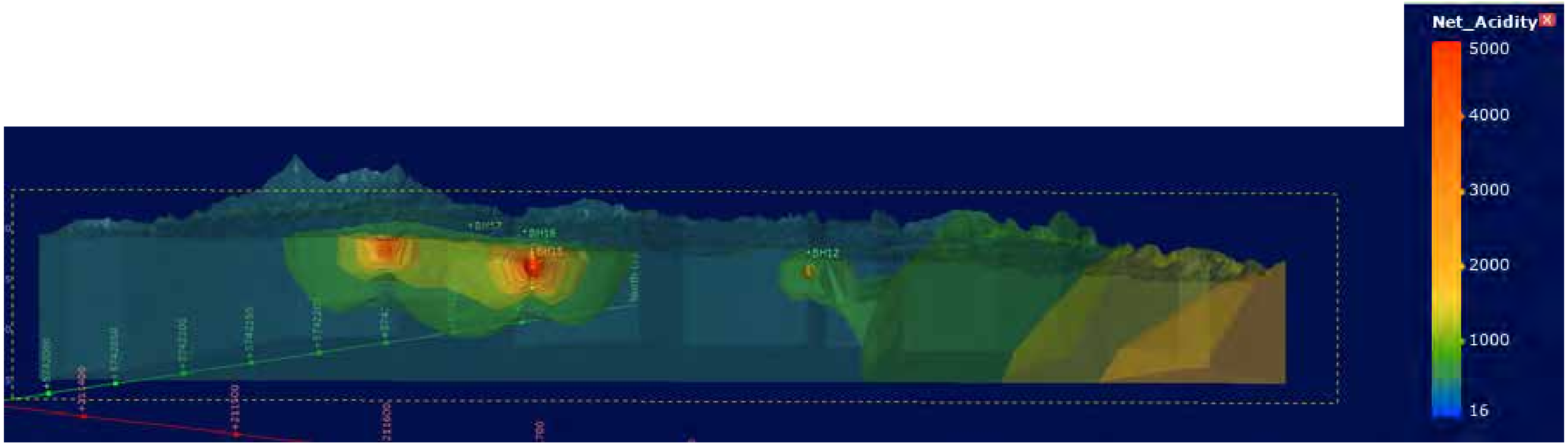


Figure 11 3D model - net acidity - cross section (Upper swamp South-west to North-east)

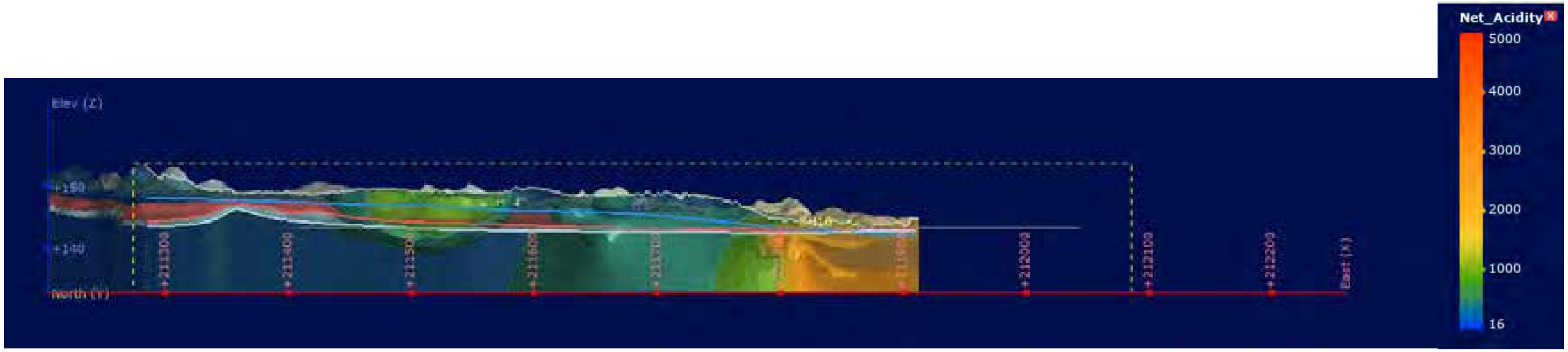


Figure 12 W-E long section with groundwater levels: actual (blue), 20 ML/day no barrier (red) and 2 ML/day no barrier (grey)

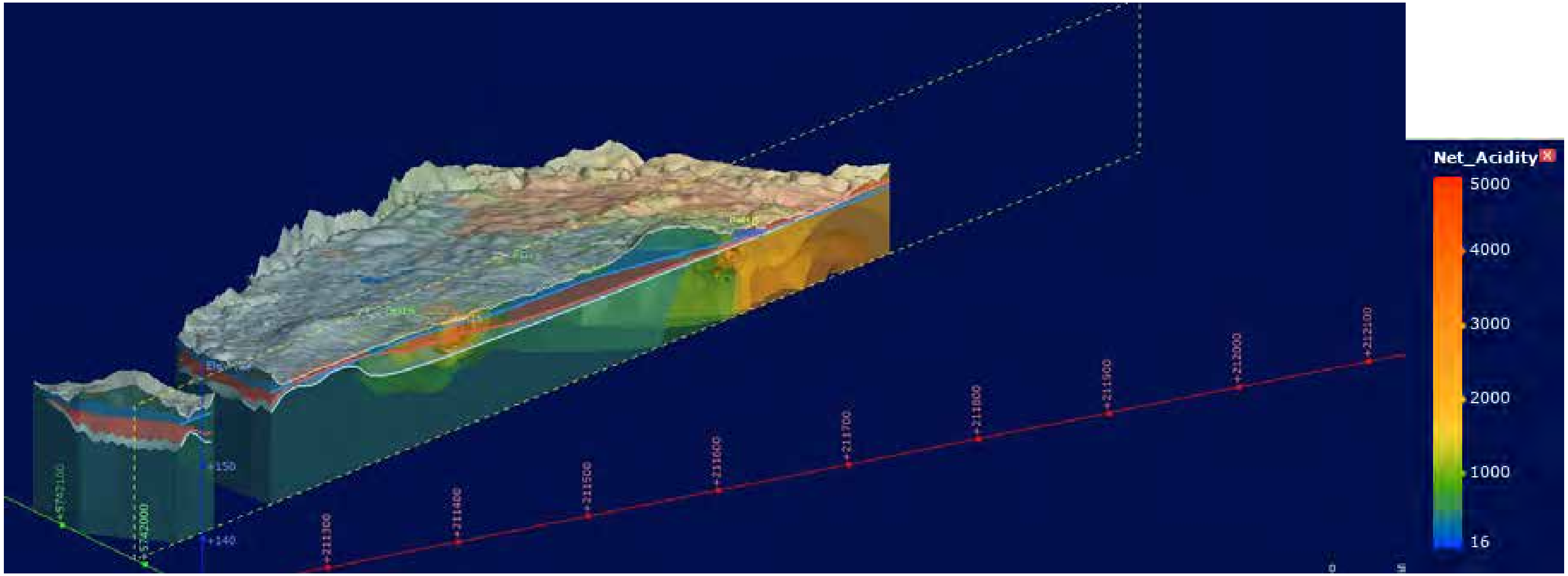
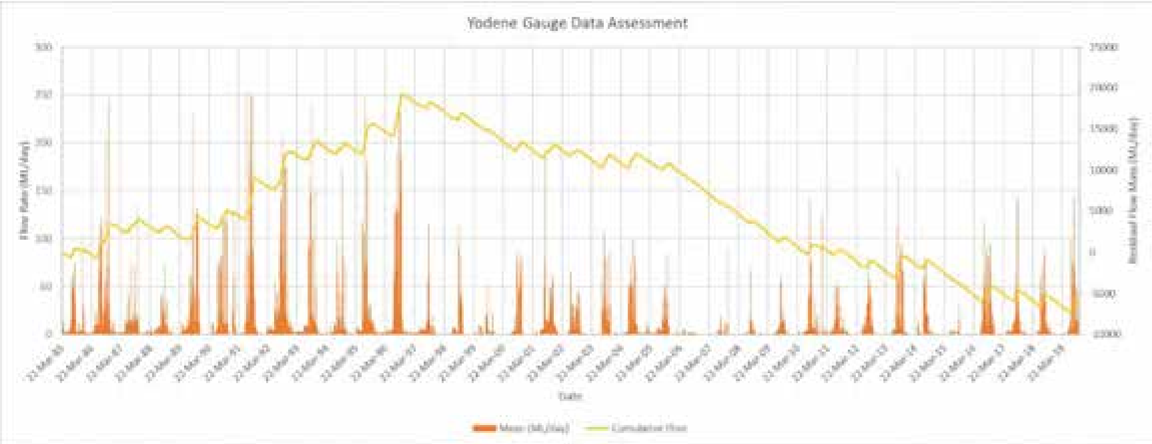


Figure 13 3D model with groundwater levels: actual (blue), 20 ML/day no barrier (red) and 2 ML/day no barrier (grey)

4.2 Flow and acid flux assessment for Reach 3 of Boundary Creek

The existing flow and pH monitoring data collected for the Yeodene Gauge was used to assess the flow and acid flux from Big Swamp into Reach 3 of Boundary Creek. The stream flow data was assessed through a simple flow and residual mass flow analysis that evaluated stream flow in Reach 3 of Boundary Creek between the mid 1980's to present. The result of the flow analysis are presented on Graph 1 and suggest the following:

- The frequency, duration and quantum of winter flows has declined after the late 1990's.
- The frequency, duration and quantum of winter flows was lowest during the millennial drought.
- Some recovery in frequency duration and quantum of winter flow is observed after 2010 but that recovery is not to the levels of flow observed in the late 1980's and most of the 1990's.
- Flow volumes have been in decline since the 1990's, with the rate of decline only slowing in recent years.



Graph 1 Summary of streamflow data for Yeodene Gauge

A statistical analysis of the flow data is summarised in Table 2 and suggests:

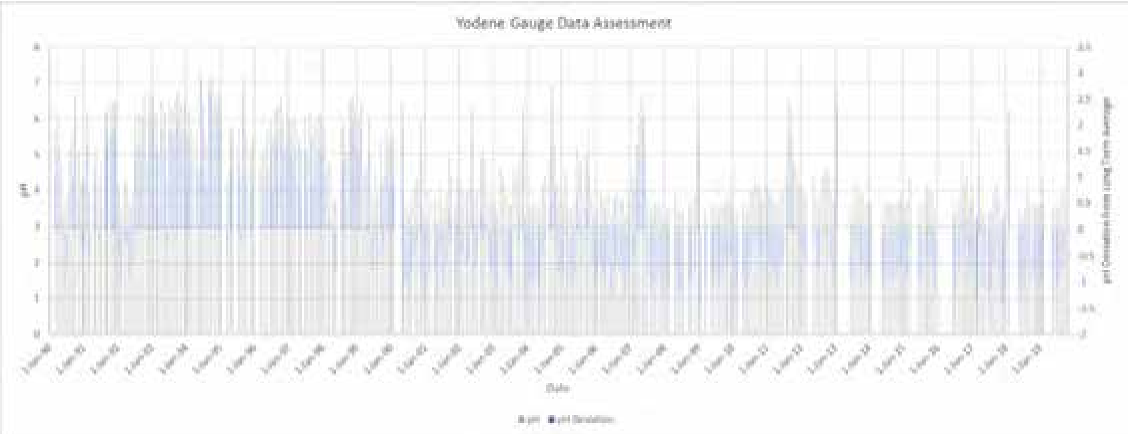
- A decline in flow between the 1990's and 2000's, with the lowest flow occurring in the first decade of the new millennium, coinciding with the millennial drought.
- Some recovery of flow during the 2010's but flow remains notably below that occurring in the 1980's and 1990's.
- Variance in flow volumes declined in the 2000's and 2010's compared to the 1980's and 1990's.

Table 2 Summary statistics of Yeodene Gauge flow data

Flow (ML/day)	All Data	1980's	1990's	2000's	2010's
Minimum	0.0	0.1	0.0	0.0	0.0
Median	1.6	3.4	2.4	0.7	1.2
Mean	8.0	10.3	11.3	4.9	6.7
Maximum	251.8	245.0	251.8	185.2	170.4
Standard Deviation	18.4	19.2	25.0	11.1	14.9

The pH data for the Yeodene Gauge was assessed over time through a time series plot of the measured pH and the deviation of pH from the long term average, with the result of that assessment summarised on Graph 2. The results suggest:

- pH values in the 1990’s were generally above 4.5 for the majority of the time, with pH frequently above 6.
- pH values less than the long term average over the monitoring period were infrequent in the 1990’s.
- Since early 2000 pH has frequently been below 4 and an overall decrease in pH is readily discernible.
- The frequency of pH values below the long term average increased noticeable after early 2000.
- No notable change in pH measurements is observed after 2010, despite an increase in flow as shown on Graph 1.



Graph 2 Summary of pH data for Yeodene Gauge

A statistical analysis of the pH data is summarised in Table 3 and suggests:

- A decline in pH between the 1990’s and 2000’s, with lower pH persisting since the first decade of the new millennium, coinciding with the millennial drought.
- No notable recovery in median and mean pH is observed in the 2000’s and 2010’s and pH remain notably lower in the first two decades of the new millennium than persisted in the 1990’s.
- Variance in pH declined in the 2000’s and 2010’s compared to the 1990’s.

Table 3 Summary statistics of Yeodene Gauge flow data

pH (Units)	All Data	1980's	1990's	2000's	2010's
Minimum	3.1	No Data	3.5	3.1	3.2
Median	4.1	No Data	5.8	3.8	3.8
Mean	4.6	No Data	5.6	4.1	3.9
Maximum	7.4	No Data	7.4	6.9	6.9
Standard Deviation	1.1	No Data	1.0	0.9	0.7

4.3 General geochemical processes in inland Acid Sulphate Soils

Big Swamp is considered an inland acid sulfate soil (ASS) site, rather than the more common and widespread coastal ASS that occur in low-lying areas adjoining the coastal fringe and primarily formed during a period of higher sea level in the Holocene.

Inland ASS form under a wide range of environmental conditions generally involving a wet swampy setting. Water chemistry in the system can range from freshwater to saline inland environmental settings at various topographic elevations. Inland ASS formation and activation mechanisms involve a wide range of soil and water conditions across a range of climate settings.

The extent of Inland ASS occurrence in Australia has only recently become apparent, primarily as a result of drying of inland wetland and river systems in the millennial drought. Consequently the study of the formation and activation mechanisms of Inland ASS systems is not as advanced as those for Coastal ASS systems.

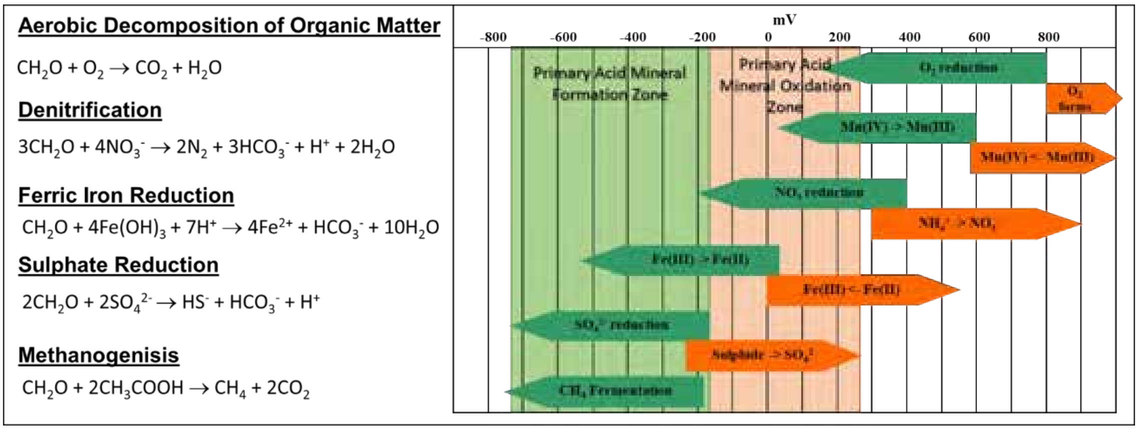
Inland ASS can generally be defined as those ASS, which occur inland of modern-day low lying coastal zones. Inland ASS, provide a range of management challenges in terms of the range and extent of formation mechanisms.

Considering all of these complexities though, there are some common aspects that universally apply to the Inland ASS sites, such as:

- They occur in wet swampy setting that are fed by either or both surface and groundwater.
- They are associated with reducing conditions that are generally created by the degradation of organic matter.
- They are associated with attenuation of dissolved phase sulfate that is fed into the Inland ASS system by either or both the surface and groundwater that enters the system.
- They are associated with acidification that results from the oxidation of the sulfide minerals that are stored in the Inland ASS system, therefore becoming the primary source of the acidification that occurs.

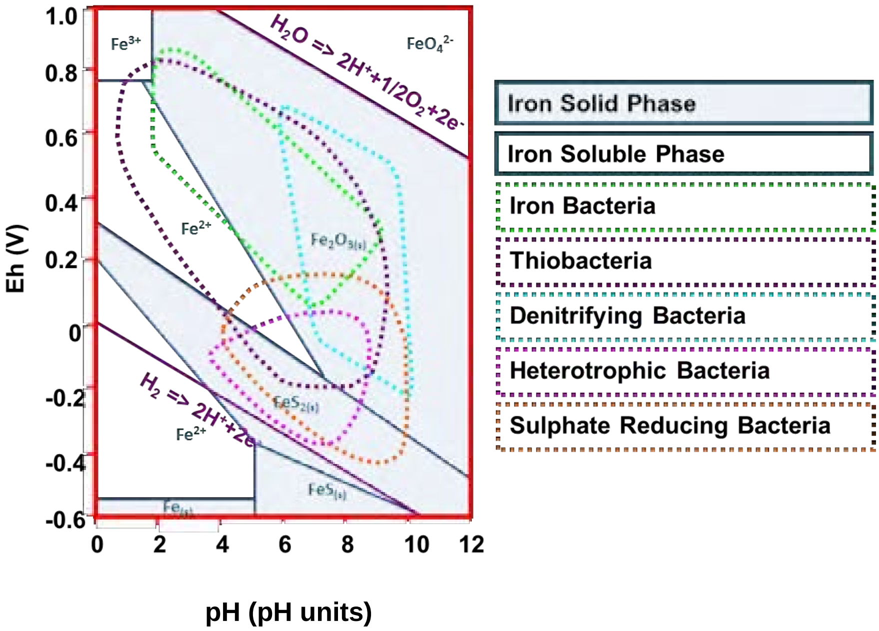
4.3.1 Primary acid source mineral formation

In order to inform the CGM, the primary mechanisms that lead to the formation of the acid source in Inland ASS systems needs to be understood. As noted, Inland ASS systems occur in wet, swampy systems where organic matter decomposition results in reducing conditions. Organic matter decomposition is a series of bacteriologically facilitated oxidation / reduction reactions that occur in a specific sequence form thermodynamically most to least favourable. The sequence of oxidation / reduction reactions that lead to the formation of primary acid forming minerals is shown on Graph 3. As shown on Graph 3, the primary acid source mineral formation occurs over the zone when reduction of sulfate occurs, while the primary acid formation processes coincides with the oxidation of sulfide.



Graph 3 Organic matter degradation reaction sequence

The decomposition of organic matter in Inland ASS environments is facilitated by microbes that liberate the energy released by the oxidation / reduction reaction to fuel their metabolism. Given the complexity and range of pH and Eh conditions over which oxidation / reduction reactions occur, bacterial species have evolved to liberate the energy released by the oxidation / reduction reaction under different environmental conditions. Graph 4 present the activity fields of the common bacteria species that are associated with organic matter degradation superimposed on the iron stability diagram. As is evident, on Graph 4, the primary bacteria species associated with the reduction of sulfate (Heterotrophic and Sulfate Reducing Bacteria) generally occur under slightly acidic, neutral and alkaline conditions. However, these key bacteria species are inactive under highly acidic conditions, which are associated with pH below 4. Thiobacteria are active under highly acidic conditions but only have a limited capacity with respect to sulfate reduction. Therefore, the accumulation of primary acid forming minerals becomes ineffective once oxidation of these minerals occurs and the sediment, pore water, groundwater and surface water pH become acidic.

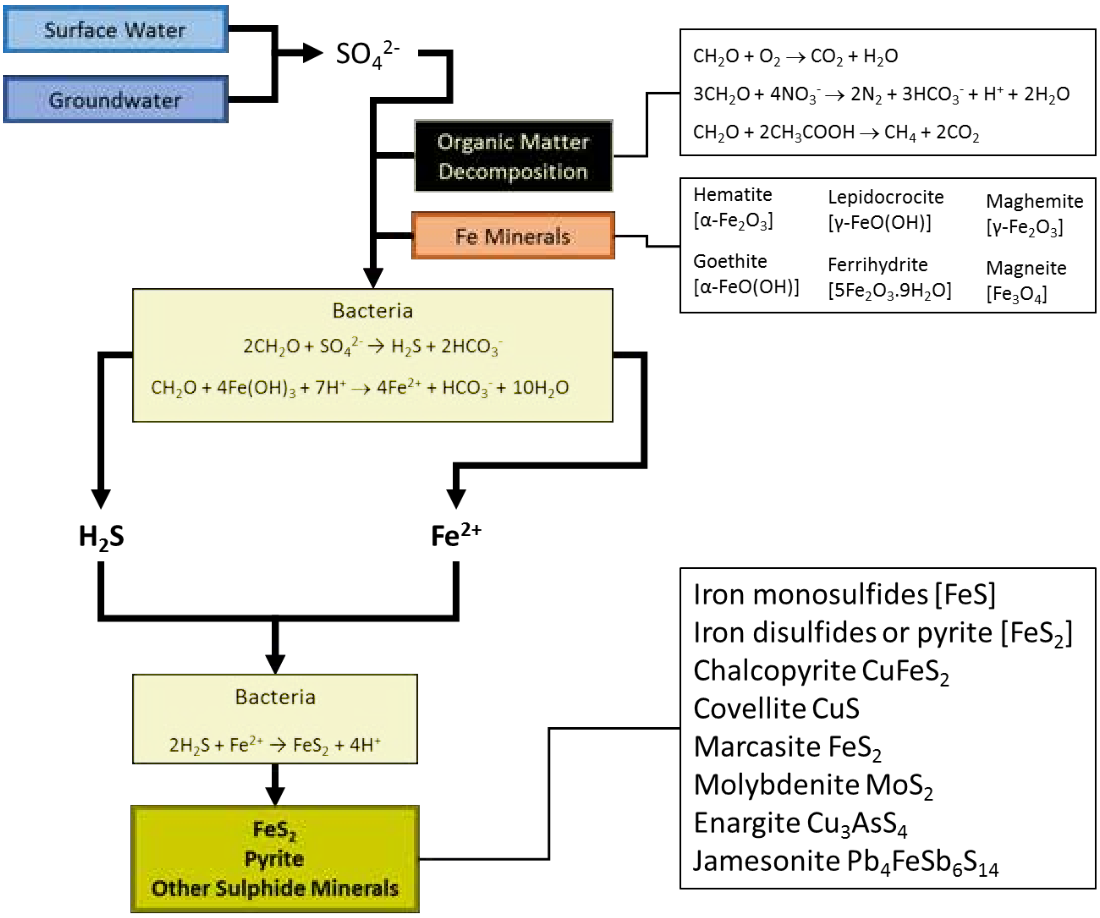


Graph 4 Environmental conditions and bacterial species activity

The primary acid mineral source formation mechanism and associated reactions that are associated with Inland ASS sites are shown on Graph 5. Iron sulfide minerals are one of the end products that form as part of the process of dissolved sulfate reduction in the Inland ASS system. Dissolved sulfate is utilised as an electron acceptor and is reduced to sulfide, while organic matter is oxidised and donate the electrons for the reduction of sulfate. Sulfate reduction generally occurs in the absence of oxygen as shown on Graph 3.

Sulfate reduction is a natural process that occurs as part of the metabolic process of bacteria and occurs in virtually all lakes, rivers, wetlands and oceans, by various bacteria species as shown on Graph 4. However, the quantities of sulfide minerals that will accumulate in a given environment are a function of several factors, with the following being those most significantly associated with sulfide accumulation:

- Continual addition of dissolved sulfate into the Inland ASS system.
- Saturation of soils and sediments for periods long enough to favour moderately to strongly reducing conditions.
- Availability of labile carbon to fuel the metabolic activity of bacteria.
- Availability of either or both dissolved Fe or Fe containing minerals, such as those listed in Graph 5.



Graph 5 Primary Acid Source Formation Process active in Big Swamp

In addition to the accumulated sulfides acting as a potential source of acid when oxidised, an additional source of acid in Inland ASS systems are Monosulfidic black ooze (MBO) which is a subaqueous or waterlogged organic-rich material that contains appreciable concentrations of monosulfides. MBO's are characterised by their gel-like consistence and generally have a field pH of 4 or more when present in saturated undisturbed form. Depending on environmental conditions and composition, MBO can have neutral to slightly alkaline (>pH 7-8).

However, when disturbed and / or drained MBO can become extremely acidic (pH <4). The nutrient rich environment of MBO together with the activity of algae and micro-organisms results in the generation of strongly reducing conditions that result in the formation of iron monosulfides, as shown on Graph 5. As a result MBO form black soils that emit strong sulfidic odours when disturbed.

When subaqueous materials rich in monosulfides are resuspended, for example during the flushing of drains by high runoff events, they rapidly oxidise, which can result in the depletion of dissolved oxygen in the water column, resulting in adverse impact on aquatic flora and fauna, such as fish kills. The risk posed to aqueous flora and fauna is generally highest in enclosed water bodies, such as aquaculture ponds or in estuaries.

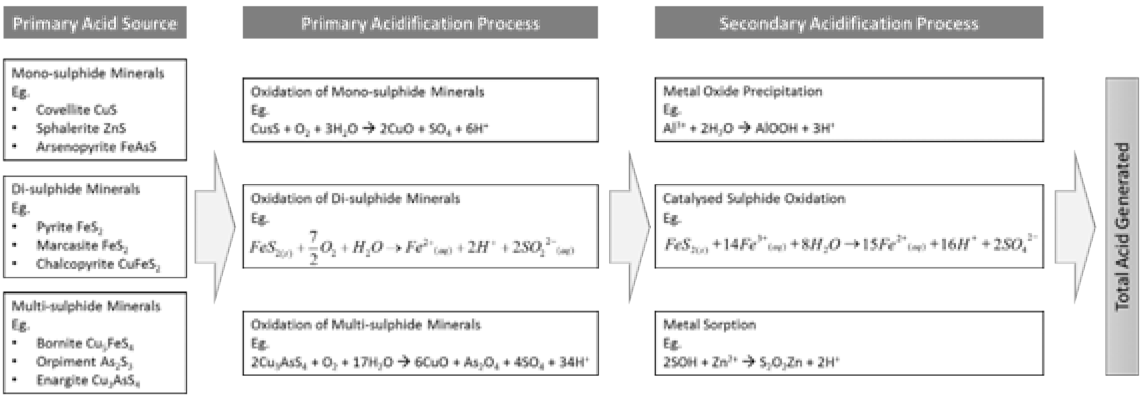
4.3.2 General acid generation processes

Acid soils are distinguished by an acidic reaction and a lack of easily soluble minerals that provide buffering capacity. The low readily soluble mineral content results in low ionic strengths in the solutions. In acid soils the pH dependent exchange sites becomes increasingly occupied with hydrogen (nonexchangeable) and the cation exchange capacity decreases. At the permanent sites Ca, Mg, Na, and K are reduced as the solution concentration of these ions increases and the concentration of Al increases. Despite the fact that extractable H^+ and Al^{3+} can be high, there is very little exchangeable H^+ on exchange sites in acid soils.

ASS generate sulfuric acid through chemical oxidation of sulfide minerals, which result in the release of soluble sulfate. This dissolved sulfate can leach into surface water drainage systems, leading to acidification and the mobilisation of aluminium, heavy metals and arsenic from minerals present in the soils and corrodes steel and concrete infrastructure.

While aluminium is abundant in the minerals present in the soil and rock, dissolved concentrations are low under naturally occurring pH in soil pore-water, groundwater and surface water. Dissolved aluminium is toxic to aquatic and terrestrial flora and fauna. Dissolved aluminium mobilised by acidification processes has been associated with fish kills and death of vegetation. In sub-lethal doses dissolved aluminium stunts growth and breaks down immunity against disease. High concentrations of dissolved heavy metals are also toxic, and heavy deposits of ochre can choke vegetation and block drains.

There are several steps in acid generation which occur in a sequence of reactions that can be divided into primary and secondary acidification processes. The most common source of acid associated with Inland ASS are sulfides, with pyrite generally being the most abundant. Oxidation of mono, di and multi sulfide minerals is generally the primary acidification process. For example, oxidation of pyrite to Fe^{2+} and sulfate is generally the first step in the reaction sequence. This can then be followed by secondary acidification processes, such as oxidation of some Fe^{2+} to Fe^{3+}, which significantly increases acid generation through oxidation of pyrite by Fe^{3+} and, finally, oxidation of the remaining Fe^{2+} to Ochre. The overall acid source and primary and secondary acidification processes are summarise on Graph 6.



Graph 6 Acid sources and primary and secondary acidification processes

Oxidation of pyrite by oxygen (equation 1) is associated with a slow kinetic rate. Oxidation of Fe^{2+} to Fe^{3+} is a more effective oxidant (equation 2) and oxidation of pyrite by Fe^{3+} (equation 3) proceeds much faster than the reaction of pyrite with oxygen but, also, much faster than the oxidation of Fe^{2+} to Fe^{3+} (equation 2). So the Fe^{2+} to Fe^{3+} transformation is, potentially, the rate-limiting step. However, generation of Fe^{3+} is mediated by iron-oxidising bacteria, particularly Thiobacillus ferooxidans. Equation 3 depends on the pH being low enough for Fe^{3+} to remain soluble (pH < 4), otherwise it is precipitated as ochre (equation 4), so rapid oxidation of pyrite, facilitated by Fe^{3+} generally only takes place at very low pH.

$$\underset{\text{pyrite}}{FeS_{2(s)}} + \underset{\substack{\text{dissolved}\\\text{oxygen}}}{\tfrac{7}{2}O_2} + H_2O \Rightarrow \underset{\substack{\text{dissolved iron}\\\text{II}}}{Fe^{2+}_{(aq)}} + \underset{\text{sulphuric acid}}{2H^+_{(aq)} + 2SO_4{}^{2-}_{(aq)}} \quad \ldots.(1)$$

$$Fe^{2+}_{(aq)} + \tfrac{1}{4}O_{2(aq)} + H^+_{(aq)} \Rightarrow \underset{\substack{\text{dissolved}\\\text{iron III}}}{Fe^{3+}_{(aq)}} + \tfrac{1}{2}H_2O \quad \ldots.(2)$$

$$FeS_{2(s)} + 14Fe^{3+}_{(aq)} + 8H_2O \Rightarrow 15Fe^{2+}_{(aq)} + 16H^+_{(aq)} + 2SO_4{}^{2-} \quad \ldots.(3)$$

$$Fe^{2+}_{(aq)} + \tfrac{1}{4}O_{2(aq)} + \tfrac{3}{2}H_2O \Rightarrow \underset{\text{ochre}}{FeO.\,OH_{(s)}} + 2H^+_{(aq)} \quad \ldots.(4)$$

The different stages of oxidation do not necessarily occur at exactly the same point in space and / or time. Field and micromorphological examination of ASS shows a distinct separation of pyrite and its oxidation products ochre, jarosite and gypsum. Under a climate with pronounced wet and dry seasons, oxidation of pyrite may continue after flooding using the oxidising capacity stored as Fe^{3+} oxide during the dry season.

The final step of oxidation of Fe^{2+} ions to ochre (equation 4) requires strongly oxidising conditions, which may be found at some distance from the pyrite source, either within the soil or in drainage or floodwaters. Under conditions of poor drainage, especially in soils rich in organic matter, the Fe^{2+} ions may migrate for several km in acid solution before precipitation as ochre in a more oxidising environment, causing further acid generation through this secondary acidification process.

In soils, a conspicuous intermediate product of sulfide oxidation is the yellow mineral jarosite, which is deposited as coatings around pores and fissures under strongly oxidising conditions, severely acid conditions (Eh greater than +400 mv, pH less than 3.7). Jarosite may occur in a range of solid solutions with natrojarosite and hydrodiumjarosite but the potassium form predominates. Its formation from pyrite may be represented as:

$$FeS_{2(s)} + \tfrac{15}{4}O_{2(aq)} + \tfrac{5}{2}H_2O_{(l)} + \tfrac{1}{3}K^+_{(aq)} \Rightarrow \underset{\text{jarosite}}{\tfrac{1}{3}KFe_3(SO_4)_2(OH)_{6(s)}} + \underset{\text{sulphuric acid}}{\tfrac{4}{3}SO_4{}^{2-}_{(aq)} + 3H^+_{(aq)}}$$

At higher pH values, jarosite is ultimately hydrolysed to goethite.

$$KFe_3(SO_4)_2(OH)_{6(s)} \Rightarrow \underset{\text{goethite}}{3FeO.\,OH_{(s)}} + 3H^+_{(aq)} + 2SO_4{}^{2-}_{(aq)}$$

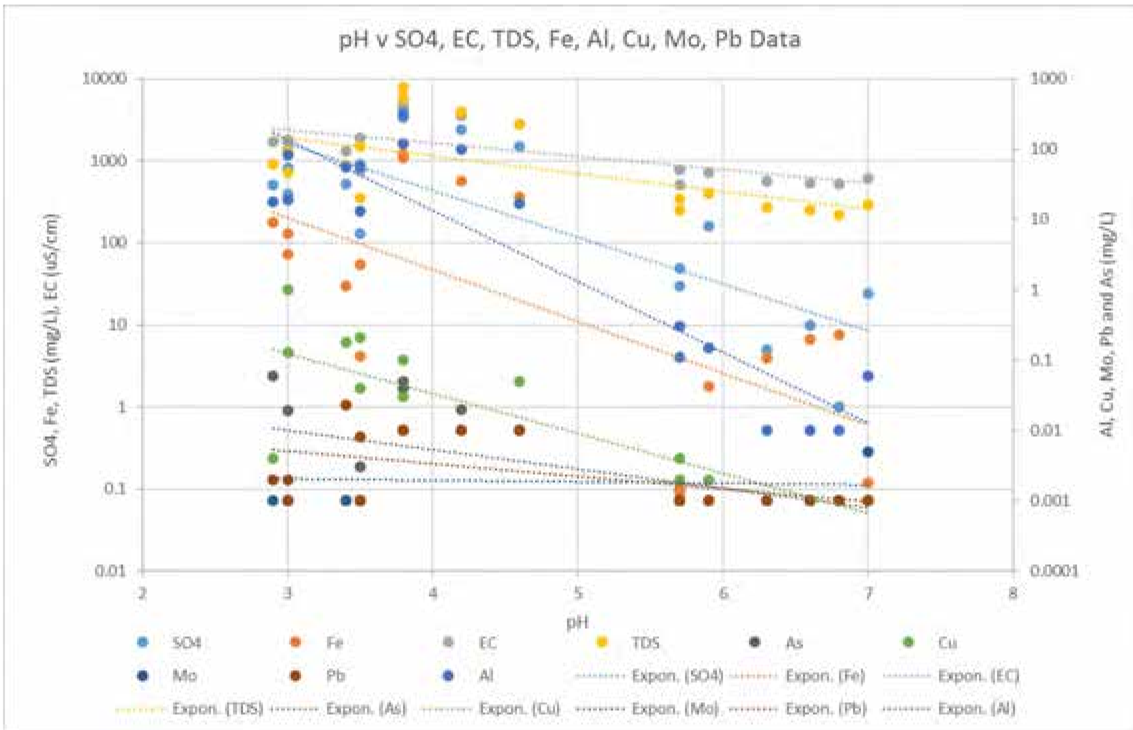
4.4 Geochemical processes in Big Swamp and Reach 3 of Boundary Creek

This section provides an assessment of the primary acid source minerals and primary and secondary acidification processes identifiable in Big Swamp and Reach 3 of Boundary Creek.

4.4.1 Primary acid source assessment for Big Swamp

Based on the understanding of the general acidification and neutralisation processes set out in the previous sections, the existing water sample analysis data for Big Swamp from May 2017 (Jacobs, 2017a), August 2017 (Jacobs, 2017b) and August 2019 (ALS, 2019) was utilised to assess the potential sulfidic source minerals for acid generation. As noted iron sulfides are generally the most common primary source minerals, as illustrated in Graph 5, with arsenic, copper and lead sulfides providing other potential acid source minerals in Big Swamp based on their presence in dissolved phase.

The dissolved phase concentration measured in pore water and groundwater samples collected from Big Swamp in August 2019 (ALS 2019) was used to assess the relationship between the concentration of these dissolved phase inorganics and pH to evaluate whether oxidation and dissolution of primary acid source minerals was apparent as a primary line of evidence. The results of this assessment are summarised on Graph 7.



Graph 7 Summary of primary acid source assessment for Big Swamp

The results of the primary acid source assessment of the data available for Big Swamp as summarised on Graph 7 suggests:

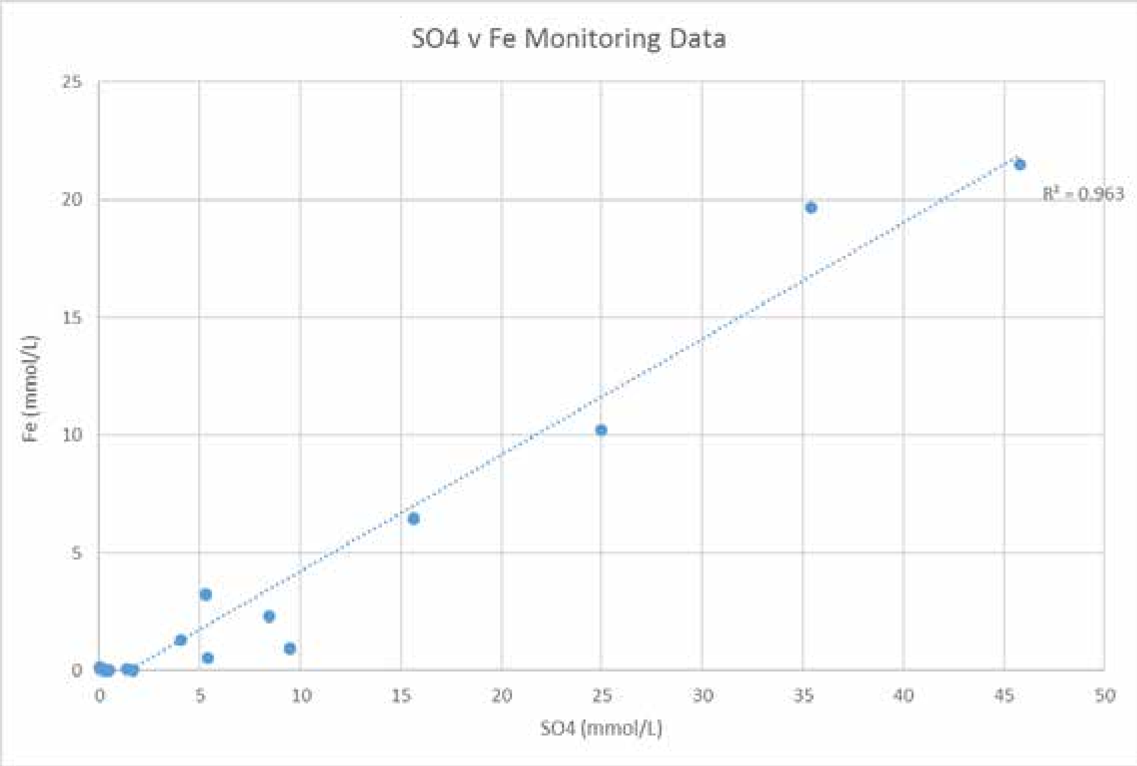
- There is a strong relationship between pH, sulfate and iron when plotted on a log scale, suggesting that iron sulfide minerals such as Iron monosulfides (FeS), Iron disulfides (pyrite) (FeS_2) and possibly Marcasite FeS_2 are the primary acid source.
- There is a relationship between pH, sulfate and salinity (EC and TDS), suggesting that oxidation and dissolution of sulfide minerals is a source of dissolved solids that increase the ionic strength of the solution.
- Arsenic, copper and lead also show relationships with pH and sulfate. However concentrations of these inorganics are significantly lower than iron concentrations, suggesting that copper sulfide minerals such as Chalcopyrite $CuFeS_2$, Covellite CuS, Enargite Cu_3AsS_4 and possibly Jamesonite $Pb_4FeSb_6S_{14}$ if present within the swamp sediments may form a minor acid source. Another potential source of these metals is release of sorbed phase into solution in response to decreasing pH. At present there is insufficient geochemical and mineralogical data to assess which geochemical processes is active with respect to these metals.
- Molybdenum shows no relationship with pH and sulfate, suggesting that molybdenum sulfides are not a detectable acid source in Big Swamp.
- Aluminium, shows a relationship with pH and sulfate, suggesting that mineral weathering and dissolution of aluminium hydroxides and oxides is occurring as a result of the decrease in pH. However, aluminium concentrations are lower than sulfate and iron concentrations, suggesting only limited weathering is occurring, which suggests that buffering capacity in Big Swamp may be limited. This aspect is further discussed in Section 4.6.

Overall there is considered to be sufficient evidence to conclude that iron sulfide minerals form the primary acid source in the Big Swamp sediments, with minor acid contributions from other sulfide minerals if present.

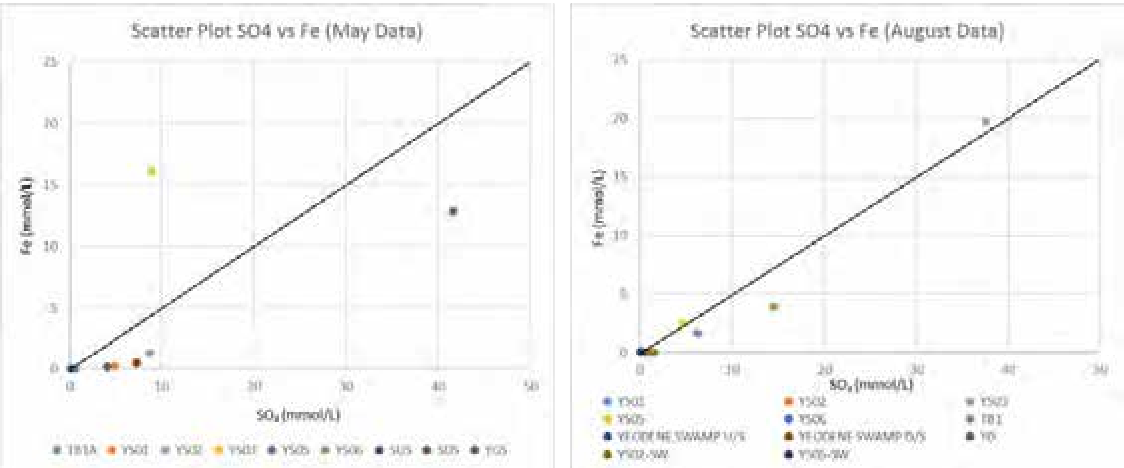
4.4.2 Primary acidification processes assessment for Big Swamp

The existing water sample analysis data for Big Swamp was utilised to assess the primary acidification processes associated with the oxidation of sulfidic source minerals. As shown on Graph 7, there is a relationship between pH, iron and sulfate that suggests that iron sulfide mineral are the primary acid source minerals. Oxidation of iron sulfides, such as Iron monosulfides (FeS), Iron disulfides (pyrite) (FeS_2) and possibly Marcasite FeS_2, are considered to be the primary acidification process responsible of the observed decreases in pH observed in Big Swamp and Reach 3 of Boundary Creek. This assessment finding is supported by the strong positive relationship between sulfate and iron shown in the scatter plots for the recent monitoring data shown on Graph 8 (August 2019). As shown on Graph 8, there is a strong correlation between sulfate and iron at an approximate 2 to 1 ratio, which would be consistent with the oxidation of pyrite (a di-sulfide mineral) as shown in the equation below:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$



Graph 8 Sulfate and iron scatter plot – monitoring data for Big Swamp



Graph 9 Sulfate and iron scatter plot – Jacobs pore and groundwater data for Big Swamp, with black line showing 2 to 1 relationship

The relationship between sulfate and iron mole ratio for the Jacobs (2017a, 2017b) monitoring bore data also supports pyrite oxidation as the primary acidification process for the August 2017 data, but not May 2017 as shown on Graph 9. The May data shows a significant deficit in iron compared to sulfate for this monitoring round, indicating that other acidification processed may have been active in Big Swamp in this period as discussed in more detail in Section 4.4.3.

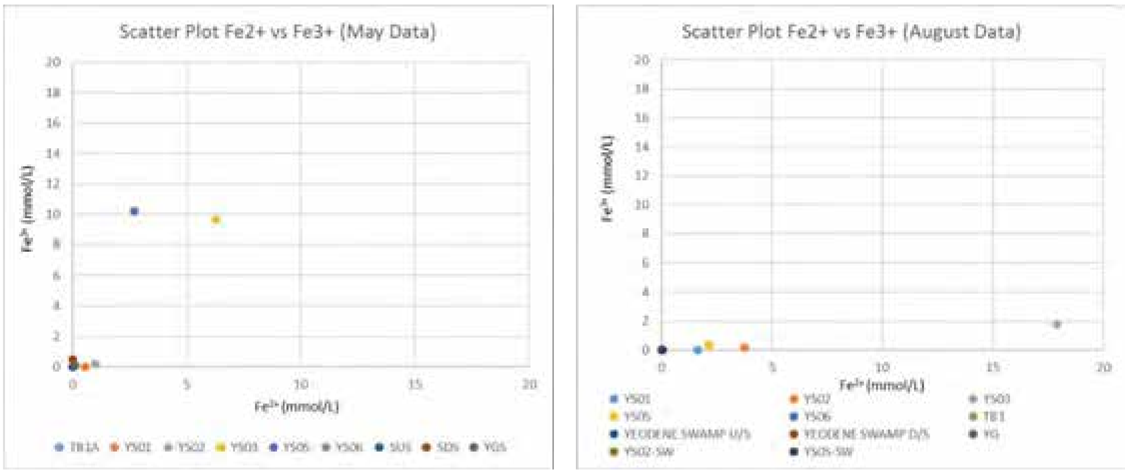
Overall there is considered to be sufficient evidence to conclude that the dominant primary acidification process is oxidation of iron sulfide minerals, with pyrite being the dominant acid source mineral apparent in Big Swamp. If oxidation of iron mono-sulfide was the dominant process, which is commonly associated with MBO, the sulfate to iron ratio’s would have plotted near to a 1:1 ratio.

4.4.3 Secondary acidification processes in Big Swamp and Reach 3 of Boundary Creek

Secondary acidification processes can occur in the surface water within Big Swamp and the Boundary Creek in Reach 3 down-stream of Big Swamp. Assessment of the available data was undertaken for each of these areas to evaluate the contributions that secondary acidification processes may make to the acid impacts in these two environments.

Big Swamp pore and groundwater quality

As is evident in the August monitoring event data (Jacobs 2017b) shown on Graph 9 there is an excess of sulfate over iron on the solution, suggesting that some secondary acidification processes are potentially active. The existing water quality monitoring data was assessed to evaluate which secondary acidification processes may be active in Big Swamp. Graph 10 presents the results of the assessment of the iron speciation data provided in the Jacobs (2018) report, which shows differences between the May and August monitoring rounds.

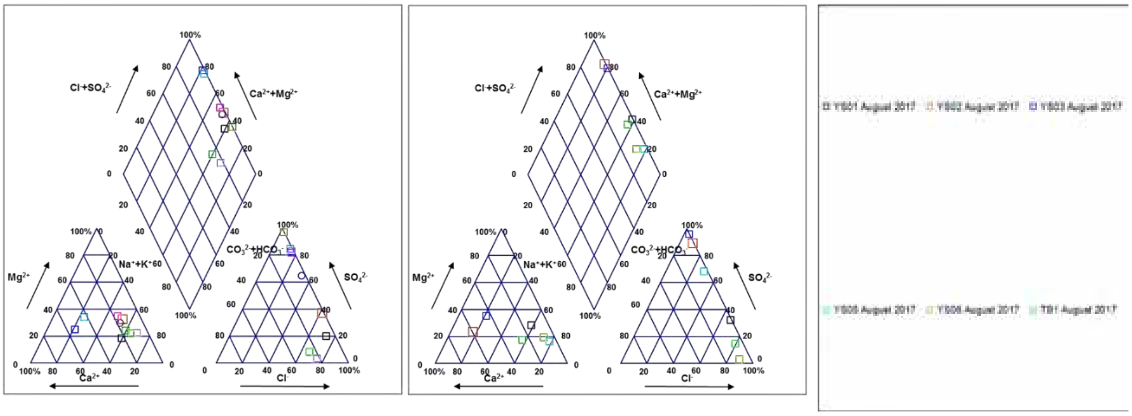


Graph 10 Ferrous and ferric iron scatter plots for surface water data

The May 2017 monitoring data for Big Swamp showed two locations (YS03 and YS05) with elevated ferric iron concentration, which suggests that at least in localised areas appreciable amounts of ferric iron may be periodically available to facilitate enhanced pyrite oxidisation as described in equation 3 shown above, suggesting that this secondary acidification process could be active periodically in Big Swamp. However, there currently is insufficient temporal data to confirm this is the case.

Further, as shown on Graph 9, there are periods of excess sulphate over iron, suggesting that dissolved phase minerals may be precipitated as jarosite, which may then be converted to goethite as pH increases resulting in the release of hydrogen and sulfate into solution, while removing iron by precipitation and conversion of jarosite to goethite. The data suggests that these secondary acidification processes may be at least periodically occurring in Big Swamp. However, there currently is insufficient temporal data to confirm this is the case nor can the duration and magnitude of secondary acidification processes as a contributor to the overall acid impact be assessed.

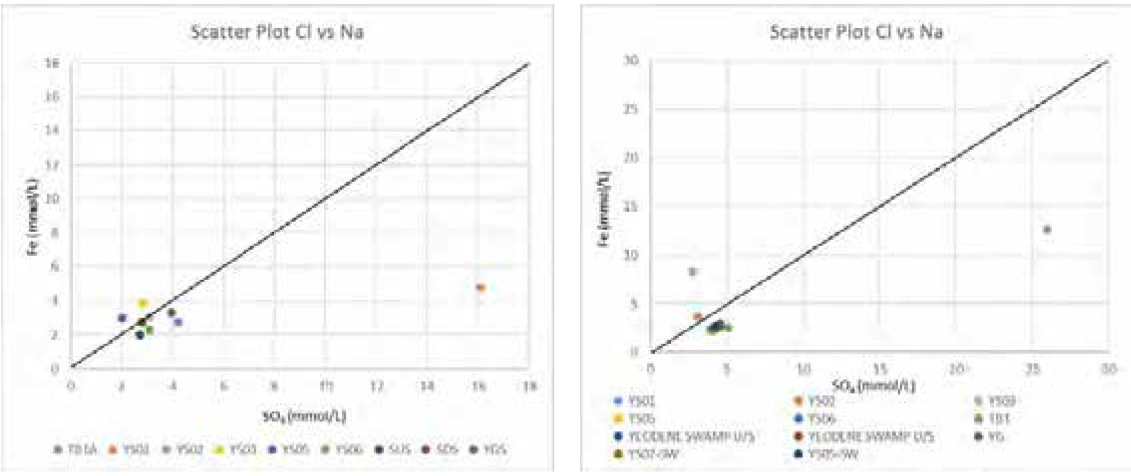
Assessment of the pore water and groundwater monitoring data shows that geochemical conditions in Big Swamp are variable both spatially and temporally suggesting the system is dynamic, as indicated in the piper plots for the May 2017 (Jacobs 2017a) and August 2017 (Jacobs 2017b) data presented on Graph 11. These dynamics will affect the severity and duration of any acid generation events and will affect the impacts on the environment as well as the ability of the environment to recover from acid impacts.



Graph 11 Piper plot of pore water and groundwater data (May left) (August right)

Reach 3 of Boundary Creek

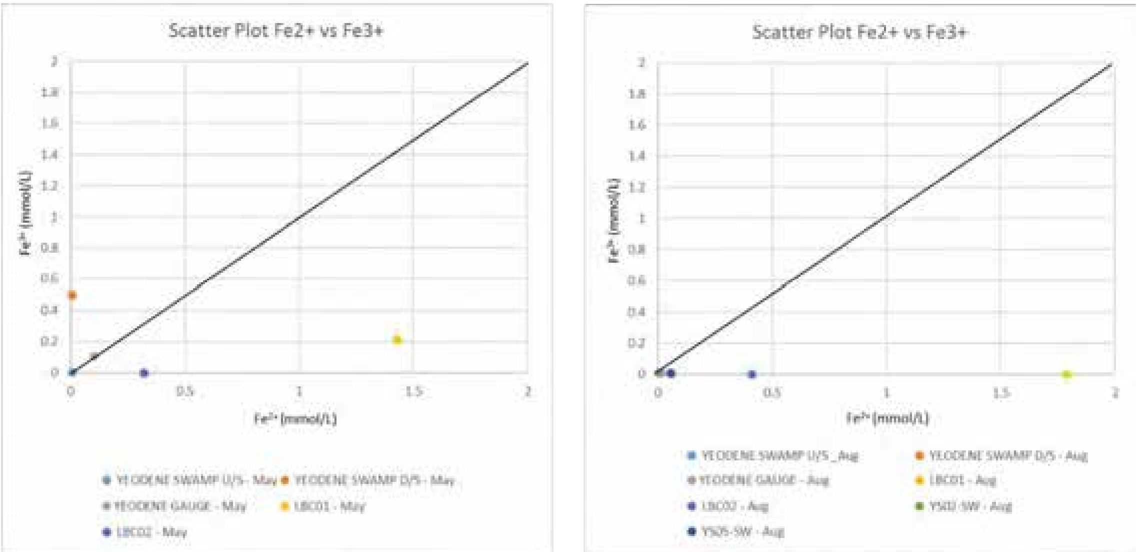
There is limited evidence to suggest that any primary acid source minerals are present in Reach 3 of Boundary Creek as there is no apparent relationship between sulfate and iron as shown on Graph 12 (Jacobs 2017a and 2017b).



Graph 12 Sulfate and iron scatter plot for surface water data

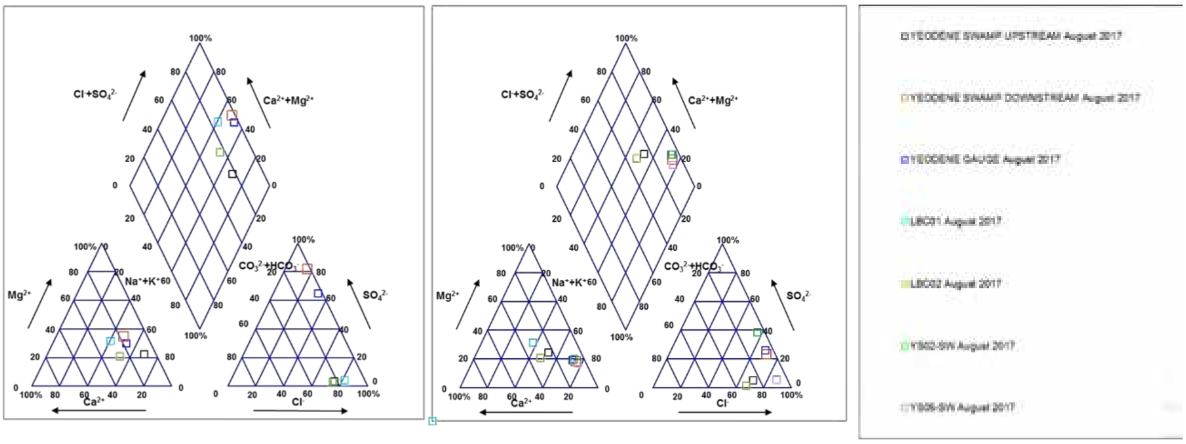
The existing surface water quality monitoring data for Reach 3 of Boundary Creek was assessed to evaluate whether secondary acidification processes may be active in Reach 3. Graph 13 presents the results of the assessment of the iron speciation data provided in the Jacobs (2018) report, which shows differences between the May 2017 and August 2017 monitoring rounds.

The May monitoring data shows that the surface water leaving Big Swamp and entering Reach 3 of Boundary Creek (Yeodene Swamp D/S) has elevated ferric iron concentration, which suggests that at least for some periods appreciable amounts of ferric iron are present in solution. The presence of both ferric and ferrous iron in solution results in an export of acidity from Big Swamp into Reach 3 of Boundary Creek that can lead to secondary acidification though oxidation of ferrous iron to ferric iron and then precipitation of ferric hydroxides.



Graph 13 Ferrous and ferric iron scatter plots for surface water data

Assessment of the surface water monitoring data shows that geochemical conditions in Boundary Creek are variable both spatially and temporally suggesting the system is dynamic, as indicated in the piper plots for the May 2017 and August 2017 data presented on Graph 14. These dynamics will affect the severity and duration of any acid generation events and will affect the impacts on the environment as well as the ability of the environment to recover from acid impacts of Reach 3 of Boundary Creek.



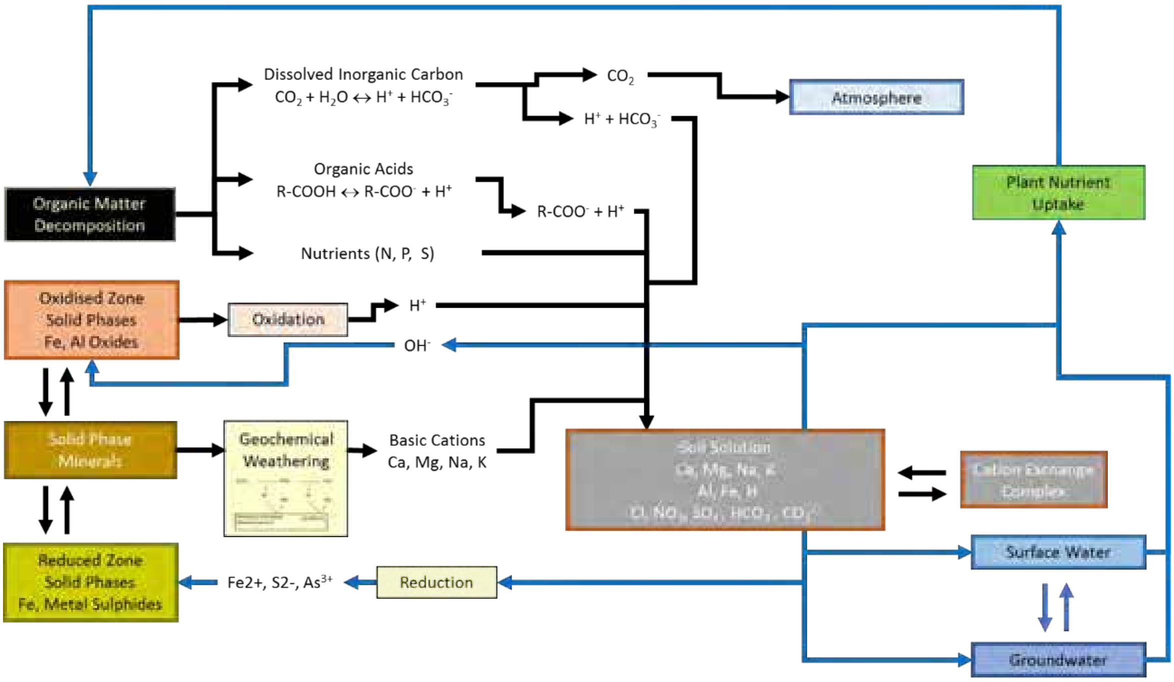
Graph 14 Piper plot of surface water data (May left) (August right)

4.5 General acid neutralisation processes

The acid neutralisation capacity of soils is controlled by a number of factors, including parent material, climate, vegetation and management. These factors control whether a soil has a neutral, acidic or alkaline reaction. These factors also control the buffering capacity of soils, which provides the capacity to neutralise acids produced by the primary and secondary acidification processes associated with the oxidation of acid source minerals.

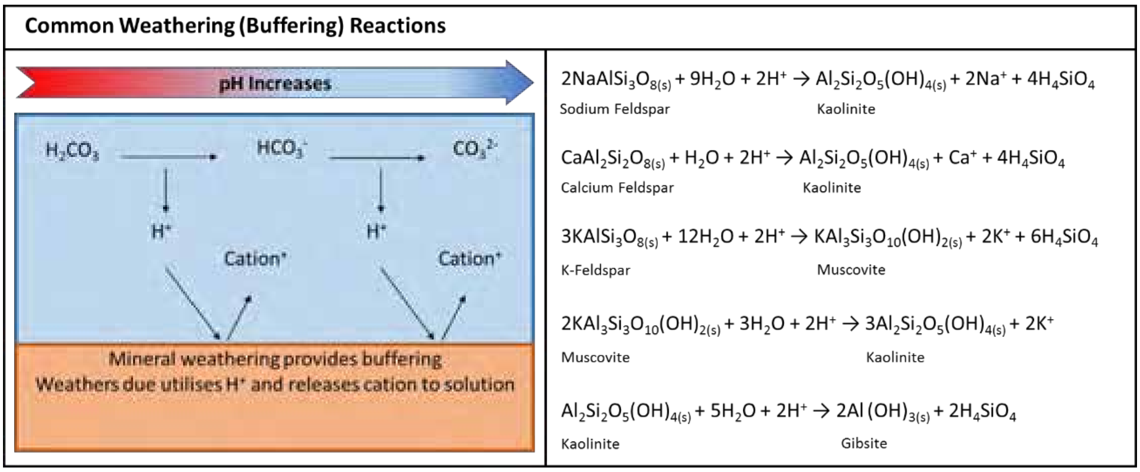
There are a number of processes in soils and sediments, which generate or consume protons (acid) and therefore affect pH. These processes interact with the local climate, parent material, and organisms over time to establish the soil pH. Water flow through the system is an important variable as it removes weathering products and supplies protons for exchange reactions. Some of the important processes that either generate or consume protons are provided on Graph 15.

Protons that are generated by these processes interact with the soil exchange complex and the solid phase. Thus, primary minerals, clay and organic matter content and percolation are important aspects of soil pH regulation.



Graph 15 Conceptual representation of soil processes and factors affecting soil pH

The release of hydrogen ions into solution as a result of oxidation of sulfide minerals provides protons for mineral weathering and buffering capacity against decrease in pH. The general process involved in buffering is illustrated on Graph 16. The amount of buffering available in soils is dependent in their mineral composition and resistance of these minerals to weathering. Inland ASS soils are characterised by high organic matter content, high sulfide mineral content and low or absence of readily weathered minerals to provide buffering, resulting in significant decreases in pH in response to sulfide mineral oxidation.



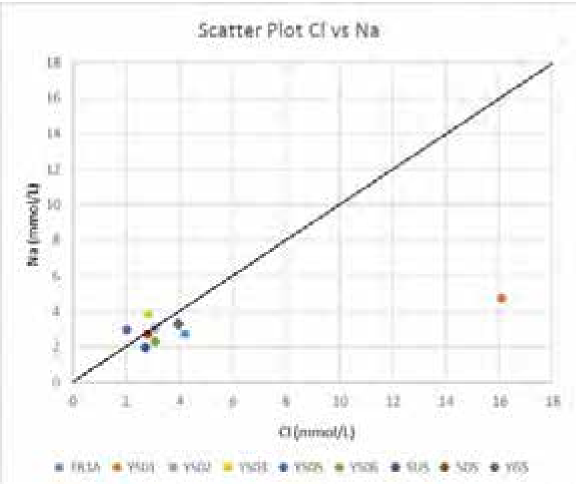
Graph 16 Common reactions that provide buffering capacity in soils

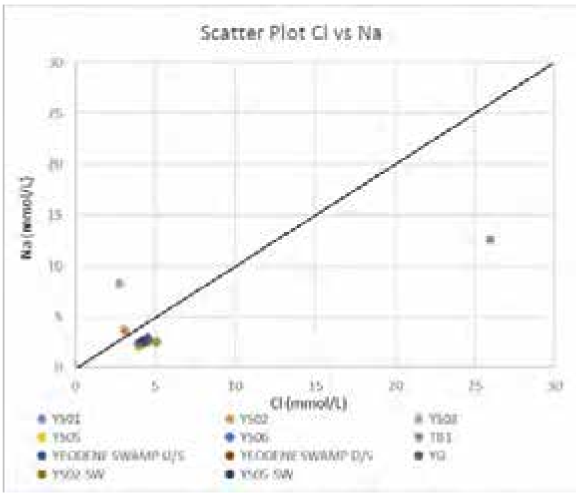
4.6 Neutralisation capacity assessment for Big Swamp and Reach 3 of Boundary Creek

The available water quality monitoring data and results of the Monash University study (2019) was used to assess the neutralising (buffering) capacity of the sediments present in Big Swamp.

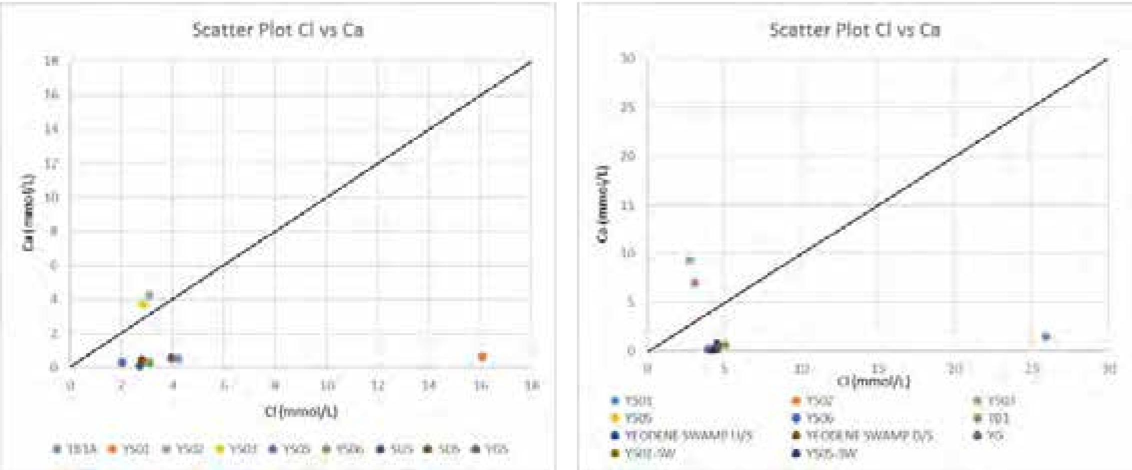
The results of the neutralisation capacity assessment indicated that the sediments in Big Swamp had limited neutralisation capacity, based on the following lines of evidence:

- The salinity range and chloride sodium relationship (Graph 17) shows relatively limited variability suggesting limited dissolution of readily soluble salts or sodium source minerals such as Na-feldspar, in response to decreases in pH.
- The chloride calcium relationship (refer to Graph 18) suggests limited dissolution of calcium source minerals, such as Ca-feldspar, in response to decreases in pH.
- The sodium calcium relationship shows some correlation in terms of concentration and shows some evidence of ion exchange in response to changes in pH. Under changes in pH conditions ion exchange sites can switch preference from di-valent to mono-valent ions, which results in release of di-valent ions such as calcium and removal of mono-valent ions, such as sodium from solution. Ion exchange can provide only limited buffering capacity, and given the results of the scatter plots presented on Graph 19, ion evidence of ion exchange occurring is limited to localised locations within Big Swamp.
- The calcium and bi-carbonate relationship suggests that limited buffering capacity would be provided by calcium carbonate minerals (refer to Graph 20). Graph 20 also supports the evidence on Graph 19 that ion exchange is the primary source of calcium in the water samples analysed.
- The chloride sulfate relationship (refer to Graph 21) suggests that there is limited correlation between the chloride concentration and sulfate concentration, which suggests that salinity (using chloride as an analogy for TDS) is not related to the neutralisation of acid generated by oxidation of sulfide acid source minerals.
- The sulfate sodium (refer to Graph 22) and sulfate calcium (refer to Graph 23) scatter plots show that there is a minor increase in these cations in response to increasing sulfate concentration that results from oxidation of sulfide acid source minerals. This suggests that there may be some limited buffering capacity through weathering of sodium and calcium source minerals or ion exchange, which supports the assessment of the relationship suggested on Graph 17 and Graph 18.

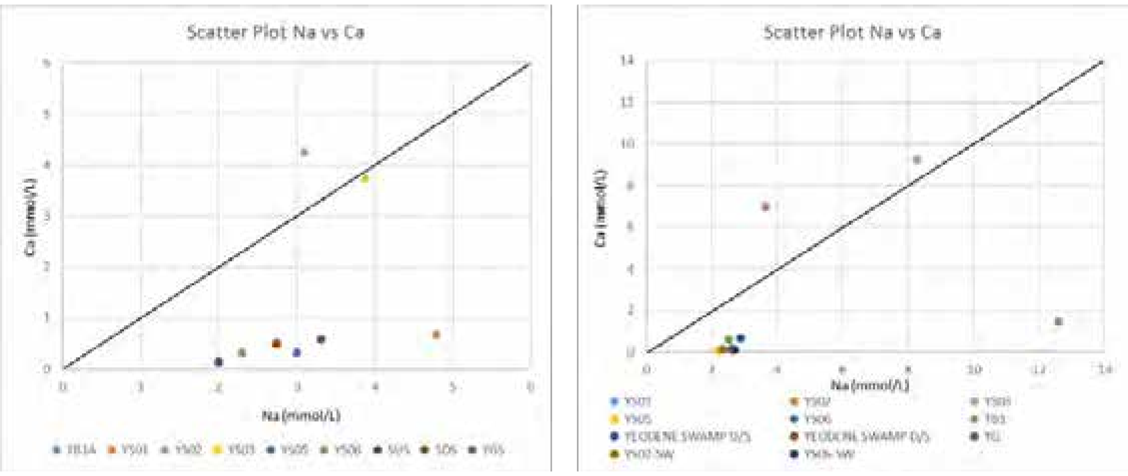




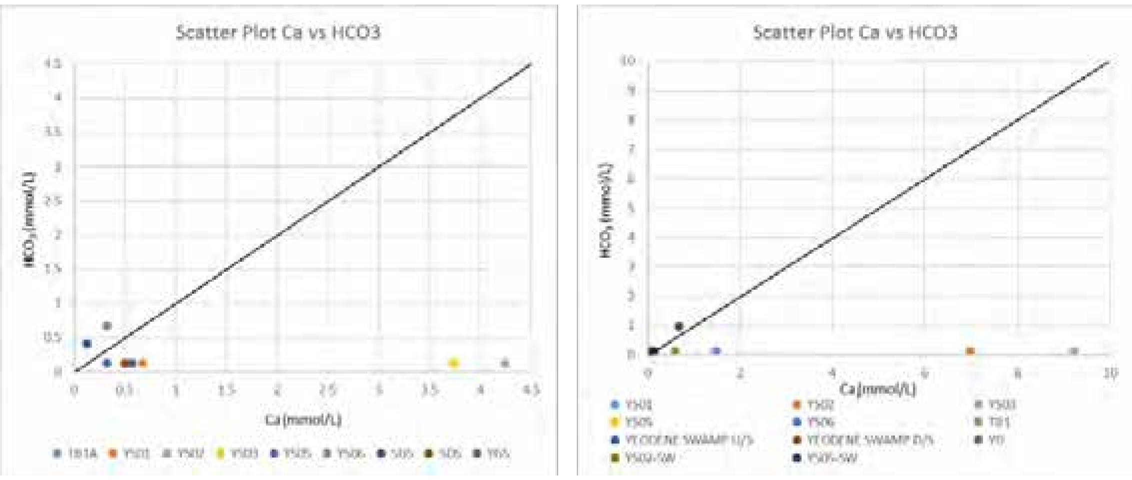
Graph 17 Chloride, sodium scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio



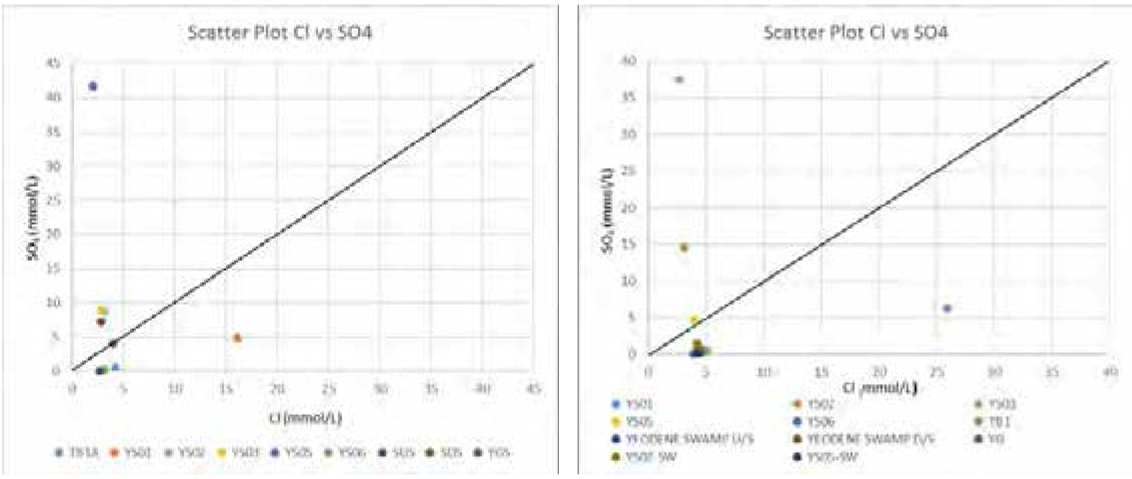
Graph 18 Chloride, calcium scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio.



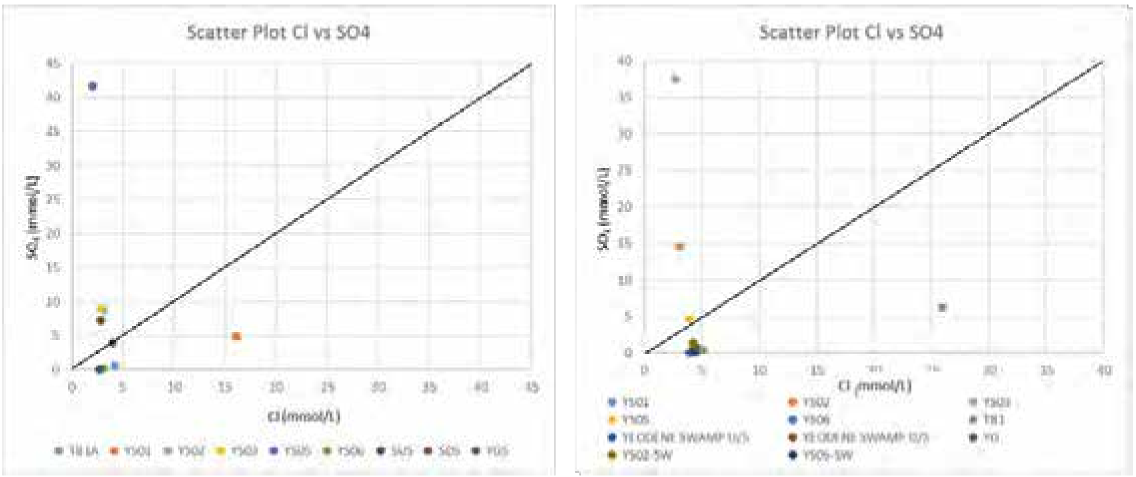
Graph 19 Sodium, calcium scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio.



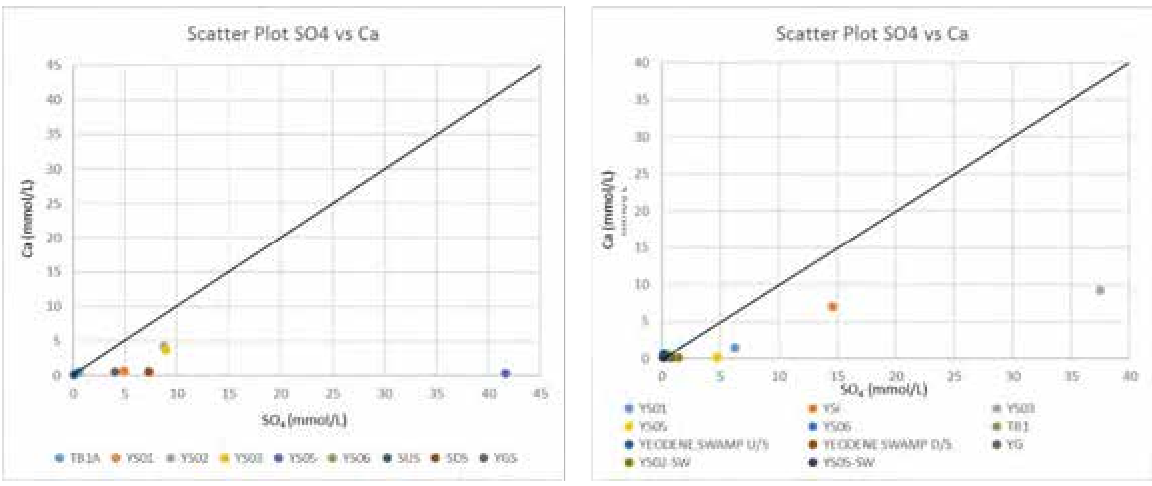
Graph 20 Calcium, bicarbonate scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio.



Graph 21 Chloride, sulfate scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio.



Graph 22 Sulfate, sodium scatter plot for May 2017 and August 2017 surface water monitoring data. Black line shows 1 to 1 ratio.



Graph 23 Sulfate, calcium scatter plot for May 2017 and August 2017 Surface Water Monitoring Data. Black line shows 1 to 1 relationship.

The Monash University (2019) incubation studies, documented in a separate progress reports (May/June, July/August and September 2019 reports), focused on 5 soils that were made up of blending soils from samples obtained from Big Swamp. These 5 soils fell into two broad categories, one group (Soil 1 and 2) was comprised of soils that had already oxidised (Acid Soils), while the second group was comprised of soils that had not yet oxidised (Soil 3,4 and 5) and therefore represented potential ASS. The second group of soils was generally distinguished by organic matter content, with Soil 3 and 5 having lower organic carbon content than Soil 4. The preliminary result of the incubation tests suggest that Soil 4 may have sufficient neutralisation capacity in the form of reduction capacity to re-attenuate sulfate by reduction to sulfide and precipitation as sulfide minerals, such as MOB or pyrite. However, Soils 3 and 5, which have lower organic matter content were considered to have insufficient neutralisation capacity in the form of reduction capacity with respect to the amount of acid generated by these soils. Further the Monash study found that while the high organic matter content soils theoretically had sufficient neutralisation capacity for the acid generated by them, the preliminary results suggest that the reaction kinetics for the attenuation of sulfate by reduction to sulfide and precipitation of sulfide mineral appear slow and may not proceed to completion.

Therefore, based on the available information, there is limited evidence that suggests the sediments in Big Swamp have a readily available and efficient buffering capacity. The buffering capacity appears limited by insignificant amounts of soluble minerals and slow kinetic reactions for the reduction of dissolved sulfate to sulfide and precipitation as of sulfide minerals.

4.7 Conceptual geochemical model summary

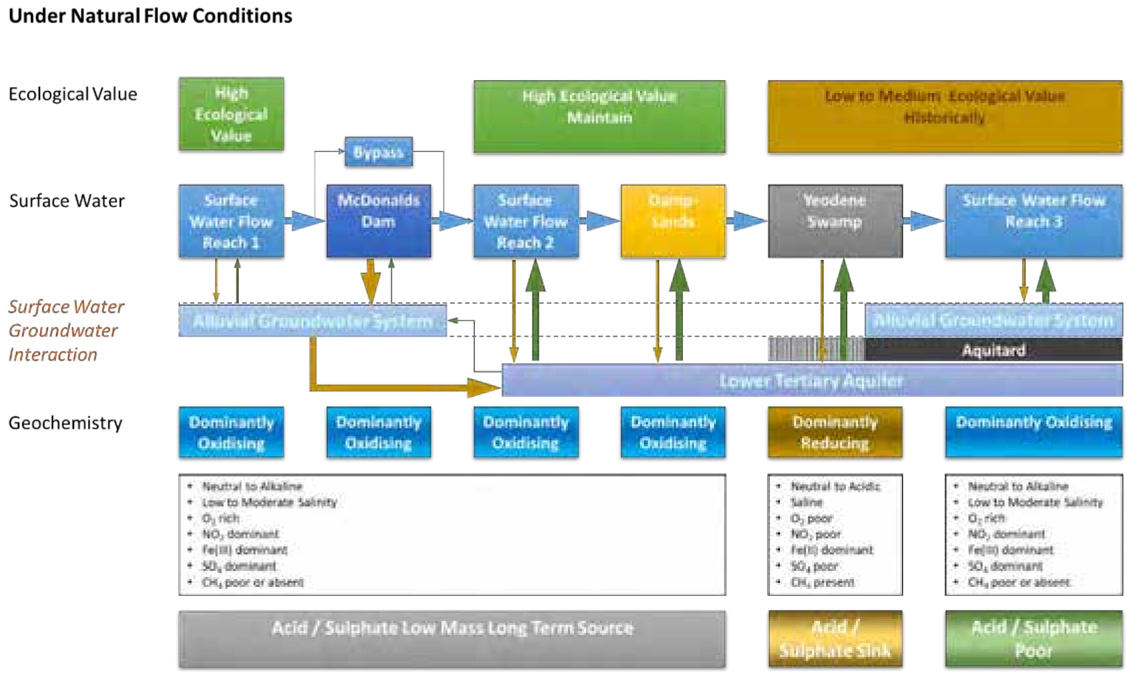
This section presents a summary of the key hydrological, hydrogeological and hydrogeochemical processes associated with Big Swamp and Reach 3 of Boundary Creek that formed the basis of the Conceptual Geochemical Model (CGM).

4.7.1 Key processes under natural flow conditions

To inform the baseline assessment and to assist in the development of realistic and practicable remediation and rehabilitation objectives, a baseline CGM was developed on the basis of the primary considerations summarised in Graph 24. The key elements of the conceptual linkages between surface water flow, groundwater surface water interaction and geochemical processes as summarised in Graph 24 are:

- The surface water flow in the catchment has been modified through the landform modification, including the installation of a dam (McDonalds) on Boundary Creek.
- The Boundary Creek catchment has been divided into the following parts, which had different ecological values:
  - Reach 1, up-stream of McDonalds Dam, which is considered to have high ecological values.
  - McDonalds Dam, which retains and stores streamflow and is subject to a theoretical bypass flow of the 2ML/day to maintain environmental flows in Boundary Creek downstream of the dam. The dam represents a highly modified ecosystem and would have low ecological value with respect to the ecological conditions prior to modification.
  - Reach 2, down-stream of McDonalds Dam and up-stream of the Damp-lands, which is considered to have high ecological values.
  - Damp-lands, down-stream of Reach 2 and up-stream of Yeodene Swamp (Big Swamp), which are considered to have high ecological values.
  - Big Swamp, which is located down-stream of the Damplands and up-stream of Reach 3 of Boundary Creek, the swamp was considered to have had high ecological value prior to the occurrence of acidification, vegetation changes and impacts of peat fire.

  - Reach 3 of Boundary Creek, which is located down-stream of Big Swamp and was subject to considerable modification following clearing of the land and use for agriculture, including chanelisation, which resulted in a degraded environmental value prior to pumping by Barwon Water commencing. Therefore, historically Reach 3 of Boundary Creek would have been considered to have had low to medium ecological value prior to the acidification occurring in Big Swamp and consequent acid discharge in to Reach 3.
- Groundwater discharge from the Lower Tertiary Aquifer (LTA) into Reach 2, Damp-lands and possibly Big Swamp was considered to have made a significant baseflow contribution to Boundary Creek prior to drawdown of the potentiometric head in the aquifer associated with groundwater extraction from the Barwon Downs borefield.
- Groundwater discharge into Reach 3 of Boundary Creek and potentially into part or all of Big Swamp was limited by the presence of an aquitard that overlies the LTA.
- Surface water flows in Reach 3 of Boundary Creek under natural flow conditions prior to pumping from the LTA aquifer ranged from lows of 0.1 ML/day to highs of 252 ML/day, with average flows of between 10 and 11 ML/day and Median flow volumes of 2.4 to 3.4 ML/day.
- Geochemical processes relevant to this study that occur in each part of the Boundary Creek catchment can be summarised as follows:
  - Oxidising conditions dominated historically in Reach 1 and 2 of Boundary Creek and the Damp-lands up-stream of Big Swamp, as well as Reach 3 of Boundary Creek, resulting in dissolved sulfate remaining in solution and not subject to accumulation in sediment through reduction. Under these oxidising conditions iron remained predominantly in the ferric iron form leading to low dissolved phase iron concentrations.
  - Reducing conditions dominated in Big Swamp due to the presence of organic matter and persistent wet conditions, which lead to the accumulation of sulfate through reduction to sulphide and precipitation of sulfide minerals from solution. This led to the accumulation of primary acid source minerals in Big Swamp through the formation of pyrite as the dominant sulfide mineral. Based on the available data the Big Swamp is anticipated to contain 600,000 to 700,000 cubic metres of sediments that contain potential primary acid producing minerals.
- Surface water pH in Reach 3 of Boundary Creek under natural flow conditions prior to pumping from the LTA aquifer ranged from lows of 3.5 to highs of 7.4, with an average of 5.6 and Median pH of 5.8.



Graph 24 Conceptual linkages for system under natural flow conditions

4.7.2 Key processes under anthropogenic flow conditions

To inform the assessment the geochemical processes occurring under modified flow conditions that resulted from both climate variation and pumping from the LTA aquifer, as well as to assist in the development of realistic and practicable remediation and rehabilitation objectives, a CGM for the conceptual linkages under anthropogenic influences was developed on the basis of the primary considerations summarised in Graph 25. The key elements of the conceptual linkages under modified flow conditions between surface water flow, groundwater surface water interaction and geochemical processes as summarised on Graph 25 are:

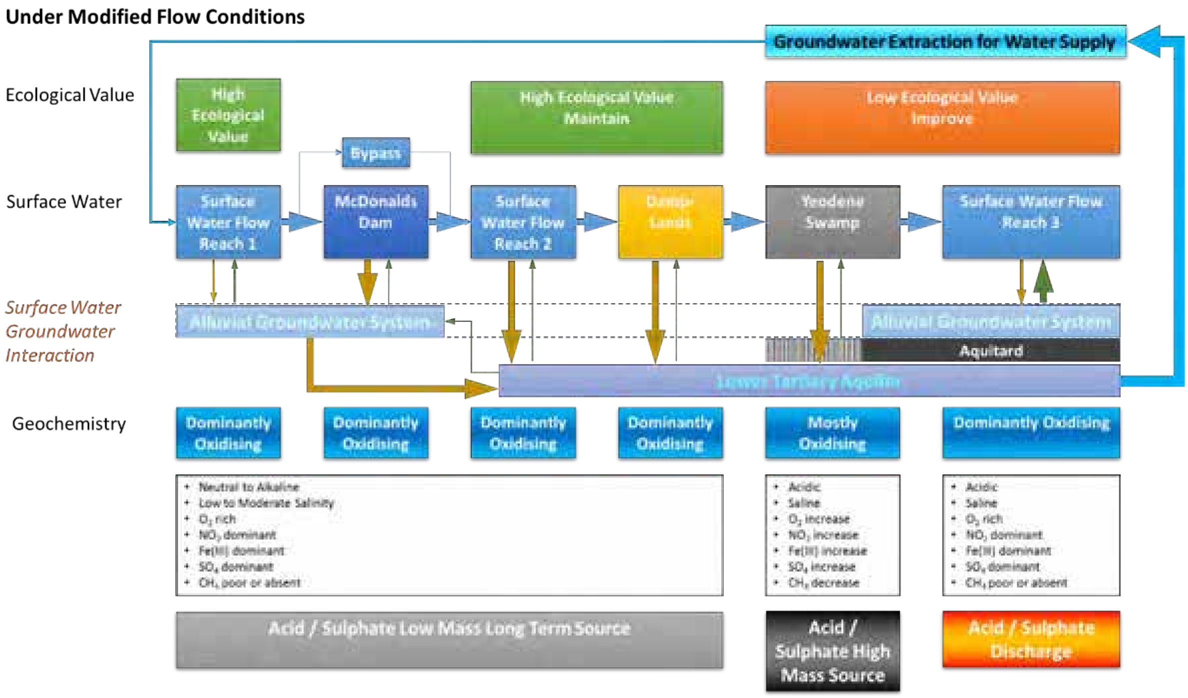
- The surface water flow in the catchment has been modified through the landform modification, including the installation of a dam (McDonalds) on Boundary Creek and the pumping from the LTA, which has affected the conceptual linkage and CGM.
- The effects of the modified flow conditions in the Boundary Creek catchment as a result of changes in rainfall and pumping from the LTA has been assessed in the context of the key parts of the catchment, with results indicating:
  - Reach 1, received an anthropogenic input of 2ML/day of additional flow from the total volume extracted from the LTA (or other sources) to compensate to the loss of baseflow contribution from groundwater in Reach 2 and the Damp-lands as a result of pumping from the LTA. Reach 1 is considered to have retained the high ecological values under the modified flow conditions.
  - McDonalds Dam, which retains and stored streamflow and is subject to a theoretical bypass flow of the 2ML/day to maintain environmental flows in Boundary Creek downstream of the dam. The dam represents a highly modified ecosystem and would have low ecological value with respect to the ecological conditions prior to modification. The changed flow regime was considered unlikely to have resulted in any significant changes to the ecological values of the Dam.
  - Reach 2, theoretically received an anthropogenic baseflow contribution of 2ML/day to compensate for baseflow loss as a result of pumping from the LTA. Reach 2 is considered to have retained the high ecological values under the modified flow conditions.

- Damp-lands, theoretically received an anthropogenic baseflow contribution of 2ML/day to compensate for baseflow loss as a result of pumping from the LTA. The Damp-lands are considered to have retained the high ecological values under the modified flow conditions.
- Big Swamp, theoretically received an anthropogenic baseflow contribution of 2ML/day to compensate for baseflow loss as a result of pumping from the LTA. However, dewatering of the swamp sediments occurred as a result of loss of groundwater baseflow contributions due to pumping and dry climatic conditions resulting in the formation of acid as a result of conditions becoming predominantly oxidising causing oxidation of the accumulated sulfide minerals resulting in acidification of the sediments, pore water, shallow groundwater and surface water present in Big Swamp. This acidification coupled with vegetation changes and impacts of fire have resulted in the degradation of the ecological values of the swamp from high to low.
- Reach 3 of Boundary Creek, which is located down-stream of Big Swamp has been adversely impacted by acid discharge from Big Swamp, which has degraded the historically low to medium ecological value prior to the acidification to low under the modified flow regime.

- Groundwater discharge from the Lower Tertiary Aquifer (LTA) into Reach 2, Damp-lands and possibly Big Swamp appears to have ceased, or significantly reduced as a consequence of pumping induced drawdown in the LTA. This is considered to have resulted in a decrease of the water table elevations in the sediments within Big Swamp leading to oxidising conditions that resulted in acidification through oxidation of sulfide mineral and export of acidity from Big Swamp into Reach 3 of Boundary Creek.
- Surface water flows in Reach 3 of Boundary Creek under the modified flow conditions as a result of pumping from the LTA aquifer and climatic conditions ranged from no flow to highs of up to 185 ML/day, which was somewhat similar to the overall range observed prior to modification of the flow regime.

  However, the most significant changes in flow conditions as a result of pumping and climate influences was a decrease in average flows from between 10 and 11 ML/day under natural flow conditions to 5 to 7 ML/day under modified flow conditions (decrease of 4 to 6 ML/day) and a decrease in median flow volumes from 2.4 to 3.4 ML/day under natural flow conditions to 0.7 to 1.2 ML/day under modified flow conditions (decrease of around 2ML/day). In addition the number of no flow days has increased significantly since 1999 (refer Figure 7).
- Changes in geochemical processes that result from the modified flow regime and relevant to this study as they occur in each part of the Boundary Creek catchment can be summarised as follows:
  - Oxidising conditions remain dominant in Reach 1 and 2 of Boundary Creek and the Damp-lands up-stream of Big Swamp, as well as Reach 3 of Boundary Creek. As such no direct changes in geochemical processes as a result of the modified flow conditions are anticipated. However, the oxidising conditions in Reach 3 of Boundary Creek are likely to contribute to acidification as a result of secondary acidification processes.
  - Reducing conditions no longer dominate in Big Swamp due to the decreases in water table elevations and drying of the organic matter rich sediments in the swamp. This led to oxidation of the accumulated sulfate minerals in the sediments that became exposed to oxygen. This oxidation of primary acid source minerals (primarily pyrite) in Big Swamp led to the formation of 600,000 to 700,000 cubic metres of sediments that potentially form acid and contain significant net acidity.

- Surface water pH in Reach 3 of Boundary Creek under modified flow conditions as a result of reduced rainfall and baseflow as a result of pumping from the LTA resulted in changes to pH in those parts of the Boundary Creek catchment, with pH ranging from lows of 3.1 to highs of 6.9, which is similar to the range recorded prior to the modification of the flow regime. However, the most significant changes in pH as a resulted of the modified flow regime were for the average pH which decreased from 5.6 prior to the modification of the flow regime to 4 after modification of the flow regime (difference to 1.6 pH Units) and a decrease in Median pH from 5.8 prior to the modification of the flow regime to 3.8 after modification of the flow regime (difference to 2 pH Units).



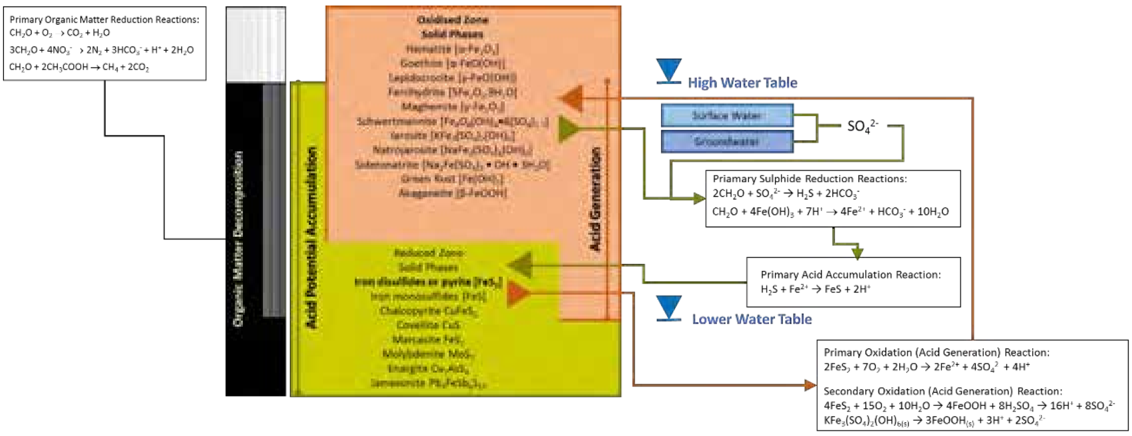
Graph 25 Conceptual linkages for system under anthropogenic influence

4.7.3 Summary of key geochemical processes occurring in Big Swamp and Reach 3 of Boundary Creek

Following completion of the data assessment a conceptual geochemical model (CGM) was development, which is summarised on Graph 26. In summary the key aspects of the CGM relevant to the project objectives are:

- Acid discharge occurred occasionally from Big Swamp under natural flow conditions and in the absence or limited pumping from the LTA.
- The decrease in baseflow contribution of groundwater from the LTA to Reach 2, Damp-land and possibly Big Swamp as a result of groundwater extraction from the Barwon Downs Borefield in combination with dry climatic conditions has resulted in a decrease in water table elevation within some 600,000 to 700,000 cubic metres of organic rich sediments that are present in Big Swamp and contain primary acid source minerals.
- The decrease in baseflow form groundwater contribution from the LTA and climatic conditions has resulted in a decrease in average and median flow on Reach 3 of Boundary Creek of between 2 to 6 ML/day.

- The decrease in water table elevation in the sediments in Big Swamp has resulted in the oxidation of primary source minerals and has increased the frequency and duration of acid impacts in Reach 3 of Boundary Creek as a result of acid discharge from Big Swamp. Since pumping from the LTA commenced the average and median pH in Reach 3 of Boundary Creek have decreased by between 1.6 to 2 pH Units.
- The acid impacts identified in Big Swamp appear to be the result of acid generated by oxidation of sulfide acid source minerals, particularly pyrite with some minor contributions by other di-sulfidic minerals if present.
- The sediments present in Big Swamp are primarily comprised of decomposing organic matter with limited other mineral content and those minerals present are generally resistant to weathering. Therefore, there is limited buffering capacity in Big Swamp for any acids generated by oxidation of sulfidic minerals.
- The primary sulfate attenuation process that could occurs in Big Swamp is related to reformation of the reducing conditions that results from organic matter decomposition in saturated environments. Based on the available data, this process appears to result in reduction of ferric iron to the ferrous species but there is limited information to suggest that sulfate reduction to sulfide is occurring. Therefore, the attenuation of acid in Big Swamp appears to be limited by insufficient sulfate being present to effectively from sulfide minerals that would attenuate to the net acidity remaining in the system.
- Secondary acidification processes are active in Big Swamp and Reach 3 of Boundary Creek, which further limits the ability of the swamp to limit the attenuation the sulfate.



Graph 26 Summarised conceptual geochemical model

The key geochemical processes and their influence on the key Solutes of Concern (SoC) associated with the acidification of sediments in Big Swamp and their fate and transport in solution within Big Swamp and Reach 3 of Boundary Creek are summarised in Table 4.

Table 4 Summary of geochemical processes and their effect of Solutes of Concern

Geochemical Process / Solute of Concern / Driver	Change in pH	Change in Oxidation / Reduction Potential	Sorption	Change in Ionic Strength
Alkalinity	Primarily driven by dissolved bicarbonate and carbonate. Change in pH affects dominance of these species and provides buffering capacity at more alkaline pH. Bicarbonate forms carbonic acid under low pH (<4.3), which also results in providing buffering capacity with respect to increase of pH.	Not directly affected by changes in redox conditions.	Generally does not participate directly in sorption reactions.	May increases overall alkalinity due to increased concentration of non-carbonate solutes.
Aluminium	Solubility primarily affected by pH, with highest solubility under acidic and alkaline conditions and lowest over a pH range 6.5 to 8.	Not directly affected by changes in redox conditions.	Generally not subject to sorption when pH is low (<4.5) but forms sorption sites as pH increases due to precipitation of Al-hydroxide and oxides.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competition for sorption sites.
Arsenic	Solubility is affected by pH, with highest solubility under acidic conditions and lower under neutral conditions.	As occurs in two primary oxidation states (3+ and 5+) in solution within surface and groundwater and is therefore sensitive to changes in redox conditions.	Sorbs strongly onto ferric iron hydroxide surfaces but is soluble when ferrous iron is stable in solution and subject to limited sorption under such conditions.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competition for sorption sites.
Copper	Solubility is affected by pH, with highest solubility under acidic conditions and lower under neutral conditions.	Cu occurs in two primary oxidation sates (1+ and 2+) in solution within surface and groundwater and is therefore sensitive to changes in redox conditions as the solubility of the redox species differs.	Readily sorbed onto clay minerals but shows limited sorption onto iron hydroxide and some organic matter and as such shows different sorption behaviour to other cations.	Effectiveness of sorption mechanisms is less affected by increasing salinity due to preference for specific sorption sites and ready preference sorption onto such sites when present.
Ferric Iron	Solubility is strongly affected by pH with solubility higher under strongly acidic conditions but decreasing rapidly as pH increases above 5.	Sensitive to changes in redox conditions, dominating the total iron concentration under oxidising conditions.	Generally not subject to sorption when pH is low (<3.5) but forms sorption sites as pH increases due to precipitation of Fe-hydroxide and oxides.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competion for sorption sites.

Geochemical Process / Solute of Concern / Driver	Change in pH	Change in Oxidation / Reduction Potential	Sorption	Change in Ionic Strength
Ferrous Iron	Solubility is strongly affected by pH with solubility higher under acidic conditions but decreasing rapidly as pH increases above 5.	Sensitive to changes in redox conditions, dominating the total iron concentration under moderate reducing conditions. Co-precipitates with sulfide as iron sulfide minerals form under strongly reducing conditions, forming primary acid source minerals.	Can sorb but significance is generally low when pH is low (<3.5) but even when sorbed can lead to subsequent acid formation when oxidised, forming retained acidity or co-precipitate with sulfide under strongly reducing conditions forming primary acid source minerals.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competition for sorption sites.
Lead	Solubility primarily affected by pH, with highest solubility under acidic and alkaline conditions and lowest under neutral pH.	Not directly affected by changes in redox conditions.	Generally not subject to sorption when pH is low (<4.5) but readily sorbs to cation sorption sites as pH increases.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competition for sorption sites.
Molybdenum	Solubility primarily affected by pH, with highest solubility under acidic and alkaline conditions and lowest under neutral pH.	Not directly affected by changes in redox conditions.	Generally not subject to sorption when pH is low (<4.5) but readily sorbs to cation sorption sites as pH increases.	Effectiveness of sorption mechanisms decreases with increasing salinity due to increased competition for sorption sites.
Sulfur	Not sensitive to changes in in pH but can be removed from solution by co-precipitation under more neutral pH.	Sensitive to changes in redox conditions due to the occurrence of multiple oxidation states in solution. The most common form is sulfate under oxidising conditions, with this species generally remaining soluble. Under strongly reducing conditions sulfide is the dominant species and is readily removed from solution by co-precipitation with inorganic cation, most commonly iron or emission as gaseous phase (HS^- and H_2S).	Generally not subject to sorption.	Generally not sensitive to salinity.

Geochemical Process / Solute of Concern / Driver	Change in pH	Change in Oxidation / Reduction Potential	Sorption	Change in Ionic Strength
Bacteriological Activity	Sensitive to pH, with metabolic rate decreasing with decreasing pH and insignificant at pH<4. Also sensitive to fluctuations in pH due to lag time in increasing metabolic rate in response to the occurrences of more favourable conditions. Metabolic activity most effective and efficient under stable and favourable pH conditions.	Sensitive to redox, with metabolic rate decreasing with changes in redox potential due to lag time in increasing metabolic rate in response to the occurrences of more favourable conditions. Metabolic activity most effective and efficient under stable redox conditions.	Metabolic activity not directly affected by sorption, but can decline when co-precipitation of sorbed phases occurs as a result of covering of the biofilms on mineral surfaces subject to mineral precipitate formation.	Some sensitivity to changes in salinity, with metabolic rate most effective and efficient under stable conditions.
Notes:	1. This summary is general in nature and no specific studies of the Big Swamp and Reach 3 of Boundary Creek environment have been undertaken to specifically study the site specific geochemical process affecting the fate and transport of the solutes of concern.			

5. Geochemical modelling

This section of the report describes the modelling package used (VISUAL MINTEQ) and outlines the input data and modelling methodology.

5.1 Modelling methodology

This section provides a general outline of the approach and methodology adopted for the development of the modelling for this project.

5.1.1 General considerations

Modelling a geochemical system requires a clear understanding of the objectives and purpose of the model with respect to the environmental problem to be addressed. This allows the modelling to focus on key issues and begin identifying those processes that are likely to be controlling the behaviour of a geochemical system. Clearly understanding the objectives and purpose also allows for selection of an appropriate approach. In general the objectives and purpose of geochemical modelling can be divided into four broad categories of increasing sophistication, with the level of sophistication adopted generally dependent on the limitations of the available data. The four categories of geochemical modelling can be summarised as follows:

	Modelling Category	Typical questions to be answered
1	Scenario Analysis	• Will reactive process be constrained by kinetic or transport considerations? • What is the maximum rate at which reactive buffering capacity can be depleted? • What are the bounding cases for the system in question?
2	Data Interpretation (laboratory/field)	• Are downstream concentrations the result of chemical attenuation or dilution? • What is the overall rate of a reactive process in the system? • Is local thermodynamic equilibrium a reasonable assumption? • Which reactive processes dominate fate and transport of solutes (solubility, complexation, sorption, colloid transport, etc.)?
3	Procedural Design	• Can the geochemical processes be reliability simulated to support development of a solution to the environmental problem? • Can the geochemical processes be quantitatively simulated to support the design of the remediation system or rehabilitation method that solves the environmental problem?
4	Performance Assessment / Risk Analysis	• At what rate and over what time will an environmental problem occur and persist? • Will the environmental problem pose an unacceptable risk to the beneficial uses of the environment and over what period will this risk to beneficial uses persist at an unacceptable rate? • Can the effectiveness of the remediation or rehabilitation solution developed be reliably and defensibly simulated by the model?

The majority of environments in which geochemical processes occur are very complex and the features that characterise the hydrological, hydrogeochemist and chemical properties of such systems are also subject to a great deal of spatial and temporal variance.

While geochemical models and theoretically simulate large and complex systems doing so requires a large data set of spatial and temporal data supported by extensive laboratory and flied experimental information. Therefore, the vast majority of geochemical modelling that is conducted required a number of simplifying assumptions and incorporate less details as this will provide results that are more transparent and thereby more easily understood than a complex model.

In general any geochemical model is only truly useful as a predictive tool if the results produced by the model can be verified by data collected form the environment being simulated. In reality, this objective is difficult to achieve for simple models and almost impossible for complex models due to the complexity of natural systems, the inadequacy of field data, and uncertainty relating to how the system will change over time. As a result, any geochemical model can be considered as being constrained by definition and represents a simplification of reality. Therefore, any results produced by the model must be considered as a heuristic tool rather than a source of absolute quantitative fact.

Notwithstanding these limitations of geochemical models, the results produced can provide a degree of predictive success when applied as sub-units within a larger stochastic framework where we can estimate the probability that a forecast may be judged to be true or false. The stochastic approach sits at the core of risk assessment and as such proves a useful means of supporting decision making in the context of uncertainty and lack of specific knowledge of the environment being studied.

In situations where the level of detail required is uncertain from the outset, or situations where there is insufficient data to support the development of a fully representative geochemical model, the most rational and defensible approach is to simplify the system to some specific scenarios for which there is sufficient data to allow for a defensible simulation to be made. The first step in the development of the modelling approach is to assess the CGM in the context of the specific environmental process that requires simulation.

The objective of the CGM is to allow identification of those geochemical processes that are of primary importance and neglect those that are of only minor importance and then develop a geochemical model that considers the primary processes. All geochemical models are based upon principles of mass conservation (mass balance accounting). Mass is neither created nor destroyed in the system, but transferred between solid, aqueous, and gaseous phases.

Geochemical models fall into two distinct categories:

1. Models that do not consider transport processes are referred to as geochemical reaction models.
2. Models that consider both transport processes and geochemical reactions are referred to as coupled transport and reaction models.

5.1.2 Conceptual and mathematical formulation of modelling approach

The starting point of any geochemical model development is the CGM, such that one described in Section 4. Geochemical Reaction Models (GRM) are mathematically distinct from Coupled Transport and Reaction Models (CTRM). However, GRMs are not conceptually decoupled from transport considerations and extensively used to evaluate the chemistry of surface and groundwater systems where transport play an important role in the fate and transport of solutes of concern.

GRMs can be used to study geochemical changes and processes that explain the observed changes in solute of concern concentration along flow path. In such uses the GRM is used as an inverse model that attempts to establish reaction mechanisms that explain measured chemical changes that occur as water composition evolves along a flow path. Inverse application of a GRM allows for verification of the model simulation results against the field data collected, which allows for a direct assessment of the robustness and defensibility of the models ability to simulate the geochemical processes of interest occurring in the environment being studied.

GRM’s can also be used predict future solute composition in a surface or groundwater as a result of geochemical process considered to be active or to occur at some future point in time. This application of GRMs is considered forward modelling. Forward modelling is generally used to support design studies for the development of remediation or rehabilitation solutions to environmental problems.

The third GRM type is the reaction path model or mass transfer model. Reaction path models can simulate dynamic systems through simulation of changes in dissolved and solid phase mineral composition changes over time with respect to incremental dissolution of target minerals. Reaction path models calculate the dissolved phase mineral composition and secondary mineral precipitation in response to dissolution of a specified target mineral to maintain equilibrium conditions. These model types are used to evaluate the chemical weathering processes that occur in natural systems (diagenetic processes) or to assess the geochemical processes with rehabilitation of environmental problems that involve the use of inorganic treatment minerals. As reaction path models simulate changes through dissolution of primary minerals in a stepwise manner, the variable of time is not included implicitly in the calculations. However, where kinetic reaction rate data is available his can be utilised to relate reaction progress to time and allow calculation of dissolved phase mineral composition as a function of time in a kinetic geochemical reaction model.

All geochemical models require that the reactions included in the simulation must be defined in terms of a set of basis components, which constitute the minimum set of fundamental species that are required to describe all the free and derived species (complexes) present in the aqueous solution.

Most GRM’s are based upon an approach in which the conservation of total component concentrations is combined with a description of chemical equilibrium. Chemical equilibrium may be computed in terms of Gibbs’ free energy minimisation or in terms of mass action equations involving equilibrium constants. The method of Gibbs’ free energy minimisation is generally regarded as being more mathematically robust than the method using equilibrium constants. However, due to a lack of reliable and internally consistent Gibbs’ free energy data geochemists have tended to favour the equilibrium constant method and the overwhelming majority of programs available today are therefore based upon this approach.

5.1.3 Numerical solution procedures

Geochemical model whether GRMs or CTRMs utilise mathematical formulation (involving equilibrium constants) that create a system of non-linear algebraic equations that are solved using a numerical methods. Most GRMs and CTRMs use a modified Newton-Raphson technique to solve the equations as this represents a fast and reliable procedure in most situation that are simulated. Given that the numerical solution utilises an iterative method, convergence problems may arise if the initial values of unknown variables are not sufficiently close to the equilibrium values. Most current programs incorporate heuristic methods to overcome convergence problems.

Other issues that can arise in numerical simulations can occur in situations where the modelling involved systems that contain multiple phases of the same constituents (i.e. containing gases or minerals as well as water) and where the number of phases exceeds that allowed by the Gibbs' Phase Rule, which can lead to development of a singular matrix in the mathematical formulation of the model and results in failure to find a solution. The best means to avoid the formation of a singular matrix is the development of a robust and defensible CGM and carefully selected input parameters.

5.1.4 Uniqueness of geochemical model predictions

An important consideration when using geochemical modelling results to support decision making is uniqueness of the solution provided by the numerical simulation. In general, numerical solutions to the general multicomponent equilibrium problem are unique under conditions of ideality (i.e. dilute concentrations) when the problem is posed in terms of mass balance constraints only. Therefore, this only corresponds to problems where the equilibrium speciation is to be calculated for a solution of known bulk composition.

However, in many situations the simulations mass balance constraints (constraints on fluid bulk composition) are combined with mass action constraints. Mass action constraints include fixed pH, pe, and individual species activity, as well as assumptions of gas and mineral equilibrium. Therefore, in simulations that involve mixed mass balance and mass action constraints the consequent solutions are not always unique even in thermodynamically ideal systems.

This can result in multiple solutions that meet to the objectives of the study and satisfy the problem under study equally well in a mathematical sense. However, some non-unique solutions may not be physically realistic. The mathematical solutions that are not physically realistic are often referred to as metastable equilibria.

Therefore, care is required in interpretation of results derived by model simulations that have non-unique solutions and reference back to the CGM is required in such situations. Under conditions of non-ideality, the uniqueness proofs are also found to be invalid as even an unrealistic and / or non-representative solution can be validated by field data.

5.1.5 Processes simulated

Most numerical simulation packages allow for precipitation and dissolution of mineral, dissolution of gases, as well as the possibility of fixing the activity of specified. Reaction types that can be simulated by the numerical models include complexation, ion-exchange, redox reaction, precipitation/dissolution, surface complexation, and other kinds of adsorption.

However, the ability of the numerical model to simulate all processes that the model is capable of considering is usually limited by the quality and quantity of the thermodynamic data available for carrying out reaction calculations. Geochemical simulation models contain databases of relevant aqueous, gaseous, and mineral phase reactions, select mineral or gaseous phases that are likely to precipitate and include them in the calculations. Some geochemical models can simulate titrations, evaporative processes, mixing of different solutions, or perform isotope mass balances. Mass balances based upon radiogenic isotopes are used primarily for estimating the age of groundwater. Geochemical models that simulate mass balances that consider stable isotopes are used to understand the source of a water, or processes that may have influenced the chemical properties of the water over time.

In general application models calculate the activities of aqueous species using the following equations:

- Davies equation
- Debye-Hückel equation
- The extended Debye-Hückel equation

These equations limit the applicability of geochemical model simulations to solutions that have an ionic strengths less than or equal to that of seawater. For simulation of highly saline solutions, such as brines, the Pitzer method for activity calculation can be used. However, simulation of highly saline solutions is limited by a lack of reliable data, particularly for redox sensitive species.

Some geochemical models include numerical routines to simulate kinetically mediated geochemical processes. However, in order to simulate kinetic processes in a robust and defensible manner site specific kinetic data is required and in some instances the kinetic reaction equations themselves need to be entered into the model. Therefore, the applicability of kinetic reaction simulations is generally limited by a lack of relevant representative data. Kinetic reactions models use different numerical methods to those applied to equilibrium systems.

5.1.6 Summary of modelling approach adopted

For this project the geochemical modelling was completed using the following approach:

- Qualitative assessment of geochemical processes to be considered in the model based on the conceptual geochemical model.
- Adoption of an equilibrium numerical simulation approach in the absence of sufficient data to inform a kinetic numerical simulation approach.
- Adoption of the Debye-Hückel equation for the numerical equilibrium simulation due to the greater stability of the numerical equation solution for the solutes present in the surface water, pore water and groundwater samples collected and analysed.
- Adoption of an iterative simulation approach for the study of the geochemical processes associated with the potential remediation and rehabilitation options under consideration.
- Developing a model for Big Swamp based on the geochemical processes relevant for the management and remediation options under consideration for rehabilitation.
- Developing a model for Reach 3 of Boundary Creek based on the geochemical processes relevant for the management and remediation options under consideration for improvement of the environmental condition for Boundary Creek downstream of Big Swamp.

A range of hydrogeological and hydrogeochemical conditions as anticipated at the site, or published in the scientific literature, were used to create the models. The models used the maximum measured solute concentrations and utilised a thermodynamic equilibrium model (MINTEQ).

5.2 Modelling package

The purpose of the VISUAL MINTEQ modelling package is to provide a tool to assist in the assessment of inorganic compounds and heavy metals in groundwater environments. The model assists in establishing which geochemical processes may be occurring in a geological system and provide insight into the fate of dissolved inorganic solutes present in surface and groundwater environments. The model allows for the most significant chemical reaction and attenuation processes, including:

- Precipitation and dissolution of minerals: Precipitation is the process by which dissolved ions combine via chemical process to form solids. This removes dissolved ions from solution. Dissolution is the process by which solids dissolve, adding dissolved ions to solution.
- Sorption of dissolved ions: Electrically charged surfaces occur on solids in virtually all groundwater systems. In addition, charged dissolved ions occur in the groundwater. Depending on the groundwater environment, the charged surfaces attract positively or negatively charged, dissolved ions. This process removes the charged dissolved ion from solution on a permanent or temporary basis. Sorption processes are reversible, should the environmental condition of groundwater vary. This reversibility can lead to retardation of many dissolved ions, by temporarily removing them from solution.
- Oxidation reduction processes: A number of dissolved ions can occur in more than one oxidation state. For some of these their solubility and / or charge can depend on the oxidation state and therefore control the mobility of that ion.

The data required to predict the equilibrium composition consists of a chemical analysis of the geochemical system to be modelled. This provides total dissolved concentrations for the solutes of interest and the associated geochemical processes that govern their behaviour in the aquatic environment, possibly (but not necessarily) including pH, Eh, or the partial pressures of one or more gases as well.

MINTEQ has an extensive thermodynamic database that is adequate for solving a broad range of problems without need for additional user-supplied equilibrium constants.

The application of a geochemical equilibrium model to an environmental problem involves four steps:

1. Formulate one or more precise and relevant chemical questions that can be answered if one knows the equilibrium composition of the system.
2. Pose the chemical questions to the model in terms of those symbols and formats that it is programmed to understand and from which it may interpret a mathematical problem.
3. Use the geochemical equilibrium model software (in this case, MINTEQ) to solve the mathematical problem.
4. Interpret the output from the model in terms of the original environmental problem.

The first step is almost always the most difficult; the ability to do this well is not obtained from reading a user manual, but by understanding the hydrogeochemical processes active in the groundwater system being studied. Therefore the development of a sound and defensible conceptual geochemical model is a prerequisite to for the development of representative numerical simulation models.

5.3 Input data

The model was used to assess the geochemical processes that are likely to be associated with the proposed management and remedial options under consideration for Big Swamp and Reach 3 of Boundary Creek. As surface and groundwater sampling to date is limited, statistical analysis of the data to develop a defensible range of input parameter for the models could not be undertaken. As such, a conservative approach using maximum values was adopted to develop the model input parameters. MINTEQ uses the environmental parameters including pH and oxidation reduction potential as well a major cation / anion and trace element information to establish solute solubility, oxidation reduction reactions and adsorption effects. Geochemical processes for Big Swamp and Reach 3 of Boundary Creek were assessed separately using the available groundwater data for Big Swamp and surface water data for Reach 3 of Boundary Creek included in the Jacobs (2018) report.

The following approach was used for the modelling:

1. Develop model input data list, refer to Table 5 and Table 6
2. Assess validity of equilibrium assumption by running the model.
3. Assess metal mobility in the various environmental conditions identified in the area around the site.

Model input data

The model input data for the Big Swamp and Reach 3 of Boundary Creek Models is summarised in Table 5 and Table 6.

Table 5 Summary of MINTEQ input data for Big Swamp Model

Parameter	Value / range	Comments
Environmental		
Temperature	15ºC	Based on data from Jacobs (2018) report. Cooler temperatures would result in higher solubility of carbonate minerals and lower solubility for non-carbonate minerals.
Activity Co-efficient Estimation	Debye–Hückel Equation	The most applicable equation for calculated TDS
pH	Calculated	This parameter was not fixed and was calculated by the model based on the solute concentration and redox conditions.
Eh	900 mV	Based on the value feasible with all solutes remaining in solution. This input parameters was established by adjustment until all solutes remained in solution.
Dissolved ions		
Ammonia	0.41 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Chloride	25.9 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.

Parameter	Value / range	Comments
Ferric Iron	10.2 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Ferrous Iron	17.9 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Fluoride	0.01 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrate	0.001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrite	0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrogen	0.05 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Phosphate	0.002 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Sulfate	41.6 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Dissolved Organic Matter	1.40 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Calcium	9.23 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Magnesium	7.40 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Potassium	0.33 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Sodium	12.61 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Carbonate	0.96 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Aluminium	4.81 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Arsenic	0.005 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Cadmium	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Chromium	0.0004 mmol/L	Measured in MW7 (May 2011)

Parameter	Value / range	Comments
Copper	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Lead	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Manganese	0.0455 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Mercury	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nickel	0.0147 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Zinc	0.0229 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Adsorption Reaction Models	-	Due to a lack of data, adsorption processes were not included in the model. The relative importance of sorption processes can be assessed by a process of elimination using the other processes including solubility and oxidation reduction reactions. Overall, sorption was not considered to a significant geochemical process with respect to the modelling objectives
Gasses at Fixed Partial Pressures	-	Due to a lack of relevant data processes involving gasses with fixed partial pressures, these were not considered. Given that the focus of the model is the assessment of acid generation and attenuation processes, this omission is not considered to have a significant impact on model results.
Oxidation Reduction Reactions	Fe^{2+}/Fe^{3+} NO_2^-/NO_3^- NH_4^+/NO_3^- HS^-/SO_4^{2-} H_3AsO_3/AsO_4	These were considered to be the most relevant and significant oxidation and reduction processes that could affect the acid generation and attenuation processes.

Notes:

1. Bicarbonate entered as equivalent amount of carbonate ion.
2. Chromium entered as equivalent amount of CrO_4^{2-} ion.

Table 6 Summary of MINTEQ input data for Reach 3 of Boundary Creek

Parameter	Value / range	Comments
Environmental		
Temperature	15°C	Based on data from Jacobs report. Cooler temperatures would result in higher solubility of carbonate minerals and lower solubility for non-carbonate minerals.
Activity Co-efficient Estimation	Debye–Hückel Equation	The most applicable equation for calculated TDS
pH	Calculated	This parameter was not fixed and was calculated by the model based on the solute concentration and redox conditions.
Eh	300 mV	Based on the value feasible with all solutes remaining in solution. This input parameters was established by adjustment until all solutes remained in solution.
Dissolved ions		
Ammonia	0.72 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Chloride	21.4 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Ferric Iron	0.5 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Ferrous Iron	1.79 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Fluoride	0.01 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrate	0.0002 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrite	0.001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nitrogen	0.028 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Phosphate	0.002 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Sulfate	7.29 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Dissolved Organic Matter	0.33 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.

Parameter	Value / range	Comments
Calcium	2.99 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Magnesium	3.00 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Potassium	0.15 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Sodium	6.96 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Carbonate	2.55 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Aluminium	2.78 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Arsenic	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Cadmium	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Chromium	<0.0001 mmol/L	Measured in MW7 (May 2011)
Copper	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Lead	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Manganese	0.0051 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Mercury	<0.0001 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Nickel	0.0037 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Zinc	0.0229 mmol/L	Maximum value measured in the two groundwater sampling rounds conducted.
Adsorption Reaction Models	-	Due to a lack of data, adsorption processes were not included in the model. The relative importance of sorption processes can be assessed by a process of elimination using the other processes including solubility and oxidation reduction reactions. Overall, sorption was not considered to a significant geochemical process with respect to the modelling objectives

Parameter	Value / range	Comments
Gasses at Fixed Partial Pressures	-	Due to a lack of relevant data processes involving gasses with fixed partial pressures, these were not considered. Given that the focus of the model is the assessment of acid generation and attenuation processes, this omission is not considered to have a significant impact on model results.
Oxidation Reduction Reactions	Fe^{2+}/Fe^{3+} NO_2^-/NO_3^- NH_4^+/NO_3^- HS^-/SO_4^{2-} H_3AsO_3/AsO_4	These were considered to be the most relevant and significant oxidation and reduction processes that could affect the acid generation and attenuation processes.
Notes: 3. Bicarbonate entered as equivalent amount of carbonate ion. 4. Chromium entered as equivalent amount of CrO_4^{2-} ion.		

Limited environmental parameter (pH, Eh) data was available for some monitoring rounds and both showed variability over the monitoring period. Major ion data was only available for the May and August monitoring events reported by Jacobs (2018). Therefore, in interpreting the model results it must be acknowledged that:

- The data set does not reflect all temporal changes in environmental parameters such as pH, Eh and temperature.
- That the data set does not show all parameters at 'one moment in time' for sequential monitoring rounds conducted over several years.

Both of these factors can increase the uncertainty around the model results generated and have to be factored into the data interpretation and conclusions drawn.

5.3.1 Validity of equilibrium assumption

An initial run of the Big Swamp and Reach 3 Boundary Creek data indicates that most soluble mineral phases would remain in solution, with some aluminium and iron hydroxides predicted to precipitate. Mass distribution output show 100% of sulfate remains in solution and with the majority as the dissolved iron remaining in solution present in ferrous oxidation state. However, the model suggests that some aluminium and the majority of ferric iron would precipitate. This indicates that the acid is being exported from Big Swamp as the precipitation of these minerals would lead to secondary acidification processes occurring in Reach 3 of Boundary Creek.

5.4 Modelling scenario for management and remediation option assessment

This section outlines the modelling methodology adopted to assess the management and remediation options proposed for Big Swamp and Reach 3 of Boundary Creek. The modelling results are discussed in the subsequent Section 5.5

5.4.1 Lime dosing of soils in Big Swamp

This model utilised the Big Swamp Thermodynamic model to assess the geochemical processes that would result from addition of a neutralising agent into the soils of Big Swamp. The addition of a neutralising agent and its effect on pore water and groundwater geochemistry was simulated through the addition of lime as a finite solid and progressively increasing the amount of available lime until further addition did not produce further predicted changes in geochemistry.

The results of this model are presented in Appendix A.

5.4.2 Return of reducing conditions in Big Swamp

This model utilised the Big Swamp Thermodynamic model to assess the geochemical processes that would result from re-saturation of the swamp sediments. Re-saturation was simulated by using this model to calculate the pH and Eh at which all solutes remain in solution and then progressively decreasing the Eh to simulate the re-formation of reducing conditions and assessing the geochemical processes that may be activated. The modelling steps adopted for this assessment were as follows:

- Eh 900 mV, base model with all solutes in solution
- Eh 800 mV, reduction step 1
- Eh 700 mV, reduction step 2
- Eh 600 mV, reduction step 3
- Eh 500 mV, reduction step 4
- Eh 400 mV, reduction step 5
- Eh 300 mV, reduction step 6
- Eh 200 mV, reduction step 8
- Eh 100 mV, reduction step 9

The results of this model are presented in Appendix B.

5.4.3 Lime dosing of water discharge from Big Swamp into Reach 3 of Boundary Creek

This model utilised the Reach 3 of Boundary Creek Thermodynamic model to assess the geochemical processes that would result from addition of a neutralising agent into the surface water discharge from Big Swamp. The addition of a neutralising agent was simulated through the addition of lime as a finite solid and progressively increasing the amount of available lime until further addition did not produce further predicted changes in geochemistry.

The results of this model are presented in Appendix C.

5.4.4 Anaerobic treatment system for water discharge from Big Swamp into Reach 3 of Boundary Creek

This model utilised the Reach 3 of Boundary Creek Thermodynamic model to assess the geochemical processes that would result from passing the surface water discharging from Big Swamp through a reducing zone in a vertical flow treatment bed. Treatment was simulated by using this model to calculate the pH and Eh at which all solutes remain in solution and then progressively decreasing the Eh to simulate the re-formation of reducing conditions and assessing the geochemical processes that may be activated. The modelling steps adopted for this assessment were as follows:

1. Eh 300 mV, base model with all solutes in solution
2. Eh 250 mV, reduction step 1
3. Eh 200 mV, reduction step 2
4. Eh 150 mV, reduction step 3

The results of this model are presented in Appendix D.

5.4.5 Summary of modelling approach for key geochemical processes for remediation and rehabilitation

The modelling of the key geochemical processes associated with the remediation and rehabilitation options under consideration for Big Swamp and Reach 3 of Boundary Creek are summarised in Table 7.

Table 7 Summary of key geochemical processes being modelled

Element \ Simulation	Lime Dosing of Soil	Return of Reducing Conditions	Lime Dosing of Water Discharge	Anaerobic Treatment System
Model Type	GRM	GRM	GEM	GEM
Model Application	Fw	Fw	Fw	Fw
Solute Activity Simulation Equation	DH	DH	DH	DH
Ionic Strength	C	C	C	C
Charge Balance Error	C	C	C	C
pH	C	F	C	F
Eh	F	C	F	C
Sorption	NI	NI	NI	NI
Speciation	C	C	C	C
Redox Couples	C	C	C	C
Precipitation	C	C	C	C
Gaseous Phases	NI	NI	NI	NI
Finite Solids	C	NI	C	NI

Notes:
1. C: Calculated
2. DH: Debye–Hückel Equation
3. Eq: Equilibrium
4. F: Fixed
5. Fw: Forward
6. GRM: Geochemical Reaction Model
7. Iv: Inverse
8. Kn: Kinetic
9. NI: Not Included

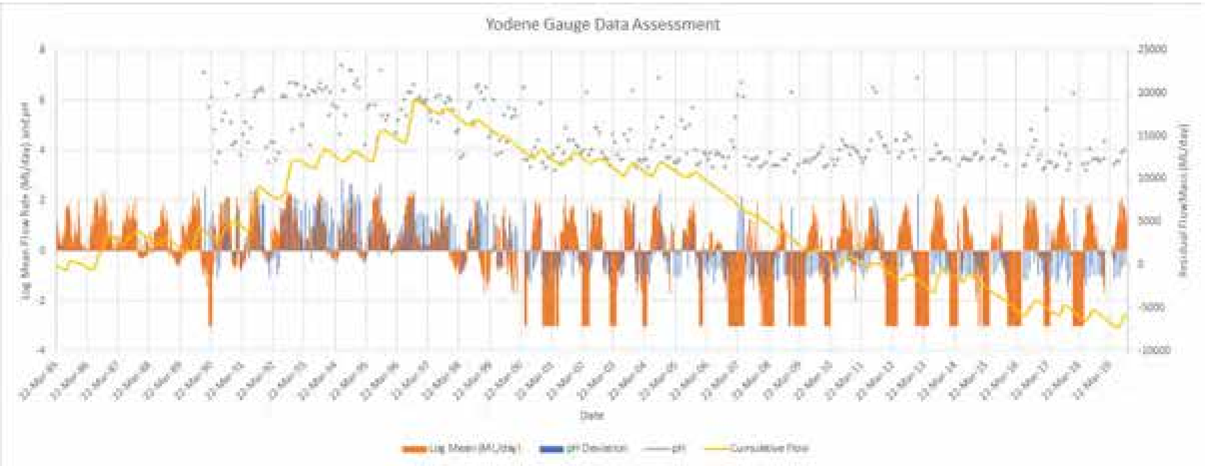
5.5 Modelling results and discussion

As set out in Sections 1.1 the primary objective of the geochemical modelling was to assist in evaluation of potential management and remediation options that would improve the environmental values of Big Swamp and Reach 3 of Boundary Creek. This section of the report discusses the modelling results in the context of the available data and the management and remediation options selected for further evaluation.

5.5.1 Option O1: True 'do nothing'

Under this option no measures would be taken to meet the project objectives and would rely solely on natural conditions to manage the acidification processes. As Big Swamp and Reach 3 of Boundary Creek currently receive an artificially introduced additional flow of 2ML per day, the historical information on flow and pH, gathered at the Yeodene Gauge was used to assess this option.

For this option the Net Acidity remaining in Big Swamp would continue to leach into the surface water within Big Swamp and discharge into Reach 3 of Boundary Creek. Therefore, use of the historical information available for the Yeodene Gauge was considered to provide relevant data for the evaluation of this option.



Graph 27 Summary of Yeodene Gauge flow and pH data

Assessment of the Yeodene Gauge data showed that frequency of occurrences of pH below the long term average of 4.6 increased from early 2000 (refer to Graph 27). The graphical representation of the flow and pH data shows that the frequency of occurrence of pH below the long term average increases after early 2000. This change in frequency appears to coincide with a decline in flow. However, flow decline does not appear to be the only controlling factor for the occurrence of low pH. There are a number of instances where low flow did not coincide with low pH and vice versa.

A statistical assessment of the frequency of pH below the long term average, <3.5 and 4 was undertaken and the results are summarised in Table 8.

Table 8 Summary of long term pH data trend

Period	% pH < long term average (4.6)	% pH < 3.5	% pH < 4
1985 to 2000	19%	0%	9%
2000 to Jul 2016	84%	10%	60%
Post Jul 2016	97%	31%	78%

The results of the three dimensional net acidity model were utilised to assess the total acidity (retained, actual and potential) that remains in Big Swamp (refer to Section 4.1.1) and could be mobilised and enter Reach 3 of Boundary Creek. Based on the Three-Dimensional Model results, the average net acidity present in the swamp sediments that could remain unsaturated was evaluated. However, given the limited data available and the uncertainty in the sediment density, the estimated acid volume is subject to considerable uncertainty. Considering these limitation the sediments that host the net acid mass considered to potentially remain in the unsaturated part of Big Swamp is around 650,000 m^3 ± 50% based on the soil volumes, net acidity and the predicted water table elevations.

The time series pH data was used to evaluate the potential amount of acid leaving Big Swamp and migrating into Reach 3 of Boundary Creek down-stream of the swamp. Given the limited data available and the variance in the measured pH the following acid mass flux into Reach 3 of Boundary Creek are subject to considerable uncertainty:

- Acid Flux Leaving Swamp: long term average ~7.2 t/day ± 50% based on pH data recorded Yeodene gauge from 1990 to date.
- Acid Flux Leaving Swamp: Pre 2000 average ~6 t/day ± 50% based on pH data recorded Yeodene gauge from 1990 to 2000.
- Acid Flux Leaving Swamp: Post 2000 average ~7.5 t/day ± 50% based on pH data recorded Yeodene gauge from 2000 to date.

Based on the net acid mass that potentially remains in the unsaturated zone of Big Swamp, the potential mass flux rate into Reach 3 of Big Swamp and the occurrence of asymptotic conditions as a result of the relatively slower oxidation rate of primary acid source minerals, acid flux from the swamp could occur for more than 300 years.

As a final step in the assessment of this remediation option, the variance in pH data in the temporal monitoring data and the relationship to measured acidity was used to evaluate the range in mass flux rate from Big Swamp into Reach 3 of Boundary Creek. Based on the limited data available and the limited temporal frequency the following mass flux rates are subject to considerable uncertainty:

- Low range Acid Flux: 0 t/day
- Median Acid Flux: 1 t/day
- Average Acid Flux: 7.3 t/day
- High range Maximum Acid Flux: 421 t/day

Option 1 was utilised as the baseline scenario as this option represented a passive approach that relied only on natural attenuation processes to deal with the acid generated and solutes of concern mobilised. The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15 (which includes a comparison of the effectiveness of all options).

5.5.2 Option O2: Implementation of contingency measures

This option would involve increasing the flow volume into Boundary Creek up-stream of Big Swamp in order to increase the water table elevation in the sediment in Big Swamp. This primary aim of this option is to reduce acid discharge from Big Swamp into Reach 3 of Boundary Creek by increasing the moisture content in the sediments in the swamp that contain primary acid source minerals and reduce acid generation through primary acidification processes. This option is currently being partially implemented through the addition of 2ML/day in surface water flow up-stream of Big Swamp in Reach 1 of Boundary Creek.

Therefore, the effectiveness of this option for the 2ML/day additional flow can be evaluated using the existing recent monitoring data available for the Yeodene Gauge.

Under this option (and to address Options O7 and O8) Jacobs developed two surface water volume addition scenarios and two different surface water flow configurations for each flow scenario were considered, as set out in Section 4.1.1.

For the evaluation of this option as well as Options O7 and O8, the results of the three dimensional net acidity model were utilised to assess the total acidity (retained, actual and potential) that remains in the sediments of Big Swamp and could be mobilised through primary acidification processes and enter Reach 3 of Boundary Creek under the scenarios set out in Section 4.1.1. Based on the model results, the average net acidity present in the swamp sediments that could remain unsaturated was evaluated. However, given the limited data available and the uncertainty in the sediment density, the estimated acid volume is subject to considerable uncertainty. Considering these limitation the sediments that host the net acid mass considered to potentially remain in the unsaturated part of Big Swamp under the scenarios considered are:

- 2ML Day and no Barrier: 650,000 m^3 ± 50% depending on density assumption.
- 2ML Day with Barrier: 645,000 m^3 ± 50% depending on density assumption.
- 20ML Day with Barrier: 465,000 m^3 ± 50% depending on density assumption.

The results for the geochemical modelling scenario for the return of reducing conditions in Big Swamp described in Section 5.4.2 were not used for evaluation of this option due to the availability of field data from the Yeodene Gauge, which was considered preferable to using the projections of a forward GRM.

The time series pH data for the Yeodene Gauge was used to evaluate the potential amount of acid leaving Big Swamp and migrating into Reach 3 of Boundary Creek down-stream of the swamp under various real and simulated flow conditions.

Given the limited data available, the variance in the measured pH and the limited number of modelling scenarios, the following acid mass flux from Big Swamp into Reach 3 of Boundary Creek though surface water flow for this option are subject to considerable uncertainty:

- Acid Flux Leaving Swamp: Post Jul 2006 average ~7.2 t/day ± 50%

Based on the net acid mass that potentially remains in the unsaturated zone of Big Swamp under the two flow scenarios as set out in Section 4.1.1, the potential mass flux rate into Reach 3 of Big Swamp after July 2006 and the potential for asymptotic conditions to occur due to limitations in oxidation rates for potential acid generating primary source minerals, acid flux from the swamp could occur for:

- 2ML Day and no Barrier: 100 years ± 50% depending on density assumption and mass flux variance.
- 2ML Day with Barrier: 80 years ± 50% depending on density assumption and mass flux variance.
- 20ML Day with Barrier: 50 years ± 50% depending on density assumption and mass flux variance.

A key limiting factor in the assessment of this option is the limited amount of temporal data from relevant monitoring points that is available, which results in any source mass, mass flux and timeframes evaluated being subject to considerable uncertainty.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.3 Option O3: Direct treatment of soils with neutralising agents

This option would involve placement of a neutralising agent, such as granular lime, onto the surface of the swamp sediments to provide neutralising capacity to Big Swamp. This options would represent the lowest cost means of adding neutralisation capacity to the sediments in Big Swamp and target primarily dissolved phase acidity in the Surface Water system of Big Swamp.

The addition of lime would result in dissolution of CaO and / or $Ca(OH)_2$, the common mineral constituents of lime. Dissolution of lime is described by the following reactions:

$$CaO_{(s)} + H2O_{(l)} \rightleftharpoons Ca(OH)_2$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$$

The release of hydroxide into solution would result in an increase in pH and the addition of solid lime to the sediment surface would increase the pH of the shallow sediments in the swamp.

Initially the rate of pH increase will be limited as the rapid solubilisation of Retained Acid and Actual Acid will occur at a similar or higher rate than the lime dissolution rate. Consequently, while the lime dissolution occurs there are likely to be acid flush events, although at a lower magnitude than if lime was not added.

Once the majority of the retained and actual acid is flushed, pH of the surface soils is likely to increase significantly and remain high until the potential acid generating primary acid forming materials that remain are flushed. This is due to the oxidation rate of disulfide minerals being slower than the lime dissolution rate.

However, as the pH increases ferric ion solubility decreases and precipitation of iron chloride hydroxide occurs, which removes hydroxide from solution, as defined by the following equation.

$$Cl^- + Fe^{3+} + 2OH- \rightleftharpoons ClFe(OH)_{2(s)} \text{ (or straight precipitation of } Fe(OH)_{3)}$$

To evaluate this option the Lime Dosing GRM described in Section 5.4.1 was utilised. This iterative dissolution model provided predictions of pH and solute of concern changes in response to the stepwise addition of lime as a finite solid. The effectiveness of the lime dosing was assessed by review of the predicted pH and dissolved phase calcium concentration to identify an effective dosing rate to deal with acid present in the surface waters within Big Swamp.

Based on the predicted calcium concentration in solution after lime dissolution (0.01 mol/L) being similar to the measured ferric iron concentration in the swamp (0.001 to 0.011 mol/L), much of the pH increase gained by lime dissolution is removed by precipitation of ferric iron hydroxides and chlorides, which consume the buffering capacity added, without necessarily also buffering the acid generated by the primary acidification processes, as illustrated in the equations included above. The thermodynamic modelling results indicated that pH increase in solution is largely off-set by precipitation of ferric iron minerals.

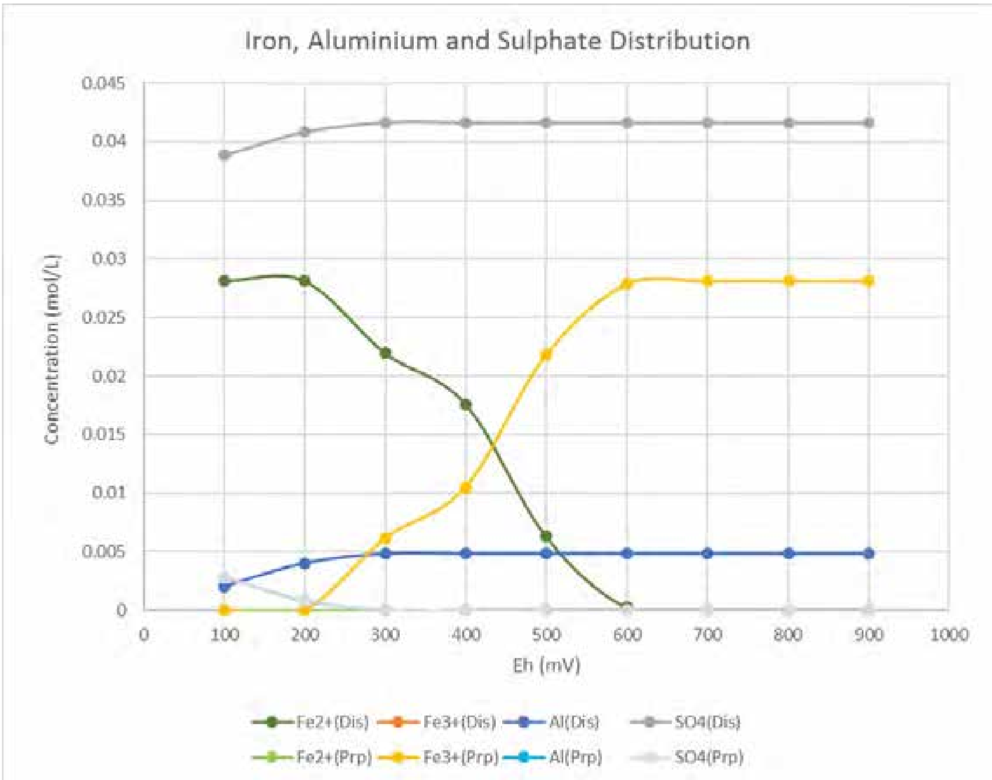
5.5.4 Option O7: Flooding of Big Swamp

Under this option a barrier would be built at the down-stream end of Big Swamp to re-flood the swamp (i.e. permanently return to a wetland). The primary aim of this option is to limit further oxidation of potential acid forming primary source minerals through reformation of dominantly reducing conditions in the swamp sediments by increasing moisture content through raising the water table elevation. The primary geochemical processes targeted by this option is the reduction of ferric iron and sulfate, which intends to attenuate acid through precipitation of dominantly iron sulfide minerals and return the swamp to an acid sink.

To evaluate this option the Return of Reducing Conditions GRM for Big Swamp described in Section 5.4.2 was utilised. This iterative reduction model provided predictions of solute of concern changes in response to the stepwise decreases in Eh. The effectiveness of the re-saturation was assessed by review of the predicted inorganic solute phase concentration to identify effectiveness of the option in attenuating solutes of concern and increase pH in the surface water, pore water and groundwater of Big Swamp.

Based on the GRM forward simulation, re-saturation of the sediments in Big Swamp is anticipated to trigger the following geochemical processes:

- The swamp sediments contain high amounts of organic carbon so there should be sufficient carbon source to form and maintain reducing conditions upon re-saturation for the foreseeable future.
- The results of the thermodynamic model based on the staged decrease of Eh support the preliminary results of the Monash study. The model predicted that once reducing conditions dominate the ferric iron present is reduced to ferrous iron and enters solution, while sulfate reduction does not appear to occur to any level of significance. The only removal of sulfate from solution as suggested in the model is precipitation of Aluminium Sulfate. Assessment of the model results showed that solid phase ferric iron would dominate the under the highest oxidising potentials but as reducing conditions form ferric iron is reduced to the ferrous form, which then enters solution. Aluminium would also remain in solution under oxidising and mildly reducing conditions, but as reduction proceeds aluminium solubility decreases, with around 60% of the dissolved aluminium and 7% of dissolved sulfate removed from solution respectively. The solubility of iron, aluminium and sulfate over the modelled Eh range is summarised on Graph 28.



Graph 28 Summary of iron, aluminium and sulfate concentrations

The model results suggest that the single most significant limitation to re-formation of acid forming processes through precipitation of iron sulfide minerals is the limited amount of dissolved sulfate in the swamp and the limitation imposed by a lack of effective flushing of the carbonate produced by the reduction of sulfate. This lack of sufficient sulfate for reduction to sulfide to facilitate precipitation of iron sulfides will limit the attenuation of acid through sulfide mineral precipitation. The Monash incubation work and geochemical assessment suggest that the reduction will proceed to the iron reduction stage, leading to ferrous iron in solution and transport out of the swamp, resulting in the export of acidity. These preliminary studies support the model findings, providing an independent line of evidence in regard to the thermodynamic model findings.

One key limitation with respect to understanding of the geochemical processes active in Big Swamp is the lack of kinetic data for the complete oxidation / reduction cycle so reliability of predictions of geochemical processes is limited at this stage.

Based on the geochemical and thermodynamic model the most significant benefit of the re-flooding remediation option would be an increase in water table in the swamp leading to limitation of any potential acidity that remains in the sediments above the historic water table low oxidising and cause further acidification.

The re-saturation of the soils will attempt to move the system behaviour back towards the pre 2000 conditions, however the likelihood of success is limited by the significantly lower sulfate concentrations in the surface water used for the re-flooding than the sulfate concentrations present in the groundwater that migrated through the swamp sediments under the historical flow conditions.

Another aspect considered as part of the re-flooding option is the risk of increased acid flushing events. The re-flooding is likely to lead to an increased risk of acid flushes, which will then abate once the retained and actual acidity is flushed from the system. The interpretation of the historic stream flow and pH data supports this contention.

This interpretation found that the pH in Reach 3 Boundary Creek at the Yeodene Gauge was below the long term average pH (i.e. 4.6):

- Prior to Jan 2000: 19% of measurements
- Post Jan 2000: 86% of measurements, however when splitting this period into the pre 2ML flow addition and post 2ML flow addition the following was observed:
  - Pre 2ML flow addition: 84%
  - Post 2ML flow addition: 97%

  This assessment support the contention that introduction of additional flow is likely to lead to additional acid flushing in the short to medium term, but would reduce the overall acid flux in the long term.
- In the context of acid flushes in response to storm events, this would be situation dependent. The historic record suggests that in the majority of storm events pH was higher during high flow, but there are occasional events where this is not the case. By increasing the saturated volume and inundated area of the swamp there is likely to be an increase in the risk of acid flush events as the retained and actual acidity enters solution leading to acidic conditions in standing water bodies in the swamp. This acid water could then exist the swamp in a first flush event in response to a localised storm event.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.5 Option O8: Managed groundwater levels within Big Swamp

Under this option water levels within the swamp would a managed by use of a series of levees and embankments. To this end the aim of this option is similar to that of Option O3 and O7, in that the aim of this option is to re-saturate the sediments in the swamp to limit the potential for acid generation through the primary acidification processes. As a consequence the GRM used was the same as that used to evaluate Option O7. The geochemical processes associated with this option would also be the same as those already described for Option O7 and are therefore not repeated in this section. The primary difference between this option and Option O7 would be the physical arrangement of the levies used to optimise the increase the water table elevations and re-saturate the sediments across the Big Swamp.

Numerical modelling completed by Jacobs provide groundwater level predictions under a 2 ML/day and 20 ML/day surface flow scenario (with a hydraulic barrier at the lower end of the swamp only). Therefore, the specific effects of a different arrangement of the physical barriers on re-saturation of the sediments on Big Swamp could not be assessed.

The unsaturated sediments and acid flux from the swamp were estimated based on the predicted groundwater levels (refer Option 2 : Section 5.5.2) It is noted that management of the groundwater levels may be done more efficiently at these flows by building small embankments and diversions at different locations along the swamp rather than just at the downstream end. Further numerical groundwater modelling would be required to assess the impacts on groundwater levels (and the reduction of unsaturated swamp area) under a refined embankment system. Therefore, the sediment volumes that contain net acidity with the potential to generate acid is assumed to be the same as for Option O3 and O8.

To evaluate this option the Return of Reducing Conditions GRM for Big Swamp described in Section 5.4.2 was utilised. This iterative dissolution model provided predictions of solute of concern changes in response to the stepwise decreases in Eh.

The effectiveness of the re-saturation was assessed by review of the predicted inorganic solute phase concentration to identify effectiveness of the option in attenuating solutes of concern and increase pH in the surface water, pore water and groundwater of Big Swamp.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.6 Option O9: Soil excavation/treatment and rehabilitation

This option would entail digging up of acid generating sediments in Big Swamp and treating these soils through addition of a neutralising agent to provide buffering capacity for the net acidity (retained, actual and potential) present in the unsaturated sediments. For the purpose of this assessment the neutralising agent applied was assumed to be lime. The chemistry of lime dissolution and the GRM utilised are already discussed under Option O3 in Section 5.5.3 and are therefore not repeated here.

Two scenarios for treatment were considered in the geochemical assessment:

1. Total Treatment of all Net Acidity
2. Treatment of Acid ‘Hot Spots’

Under the total treatment option the three dimensional model of the swamp sediment distribution was used to estimate the total sediment volume present and then using the average net acidity data from the Monash University study to provide a range of values for the lime dosing requirements.

For the ‘Hot Spot’ treatment option the three dimensional model of the swamp net acidity was used to calculate the lime dosing requirements for a range of progressively increasing net acidity ‘Hot Spots’.

The assessment results of the sediment volumes that contain primary acid forming minerals for each of the re-flooding scenarios set out for Option O1 in Section 5.4.1 with results summarised in Table 9. These lime dosing values are subject to considerable uncertainty due the limited data available and the lack of a reliable long term prediction of the water table position in the sediments of Big Swamp.

Table 9 Summary of lime dosing for net acidity present

Volume Scenario	Sediment Volume (m^3)			Lime Requirement (tonnes)		
	2ML/Day No Barrier	2ML/Day With Barrier	20ML/Day With Barrier	2ML/Day No Barrier	2ML/Day With Barrier	20ML/Day With Barrier
Total Treatment	610,000	600,000	435,000	135,000	133,000	96,000
Treatment above 500 mg CaCO3 / kg acidity	550,000	535,000	390,000	36,000	35,000	26,000
Treatment above 1500 mg CaCO3 / kg acidity	65,000	62,000	45,000	13,500	13,000	9,000
Treatment above 2500 mg CaCO3 / kg acidity	2800	2700	1800	900	870	560
Treatment above 3500 mg CaCO3 / kg acidity	380	370	250	180	170	105
Treatment above 4500 mg CaCO3 / kg acidity	100	90	60	55	50	35
Treatment above 6000 mg CaCO3 / kg acidity	50	50	20	45	40	15

The volumes and lime dosing rates provided in Table 9 are based on limited geological and geochemical data and are therefore subject to considerable uncertainty. Therefore application of these values in the preliminary remediation design need to be treated with an appropriate amount of caution and conservatism.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.7 Option O10: Deep soil mixing

This option is essentially similar to Option O9 in that a neutralising agent is added to the swamp sediments. However, rather than excavating the sediments and then treating them ex-situ, the sediments are treated in-situ by mixing the neutralising agent into the sediments using a mechanical mixing device.

From a geochemical perspective this option is essentially the same as Option O9 and given the limited data available and the uncertainties associated with the geological and geochemical information currently available this option cannot be distinguished from Option O9 from a geochemical perspective.

The only geochemical differentiator that can be anticipated based on the limited information available is that in-situ mixing is generally less effective than ex-situ methods and therefore some residual acid generation is more likely under this remediation option.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.8 Option O13: In-stream active treatment system

Under this option the surface discharge from Big Swamp into Reach 3 of Boundary Creek would be treated with a neutralising agent to raise pH to acceptable levels and allowing discharge of the treated water after removal of precipitates in an aeration and settlement pond.

Assessment of the geochemical aspects of this option was conducted using the predicted stream flow volumes considered in the hydrogeological model, the treatment volume capacity (up to 4ML/day) and the result of the staged thermodynamic model.

Based on the available stream flow information the following observations were made:

- Stream flows in excess of 4ML/day occur around 34% over the total monitoring period.
- Stream flows in excess of 4ML/day occur around 43% over the monitoring period prior to Jan 2000.
- Stream flows in excess of 4ML/day occur around 27% over the monitoring period post to Jan 2000.

Streamflow's in excess of 4ML/day are likely to occur more frequently than 27% of the time under some of the remediation options considered for Big Swamp, such as re-flooding or increase to flow inputs. Further work and hydrological modelling would be required to establish a more precise estimate of the predicted flow volumes under the various management and remediation options under consideration for Big Swamp.

Based on the observed pH data obtained at the Yeodene Gauge and the relationship between pH and measured acidity in samples collected, the observations made in relation to acid concentrations in the discharge water from Big Swamp entering Reach 3 of Boundary Creek are summarised as follows:

- All data (refer to Table 10)
- Pre 2000 Data (refer to Table 11
- 2000 to Jul 2006 Data (refer to Table 12)
- Jul 2006 to date Data (refer to Table 13)

Table 10 Summary of acidity in surface water flow – all data

Acidity as $CaCO_3$	Number of Exceedances	Percent of Exceedances
Acidity >50mg/L	10343	80%
Acidity >100mg/L	10199	79%
Acidity >300mg/L	9551	74%
Acidity >500mg/L	8746	67%
Acidity >1000mg/L	6445	50%

Acidity as $CaCO_3$	Number of Exceedances	Percent of Exceedances
Acidity >1500mg/L	4165	32%
Acidity >2000mg/L	2232	17%
Acidity >3000mg/L	173	1%

Table 11 Summary of acidity in surface water flow – pre 2000 data

Acidity as $CaCO_3$	Number of Exceedances	Percent of Exceedances
Acidity >50mg/L	3656	66%
Acidity >100mg/L	3543	64%
Acidity >300mg/L	3103	56%
Acidity >500mg/L	2703	49%
Acidity >1000mg/L	1626	29%
Acidity >1500mg/L	678	12%
Acidity >2000mg/L	135	2%
Acidity >3000mg/L	0	0%

Table 12 Summary of acidity in surface water flow – post 2000 data

Acidity as $CaCO_3$	Number of Exceedances	Percent of Exceedances
Acidity >50mg/L	3656	66%
Acidity >100mg/L	3543	64%
Acidity >300mg/L	3103	56%
Acidity >500mg/L	2703	49%
Acidity >1000mg/L	1626	29%
Acidity >1500mg/L	678	12%
Acidity >2000mg/L	135	2%
Acidity >3000mg/L	0	0%

Table 13 Summary of acidity in surface water flow – post Jul 2006 data

Acidity as $CaCO_3$	Number of Exceedances	Percent of Exceedances
Acidity >50mg/L	4540	91%
Acidity >100mg/L	4512	90%
Acidity >300mg/L	4337	87%
Acidity >500mg/L	4104	82%
Acidity >1000mg/L	3263	65%
Acidity >1500mg/L	2383	48%
Acidity >2000mg/L	1458	29%
Acidity >3000mg/L	109	2%

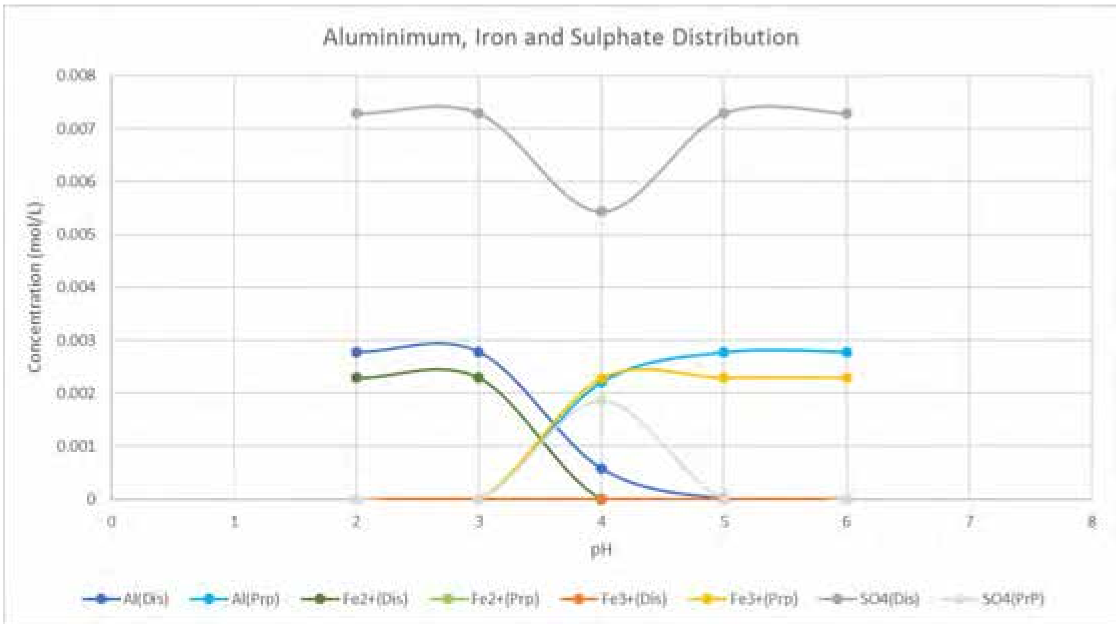
Assessment of the time series data summarised on Table 10 to Table 13 shows that the frequency and intensity of acid flux from Big Swamp into Reach 3 of Boundary Creek increased form early 2000 and intensified further after July 2006, as shown in Graph 27.

To evaluate this option the Lime Dosing GRM for Reach 3 of Boundary Creek described in Section 5.4.3 was utilised. This iterative dissolution model provided predictions of pH and solute of concern changes in response to the stepwise addition of lime to the surface water discharge from Big Swamp into Reach 3 of Boundary Creek as a finite solid. The effectiveness of the lime dosing was assessed by review of the predicted pH and dissolved phase calcium concentration to identify an effective dosing rate to deal with acid present in the surface waters discharge from Big Swamp into Reach 3 of Boundary Creek.

The iterative forward GRM identified a number of geochemical processes that potentially occur in response to addition of lime as neutralising agent to the surface water discharge from Big Swamp. Addition of lime would result in an increase in pH that would lead to precipitation of some minerals. The potential precipitate minerals identified by the GRM are:

- $ClFe(OH)_{2(s)}$ (Predicted by Model) and / or $Fe(OH)_3$ (As observed in Field Studies)
- $AlOHSO_{4(s)}$
- Diaspore (α-AlO(OH)) (Predicted by Model) and / or $Al(OH)_3$ (As observed in Field Studies)
- Nsutite (Mn_4+1−xMn_2+xO_2-2x$(OH)_{2x}$)
- FCO_3-Apatite ($Ca_5(PO_4F_3)$)

The changes in concentration of key solutes of concern (Aluminium, Iron and Sulfate) in solution in response to an increase in pH as a consequence of lime addition are shown on Graph 29. The model suggests that while iron and aluminium are removed from solution, sulfate largely remains soluble, with any removal limited to a specific pH range and to a minor amount.



Graph 29 Summary of iron, aluminium and sulfate concentrations

Based on the range of concentrations measured in the stream samples (low, mid and high), the range of flow volumes (low, mid and high) and pH achieved through lime dosing, the following precipitate volumes should be anticipated in the design of the dosing and setting pond:

- pH 2: Minor
- pH 3: Minor
- pH 4: Low 0.3 g/L, mid 0.6 g/L, high 3 g/L
- pH 5: Low 0.8 g/L, mid 1.6 g/L, high 8 g/L

- pH 6: Low 1.6 g/L, mid 3.2 g/L, high 16 g/L

The reagent requirements for specified pH increases, based on the iterative lime addition forward GRM are predicted to result in an increase in TDS, which may result in impacts to the beneficial uses that the water would otherwise be suitable for. Therefore, caution is required in dosing the water discharging from Big Swamp to manage final water quality entering Reach 3 of Boundary Creek to protect beneficial uses of the surface water resource.

The model indicated that once pH reaches 5, minor amounts of calcium that are added as an ion included in the lime minerals is removed from solution by precipitation of FCO3-Apatite, with mineral precipitates removing carbonate from the system. This is likely to reduce the effectiveness of lime dosing in increasing pH and could result in additional precipitate formation, which increases management requirements, for limited additional increase in pH.

Based on the thermodynamic modelling, dosing rates of lime that achieve an increase of pH in would depend on flow rate, with result of the assessment summarised in Table 14.

Table 14 Summary of lime dosing requirements

Flow Rate	1 pH unit increase (kg)	2 pH units increase (kg)	3 pH units increase (kg)
0.5ML Day	30	40	45
1ML Day	65	75	85
2ML Day	125	150	170
3ML Day	190	225	250
4ML Day	250	300	340

However, the rates shown in Table 14 are based on very limited data and need to be verified by laboratory and field trials as part of the next stage of works to inform a more detailed design of the treatment system required for implementation of this option.

The effectiveness of this option in achieving management or remediation of the relevant geochemical process aspects for this option are summarised in Table 15.

5.5.9 Option O17: Constructed vertical flow anaerobic wetland

The final remediation option considered in the geochemical modelling was the use of a vertical flow anaerobic wetland that comprised an upper layer of organic matter to create reducing conditions followed by a limestone or similar treatment zone designed to provide buffering capacity and neutralise acid.

To evaluate this option the Return of Reducing Conditions GRM for Reach 3 of Boundary Creek described in Section 5.4.4 was utilised. This iterative reduction model provided predictions of solute of concern changes in response to the stepwise decreases in Eh. The effectiveness of the re-saturation was assessed by review of the predicted inorganic solute phase concentration to identify effectiveness of the option in attenuating solutes of concern and increase pH in the surface water of Reach 3 of Boundary Creek.

The interactive forward GRM results suggests that on development of reducing conditions there is limited change to pH within the anaerobic treatment section of the system. The reduction of iron in the anaerobic treatment zone also appears limited and no attenuation of acid was suggested in the model predictions. The only mineral precipitates that form as reducing conditions develop in the anaerobic treatment zone are Metacinnabar and Covellite which result in the removal of mercury and copper from solution. As these ions were only present in trace or very low concentrations, precipitate clogging of the anaerobic treatment zone of the vertical flow system is not anticipated to be significant. However, the lack of removal of Aluminium and Iron through precipitation in the organic layer allows these solutes to enter the secondary treatment zone, where dissolution of limestone is intended to raise pH.

To evaluate this option the Lime Dosing GRM for Reach 3 of Boundary Creek described in Section 5.4.3 was utilised. This iterative dissolution model provided predictions of pH and solute of concern changes in response to the stepwise addition of lime to the surface water flowing through the limestone treatment zone after treatment in the anaerobic treatment zone as a finite solid. The effectiveness of the treatment by flow the limestone treatment zone was assessed by review of the predicted pH and dissolved phase calcium concentration to evaluate treatment and attenuation of the solutes of concern prior to discharge into Reach 3 of Boundary Creek.

Given the limited removal of acid, aluminium and iron as suggested by the model, the performance of the limestone layer is anticipated to be similar to that of the in stream active treatment system with respect to geochemical processes. The key difference between the two remediation methods is that the organic layer intends to convert ferric iron to the ferrous iron form allowing the ion to migrate into the limestone treatment zone in the more soluble iron from, which should limit the occurrence of iron precipitation in the limestone treatment zone which causes clogging and armouring and reduces the effectiveness of the limestone treatment zone.

However, the formation of aluminium precipitates in response to the increase in pH as predicted in the model for Option O13 would occur within the limestone treatment layer causing clogging and armouring of the limestone reducing the effectiveness of this treatment layer and decreasing the efficiency and effectiveness of the treatment system.

Given the uncertainties that resulted from the limited data available and the overall modelling limitations and given the thermodynamic modelling results, the aeration and settling pond requirements for this remediation option would be similar to those of Option O13.

Additional information based on further monitoring and pilot trials, followed by geochemical modelling would be required to support the more detailed design phase should this remediation option be considered further.

5.6 Effectiveness of management and remediation option considered

The results of the GRMs were utilised to assess the potential effectiveness of the management and remediation options under consideration with respect to the key geochemical processes and the fate and transport of solutes of concern, with results summarised in Table 15 based on the assessment and discussion set out in the previous section.

Table 15 Summary of effectiveness of geochemical processes

Geochemical Process Targeted / Remediation Option	Option 1: Do Nothing	Option O2: Implementation of contingency measures	Option O3: Direct treatment of soils with neutralising agents	Option O7: Flooding of Big Swamp	Option O8: Managed groundwater levels within Big Swamp	Option O9: Soil excavation/ treatment and rehabilitation		Option O10: Deep soil mixing	Option O13: In-stream active treatment system	Option O17: Constructed vertical flow anaerobic wetland
						All	Hot Spot			
Remove Primary Acid Source Minerals from Sediments in Big Swamp	Red	Red	Red	Red	Red	Green	Yellow	Yellow	Red	Red
Prevent Further Oxidation of Primary Acid Source Minerals in Sediments of Big Swamp	Red	Yellow	Red	Yellow	Yellow	Green	Yellow	Yellow	Red	Red
Neutralise Acidity Generated by Primary Acidification Process in Surface Water of Big Swamp	Red	Red	Green	Red	Red	Green	Yellow	Yellow	Red	Red
Neutralise Acidity Generated by Primary Acidification Process in Pore-Water and Groundwater of Big Swamp	Red	Red	Yellow	Orange	Orange	Green	Yellow	Yellow	Red	Red
Neutralise Acidity Generated by Secondary Acidification Process in Surface Water of Big Swamp	Red	Red	Orange	Red	Red	Green	Yellow	Yellow	Red	Red
Neutralise Acidity Generated by Secondary Acidification Process in Pore-Water and Groundwater of Big Swamp	Red	Red	Orange	Orange	Orange	Green	Yellow	Yellow	Red	Red
Neutralise Acid Discharged from Big Swamp into Reach 3 of Boundary Creek	Red	Red	Yellow	Red	Red	Green	Yellow	Yellow	Green	Yellow
Neutralise Acidity Generated by Secondary Acidification Process in Surface Water of Reach 3 of Boundary Creek	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Attenuate Aluminium through Precipitation of Mineral Species	Red	Red	Yellow	Orange	Orange	Green	Green	Green	Yellow	Green
Attenuate Aluminium through Sorption	Red	Red	Orange	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Arsenic through Precipitation of Mineral Species	Red	Red	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Red
Attenuate Arsenic through Sorption	Red	Red	Orange	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Copper through Precipitation of Mineral Species	Red	Red	Orange	Yellow	Yellow	Green	Green	Green	Yellow	Orange
Attenuate Copper through Sorption	Red	Red	Orange	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Ferric Iron through Precipitation of Mineral Species	Red	Red	Green	Red	Red	Green	Green	Green	Yellow	Orange
Attenuate Ferris Iron through Sorption	Red	Red	Yellow	Red	Red	Green	Green	Green	Orange	Orange
Attenuate Ferrous Iron through Precipitation of Mineral Species	Red	Red	Orange	Orange	Orange	Green	Green	Green	Yellow	Orange
Attenuate Ferrous Iron through Sorption	Red	Red	Orange	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Lead through Precipitation of Mineral Species	Red	Red	Green	Yellow	Yellow	Green	Green	Green	Yellow	Orange
Attenuate Lead through Sorption	Red	Red	Green	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Molybdenum through Precipitation of Mineral Species	Red	Red	Green	Yellow	Yellow	Green	Green	Green	Yellow	Orange
Attenuate Molybdenum through Sorption	Red	Red	Green	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Sulfur through Precipitation of Mineral Species	Red	Red	Orange	Orange	Orange	Green	Green	Green	Orange	Orange
Attenuate Sulfur through Sorption	Red	Red	Orange	Red	Red	Green	Green	Green	Orange	Orange

Notes:
1. Green = Likely to be effective
2. Yellow = Possibly effective
3. Orange = May be effective
4. Red = Unlikely to be effective

6. Conclusions

Based on the data review and geochemical modelling the following conclusions can be drawn from the Basic Hydrogeochemical Model:

6.1 Formation mechanism

- Big Swamp is an inland ASS system that appears to have formed as a result of long term groundwater seepage, possibly related to the interface zone where the regional LTA aquifer becomes confined by an overlying aquitard.
- The combination of swampy conditions in which organic matter accumulated creating strongly reducing conditions into which the groundwater seepage fed sulfate resulting in reduction of the sulfate to sulfide that led to precipitation of sulfide minerals, forming the primary acid source minerals.
- Over time this system led to accumulation of a stock of primary acid source mineral in the swamp sediments.

6.2 Geochemical process under natural flow conditions

- Under natural flow conditions, the swamp sediments were saturated the majority of the time, which maintained reducing conditions which kept the primary source minerals stable and limiting the generation of acid discharge form Big Swamp.
- Under natural dry conditions when surface flow and groundwater seepage rates slow, the water table in the swamp declined and some sediments became unsaturated, leading to oxidation of primary acid source minerals and acid discharge from Big Swamp.
- The historical flow and pH monitoring data for the Yeodene Gauge found that:
  - The cumulative flow analysis data suggests an increasing flow trend in the early and mid 1990's, suggesting relatively wetter conditions prevailed in Big Swamp and Reach 3 of Boundary Creek.
  - Prior to 2000, pH measurements below the long term average (i.e. occurred for around 19% of measurements. Therefore, acid discharge from Big Swamp occurred under natural flow conditions at least periodically.

6.3 Anthropogenic effects on acid generation process

- Extraction of groundwater from the LTA during the millennial drought, in combination with the dry climatic conditions, resulted in a lowering of the water table in the sediments of Big Swamp leading to oxidation of primary acid source minerals and an increased occurrence of acid discharge from Big Swamp.
- The historical flow and pH monitoring data for the Yeodene Gauge showed that:
  - The cumulative flow analysis data suggests a decreasing flow trend since the late 1990's, suggesting relatively drier conditions in Big Swamp and Reach 3 of Boundary Creek, leading to drying of the sediments in the swamp.
  - Post 2000, pH measurements below the long term average occurred in around 86% of measurements. This notable change in acid discharge from Big Swamp appears to be a consequence of the oxidation of primary acid source minerals as a result of lowering the water table in the swamp sediments.

6.4 Basic hydrogeochemical model

- The available data was used to develop a conceptual geochemical model that informed the development of a thermodynamic model.
- The MINTEQ-2A software package was used to conduct the thermodynamic modelling.
- The Geochemical Reaction Model results assisted in understanding the geochemical processes associated with the potential management and remediation options under consideration for Big Swamp and Reach 3 of Boundary Creek.

6.5 Remediation option geochemical processes

The geochemical processes associated with nine remediation options were assessed. The potential effectiveness of the management and remediation options under consideration, with respect to the key geochemical processes and the fate and transport of solutes of concern, are summarised in Table 15, with key conclusions below.

6.5.1 Management and remediation of Big Swamp

- The geochemical processes potentially associated with Option O1 (do nothing) were considered to primarily relate to the leaching of the retained and actual acidity in the short to medium term and the long term ongoing acid generation from oxidation of primary acid source minerals that remain in the unsaturated sediments in the swamp. Based on the estimated net acid mass remaining in the unsaturated zone of the swamp, acid flux could occur for more than 300 years.
- Geochemical processes associated with Option O2 implementing contingency measures) would entail re-saturating the sediments in Big Swamp using supplementary surface water flows, in an attempt to re-create reducing conditions to attenuate acid present in the system. Based on the estimated net acid mass remaining in the unsaturated zone of the swamp, acid flux could occur for 50-100 years (±50 years) depending on the surface water flow and barrier scenario. However, the Monash University (2019) study and thermodynamic model suggest that the effectiveness of re-saturation may be limited as there is insufficient sulfate in the system. The study suggested that iron would reduce to the ferrous form, which would increase solubility of iron and allow the ion to migrate in solution, exporting acid that forms down-stream when ferrous iron oxidises to the ferric form and precipitates as ferric hydroxides leading to a decrease in pH. This process also applies to the other re-saturation options, including Options O7 and O8.
- Geochemical processes associated with Option O3 would entail adding a neutralising agent such as lime to the sediment to provide buffering capacity and reduce the potential for acid discharge from Big Swamp into Reach 3 of Boundary Creek. The dissolution of lime adds calcium and hydroxide ions to the solution, which increases pH. These processes also apply to Options O9 and O10, which also add buffering capacity to the sediments in Big Swamp. The addition of buffering capacity and resultant increase in pH leads to precipitation of a range of iron and aluminium hydroxide mineral precipitation as well as some limited removal of sulfate by precipitation of aluminium sulfate over a narrow range of pH. One limiting factor of mineral precipitation as pH increases is armouring of the neutralising agent added resulting in a coating of the surface of the treatment agent granules, which limits or stops dissolution of the neutralising agent reducing its effectiveness.

6.5.2 Management and remediation of Reach 3 of Boundary Creek

- The geochemical processes associated with Option O13 would entail adding a neutralising agent by mechanical mixing into the surface water discharging from Big Swamp and then allowing the treated water to discharge into Reach 3 of Boundary Creek after passing through an aeration and settlement pond. The addition of the neutralising agent introduces buffering capacity and rises pH of acidic waters discharging from Big Swamp. The addition of buffering capacity would result in precipitation of aluminium, iron, manganese and calcium minerals. The majority of the mineral precipitates that formed are iron hydroxides, which remove buffering capacity and decrease pH. Some sulfate is also removed from solution by precipitation of aluminium sulfate over a relatively narrow pH range. Also dissolved calcium is removed from solution by precipitation of phosphate minerals, which leads to removal of some buffering capacity.
- The geochemical processes associated with Option O17 would entail adding a neutralising agent under anaerobic conditions in a passive treatment system into the surface water discharging from Big Swamp and then allowing the treated water to discharge into Reach 3 of Boundary Creek after passing through an aeration and settlement pond. The treatment of the acid water in the reduction later of the system (comprising and organic matter layer) would result in the reduction of ferric ion to the more soluble ferrous form which would limit the potential for clogging and armouring of the limestone treatment layer by precipitation of iron hydroxide minerals. However, clogging and armouring of the limestone layer by aluminium sulfate and hydroxide minerals is likely as the pH of the acidic water increases.

6.6 General

- The available soil, surface water and groundwater data is currently limited and further spatial and temporal data would be required to support more detailed and representative thermodynamic modelling of the geochemical processes associated with the management and remediation options under consideration.
- The availability of a limited data set for surface and groundwater prevented the undertaking of a statistical analysis of input parameter variance. As a result a conservative approach using the maximum values for the input parameters was adopted.
- Given the data limitation the results of the geochemical assessment are subject to considerable uncertainty and should be used with an appropriate amount of caution in the design of the management and remediation options considered for Big Swamp and Reach 3 of Boundary Creek.
- The geochemical processes associated with each management and remediation option under consideration suggest that no single management and remediation option under consideration is capable of mitigating acid generating processes associated with the primary acid source minerals, primary acidification reactions and secondary acidification reactions. Therefore, a combination of management and remediation processes is likely to be required.

7. Recommendations

Based on the data available, the results of the geochemical assessment and modelling and conclusions reached the following recommendations should be implemented with respect to further geochemical data requirements, assessment and modelling:

- Collection of further spatial and temporal geochemical data as follows:
  - Soil samples to further characterise the spatial geochemical characteristics of the sediments in Big Swamp. This should include lateral and vertical extent of sediments within Big Swamp to obtain a more accurate understanding of the sediment volume.
  - Chemical analysis of soil samples to characterise their mineralogical composition, retained acid, actual acidity and potential acidity to provide a more detailed characterisation of the net acidity laterally and vertically.
  - Kinetic reaction rate analysis of soil samples to characterise the rate of acid leaching and oxidation rate of primary acid source minerals through use of simple drying and cyclic drying and wetting simulations (noting some work is currently in progress).
  - Regular collection of surface water sampled on at least a quarterly basis at 10 locations distributed across the swamp to further characterise the spatial and temporal variance in geochemical character of the surface water system.
  - Regular collection of groundwater sampled on at least a quarterly basis at the existing monitoring well locations installed in Big Swamp to further characterise the spatial and temporal variance in geochemical character of the groundwater system.
- Undertake a statistical analysis of the soil, surface water and groundwater data set to assess variance and support the development of an improved conceptual geochemical model and support more robust and reliable decision making in regard to management and remediation options.
- Undertake further thermodynamic modelling using both equilibrium and kinetic approaches to provide improved estimates of the geochemical processes associated with the management and remediation option considered suitable for Big Swamp and Reach 3 of Boundary Creek.

8. References

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Monash University 2019a, Progress report for Barwon Water on Big Swamp Static testing, May and June 2019.

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Monash University 2019c, September Progress report for Barwon Water on Big Swamp static testing and process rates, September 2019.

9. Limitations

This report: has been prepared by GHD for Barwon Water and *may only be used and relied on by Barwon Water for the purpose agreed between GHD and the Barwon Water as set out in section 1.2 of this report.*

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Appendices

Appendix A - Lime dosing of soils in Big Swamp

A1: Aqueous species in solution

Species	Concentration	Activity	Log activity
Al DOM1	9.39E-06	9.29E-06	-5.032
Al(OH)2+	2.88E-11	2.26E-11	-10.647
Al(OH)3 (aq)	8.02E-16	8.23E-16	-15.085
Al(OH)4-	9.2E-20	7.1E-20	-19.149
Al(SO4)2-	0.000989	0.000763	-3.117
Al+3	0.000381	6.61E-05	-4.18
Al2(OH)2+4	6.41E-11	1.16E-12	-11.935
Al2(OH)2CO3+2	4.85E-15	1.78E-15	-14.75
Al2PO4+3	1.54E-10	1.61E-11	-10.793
Al3(OH)4+5	3.86E-16	7.31E-19	-18.136
AlCl+2	1.22E-06	4.46E-07	-6.35
AlF+2	1.31E-05	4.96E-06	-5.305
AlF2+	1.96E-08	1.53E-08	-7.814
AlF3 (aq)	1.37E-12	1.4E-12	-11.853
AlF4-	7.12E-18	5.49E-18	-17.26
AlHPO4+	1.72E-08	1.34E-08	-7.872
AlOH+2	1.74E-07	6.59E-08	-7.181
AlSO4+	0.003424	0.002644	-2.578
As3S4(HS)-	4.9E-224	3.8E-224	-223.418
AsO4-3	1.63E-20	1.71E-21	-20.768
AsS(OH)HS-	1.24E-79	9.62E-80	-79.017
Ca DOM1	2.16E-06	1.84E-06	-5.735
Ca(NH3)2+2	5.61E-24	2.06E-24	-23.687
Ca(NO3)2	6.7E-105	6.9E-105	-104.162
Ca+2	0.006371	0.002615	-2.583
CaCl+	0.000132	0.000103	-3.988
CaCO3 (aq)	1.94E-15	1.99E-15	-14.7
CaCrO4 (aq)	3.12E-11	3.2E-11	-10.495
CaF+	2.98E-10	2.32E-10	-9.635
CaH2PO4+	3.09E-08	2.43E-08	-7.615
CaHCO3+	2.56E-09	2.03E-09	-8.693
CaHPO4 (aq)	5.71E-12	5.86E-12	-11.232
CaNH3+2	3.6E-13	1.32E-13	-12.88
CaNO3+	3.31E-51	2.57E-51	-50.59
CaOH+	5.22E-14	4.14E-14	-13.383
CaPO4-	3.09E-18	2.43E-18	-17.615
CaSO4 (aq)	0.003627	0.003721	-2.429
Cd DOM1	1.68E-12	1.43E-12	-11.844
Cd(CO3)2-2	1.07E-32	3.92E-33	-32.407
Cd(HS)2 (aq)	6.42E-84	6.58E-84	-83.182
Cd(HS)3-	1.1E-126	8.3E-127	-126.081
Cd(HS)4-2	7.1E-169	2.6E-169	-168.581

Species	Concentration	Activity	Log activity
Cd(NH3)2+2	2.7E-26	9.9E-27	-26.004
Cd(NH3)3+2	1.06E-35	3.88E-36	-35.411
Cd(NH3)4+2	1.22E-45	4.49E-46	-45.348
Cd(NO2)2 (aq)	4.91E-81	5.03E-81	-80.298
Cd(NO3)2 (aq)	1E-106	1.1E-106	-105.972
Cd(OH)2 (aq)	1.49E-25	1.53E-25	-24.814
Cd(OH)3-	3.75E-36	2.92E-36	-35.534
Cd(OH)4-2	1.58E-47	5.8E-48	-47.236
Cd(SO4)2-2	3.28E-10	1.2E-10	-9.919
Cd+2	2.21E-09	8.09E-10	-9.092
Cd2OH+3	2.55E-25	2.67E-26	-25.574
CdCl+	1.6E-09	1.24E-09	-8.905
CdCl2 (aq)	8.08E-11	8.29E-11	-10.082
CdCO3 (aq)	9.87E-21	1.01E-20	-19.994
CdF+	1.2E-16	9.35E-17	-16.029
CdHCO3+	1.93E-15	1.5E-15	-14.824
CdHPO4 (aq)	1.88E-17	1.93E-17	-16.715
CdHS+	2.12E-46	1.65E-46	-45.782
CdNH3+2	1.42E-17	5.22E-18	-17.282
CdNO2+	3.94E-45	3.06E-45	-44.514
CdNO3+	1.27E-57	9.9E-58	-57.004
CdOH+	7.46E-18	5.8E-18	-17.236
CdSO4 (aq)	1.12E-09	1.15E-09	-8.939
Cl-1	0.022072	0.016569	-1.781
CO3-2	1.41E-15	5.34E-16	-15.272
Cr2O7-2	1.4E-11	5.13E-12	-11.29
CrO3Cl-	2.39E-10	1.86E-10	-9.73
CrO3H2PO4-	1.67E-12	1.3E-12	-11.887
CrO3HPO4-2	1.43E-12	5.25E-13	-12.28
CrO3SO4-2	1.02E-08	3.73E-09	-8.428
CrO4-2	6.08E-11	2.08E-11	-10.683
Cu DOM1	1.61E-09	1.38E-09	-8.862
Cu(CO3)2-2	2.41E-28	8.83E-29	-28.054
Cu(N3)2 (aq)	2.41E-17	2.47E-17	-16.607
Cu(N3)3-	3.07E-22	2.39E-22	-21.621
Cu(N3)4-2	3.31E-28	1.22E-28	-27.915
Cu(NH3)2+2	5.58E-22	2.05E-22	-21.689
Cu(NH3)3+2	7.17E-30	2.63E-30	-29.58
Cu(NH3)4+2	1.91E-38	6.99E-39	-38.156
Cu(NO2)2 (aq)	2.89E-80	2.96E-80	-79.529
Cu(NO3)2 (aq)	6.3E-106	6.5E-106	-105.189
Cu(OH)2 (aq)	1.14E-20	1.17E-20	-19.934
Cu(OH)3-	4.14E-28	3.22E-28	-27.492
Cu(OH)4-2	1.13E-39	4.16E-40	-39.381
Cu+2	4.96E-08	1.95E-08	-7.709

Species	Concentration	Activity	Log activity
Cu2(OH)2+2	4.45E-22	1.63E-22	-21.787
Cu2OH+3	9.4E-20	9.84E-21	-20.007
Cu2S3-2	2.2E-145	7.9E-146	-145.1
Cu3(OH)4+2	1.04E-35	3.82E-36	-35.418
CuCl+	7.52E-10	5.75E-10	-9.24
CuCl2 (aq)	1.55E-12	1.59E-12	-11.799
CuCl3-	2.67E-16	2.04E-16	-15.69
CuCl4-2 1	6.51E-20	2.4E-20	-19.62
CuCO3 (aq)	5.99E-17	6.14E-17	-16.212
CuF+	8.2E-15	6.38E-15	-14.195
CuHCO3+	9.27E-14	7.21E-14	-13.142
CuHPO4 (aq)	1.19E-15	1.22E-15	-14.912
CuHSO4+	1.93E-10	1.51E-10	-9.822
CuN3+	3.51E-12	2.73E-12	-11.563
CuNH3+2	1.13E-14	4.16E-15	-14.381
CuNO2+	9.88E-44	7.69E-44	-43.114
CuNO3+	2.42E-56	1.89E-56	-55.724
CuOH+	9.52E-14	7.28E-14	-13.138
CuS(aq)	1.17E-53	1.2E-53	-52.92
CuSO4 (aq)	2.65E-08	2.72E-08	-7.566
DOC (Gaussian DOM)	0.001399	0.001435	-2.843
DOM1	3.26E-05	4.56E-06	-5.341
F-1	1.03E-08	7.82E-09	-8.107
Fe DOM1	9.43E-08	9.33E-08	-7.03
Fe(N3)2+	3.82E-14	2.97E-14	-13.527
Fe(N3)3 (aq)	1.2E-18	1.23E-18	-17.91
Fe(NH3)2+2	5.73E-22	2.1E-22	-21.678
Fe(NH3)3+2	2.65E-32	9.72E-33	-32.012
Fe(NH3)4+2	5.23E-43	1.92E-43	-42.717
Fe(NO2)2+	2E-79	1.56E-79	-78.807
Fe(NO2)3 (aq)	6.6E-115	6.7E-115	-114.172
Fe(OH)2 (aq)	9.05E-20	9.29E-20	-19.032
Fe(OH)2+	1.05E-10	8.22E-11	-10.085
Fe(OH)3-	6.67E-28	5.19E-28	-27.285
Fe(OH)3 (aq)	5.14E-18	5.27E-18	-17.278
Fe(OH)4-	8.52E-24	6.68E-24	-23.175
Fe(SO4)2-	2.33E-08	1.81E-08	-7.742
Fe+2	0.010531	0.004144	-2.383
Fe+3	1.21E-08	2.1E-09	-8.678
Fe2(OH)2+4	5.27E-15	9.53E-17	-16.021
Fe3(OH)4+5	1.41E-21	2.67E-24	-23.574
FeCl+	5.57E-05	4.33E-05	-4.363
FeCl+2	2.07E-09	7.62E-10	-9.118
FeCrO4+	2.06E-12	1.6E-12	-11.796
FeF+	6.75E-10	5.25E-10	-9.28

Species	Concentration	Activity	Log activity
FeF+2	4.25E-11	1.57E-11	-10.805
FeF2+	5.94E-15	4.62E-15	-14.335
FeF3 (aq)	3.27E-20	3.35E-20	-19.475
FeH2PO4+	1.01E-06	7.91E-07	-6.102
FeH2PO4+2	4E-11	1.51E-11	-10.82
FeHCO3+	3.86E-09	3.05E-09	-8.515
FeHPO4 (aq)	7.56E-11	7.76E-11	-10.11
FeHPO4+	1.57E-10	1.23E-10	-9.91
FeHS+	4.43E-42	3.45E-42	-41.462
FeN3+2	1.72E-10	6.33E-11	-10.199
FeNH3+2	4.87E-12	1.79E-12	-11.748
FeNO2+2	3.41E-43	1.25E-43	-42.902
FeOH+	1.89E-10	1.47E-10	-9.833
FeOH+2	7.4E-09	2.73E-09	-8.564
FeSO4 (aq)	0.006081	0.006238	-2.205
FeSO4+	2.32E-07	1.81E-07	-6.743
H DOM1	7.61E-05	3.38E-05	-4.472
H+1	0.006241	0.005137	-2.289
H2AsO3-	4.87E-13	3.79E-13	-12.421
H2AsO4-	4.8E-07	3.74E-07	-6.427
H2CO3* (aq)	0.000967	0.000992	-3.003
H2CrO4 (aq)	6.32E-10	6.48E-10	-9.188
H2PO4-	6.25E-07	4.9E-07	-6.31
H2S (aq)	1.46E-40	1.49E-40	-39.826
H3AsO3	4.13E-06	4.24E-06	-5.373
H3AsO4	3.34E-07	3.43E-07	-6.465
H3PO4	3.11E-07	3.19E-07	-6.497
HAsO3-2	1.02E-24	3.76E-25	-24.425
HAsO4-2	1.95E-11	7.14E-12	-11.146
HCO3-	9.38E-08	7.36E-08	-7.133
HCrO4-	4.31E-07	3.36E-07	-6.474
HF (aq)	4.92E-08	5.05E-08	-7.297
HF2-	1.96E-15	1.48E-15	-14.829
Hg(CO3)2-2	3.94E-36	1.44E-36	-35.84
Hg(HS)2 (aq)	1.36E-72	1.4E-72	-71.855
Hg(N3)2 (aq)	1.85E-14	1.9E-14	-13.721
Hg(NH3)2+2	3.9E-24	1.43E-24	-23.844
Hg(NH3)4+2	4.28E-44	1.57E-44	-43.805
Hg(NO2)2 (aq)	1.49E-86	1.53E-86	-85.815
Hg(NO2)3-	2.6E-122	2E-122	-121.7
Hg(NO2)4-2	5.3E-159	1.9E-159	-158.715
Hg(NO3)2 (aq)	1.8E-119	1.8E-119	-118.735
Hg(OH)2	3.35E-23	3.44E-23	-22.464
Hg(SO4)2-2	5.16E-22	1.89E-22	-21.723
Hg+2	6.39E-21	2.34E-21	-20.63

Species	Concentration	Activity	Log activity
Hg2OH+3	4.2E-42	4.4E-43	-42.357
Hg3(OH)3+3	6.79E-62	7.11E-63	-62.148
HgCl+	1.42E-15	1.1E-15	-14.957
HgCl2 (aq)	1.37E-10	1.4E-10	-9.853
HgCl3-1	2.97E-11	2.31E-11	-10.636
HgCl4-2	4.67E-12	1.71E-12	-11.766
HgClOH (aq)	1.45E-16	1.49E-16	-15.827
HgCO3 (aq)	9.35E-25	9.59E-25	-24.018
HgF+	8.78E-28	6.83E-28	-27.166
HgHCO3+	1.05E-22	8.18E-23	-22.087
HgHS2-	1.13E-76	8.79E-77	-76.056
HgN3+	7.82E-11	6.09E-11	-10.215
HgNO2+	5.6E-53	4.36E-53	-52.36
HgNO3+	1.97E-70	1.53E-70	-69.814
HgOH+	1.74E-22	1.36E-22	-21.868
HgOHCO3-	2.8E-29	2.18E-29	-28.662
HgS2-2	9.1E-83	3.34E-83	-82.477
HgSO4 (aq)	2.63E-21	2.7E-21	-20.569
HN3 (aq)	4.98E-05	5.1E-05	-4.292
HNO2 (aq)	2.66E-37	2.73E-37	-36.564
HPO4-2	1.57E-11	5.8E-12	-11.237
HS-1	2.64E-45	2E-45	-44.7
HSO4-	0.003395	0.002621	-2.582
K+1	0.000318	0.000239	-3.622
K2HPO4 (aq)	3.48E-18	3.57E-18	-17.447
K2PO4-	5.15E-27	4E-27	-26.397
KCl (aq)	2.04E-06	2.1E-06	-5.678
KCr2O7-	1.36E-14	1.06E-14	-13.975
KCrO4-	2.37E-14	1.84E-14	-13.735
KF (aq)	8.32E-13	8.53E-13	-12.069
KH2PO4 (aq)	1.77E-10	1.82E-10	-9.741
KHPO4-	1.09E-14	8.52E-15	-14.07
KNO3 (aq)	5.13E-53	5.26E-53	-52.279
KOH (aq)	3.6E-16	3.7E-16	-15.432
KPO4-2	5.48E-24	2.01E-24	-23.697
KSO4-	1.23E-05	9.68E-06	-5.014
Mg DOM1	1.73E-07	1.47E-07	-6.832
Mg(NH3)2+2	2.24E-24	8.2E-25	-24.086
Mg+2	0.004895	0.002089	-2.68
Mg2CO3+2	2.47E-17	9.07E-18	-17.043
MgCl+	0.000167	0.00013	-3.885
MgCO3 (aq)	7.76E-16	7.96E-16	-15.099
MgF+	1.4E-09	1.08E-09	-8.966
MgHCO3+	1.95E-09	1.49E-09	-8.826
MgHPO4 (aq)	6.3E-12	6.46E-12	-11.19
MgOH+	7.87E-13	6.28E-13	-12.202

Species	Concentration	Activity	Log activity
MgPO4-	3.86E-20	3.03E-20	-19.519
MgSO4 (aq)	0.002343	0.002404	-2.619
Mn+3	4.55E-05	7.89E-06	-5.103
N3-1	2.48E-07	1.93E-07	-6.714
Na+1	0.012083	0.009416	-2.026
Na2HPO4 (aq)	3.58E-15	3.67E-15	-14.435
Na2PO4-	1.71E-23	1.33E-23	-22.876
NaCl (aq)	8.52E-05	8.75E-05	-4.058
NaCO3-	1.59E-16	1.25E-16	-15.905
NaCrO4-	1.25E-12	9.71E-13	-12.013
NaF (aq)	6.35E-11	6.52E-11	-10.186
NaH2PO4 (aq)	6.98E-09	7.16E-09	-8.145
NaHCO3 (aq)	4E-10	4.11E-10	-9.386
NaHPO4-	6.63E-13	5.2E-13	-12.284
NaNO3 (aq)	7.46E-52	7.66E-52	-51.116
NaOH (aq)	9.73E-15	9.98E-15	-14.001
NaPO4-2	2.38E-22	8.74E-23	-22.058
NaSO4-	0.000446	0.00035	-3.456
NH3 (aq)	1.48E-11	1.52E-11	-10.819
NH4+1	0.000385	0.000284	-3.546
NH4Cr2O7-	1.88E-14	1.46E-14	-13.834
NH4SO4-	2.68E-05	2.09E-05	-4.68
Ni DOM1	7.7E-09	6.56E-09	-8.183
Ni(N3)2 (aq)	1.33E-17	1.37E-17	-16.864
Ni(NH3)2+2	2.69E-22	9.88E-23	-22.005
Ni(NH3)3+2	2.37E-31	8.69E-32	-31.061
Ni(NH3)4+2	6.18E-41	2.27E-41	-40.645
Ni(NH3)5+2	5.2E-51	1.91E-51	-50.72
Ni(NH3)6+2	9.33E-62	3.42E-62	-61.466
Ni(NO2)2 (aq)	3.15E-79	3.23E-79	-78.491
Ni(OH)2 (aq)	1.37E-20	1.4E-20	-19.853
Ni(OH)3-	3.5E-29	2.73E-29	-28.564
Ni(SO4)2-2	3.14E-09	1.15E-09	-8.939
Ni+2	1.01E-05	3.71E-06	-5.431
NiCl+	2.85E-08	2.22E-08	-7.654
NiCl2 (aq)	1.28E-11	1.31E-11	-10.883
NiCO3 (aq)	7.17E-17	7.35E-17	-16.133
NiF+	6.72E-13	5.23E-13	-12.281
NiH2PO4+	1.53E-11	1.19E-11	-10.923
NiHCO3+	3.44E-11	2.67E-11	-10.573
NiHPO4 (aq)	1.53E-14	1.57E-14	-13.804
NiHS+	2.94E-45	2.29E-45	-44.641
NiN3+	1.73E-11	1.35E-11	-10.87
NiNH3+2	1.01E-13	3.69E-14	-13.433
NiNO2+	4.3E-42	3.34E-42	-41.476
NiNO3+	3.45E-54	2.69E-54	-53.571

Species	Concentration	Activity	Log activity
NiOH+	5.65E-14	4.39E-14	-13.357
NiSO4 (aq)	4.56E-06	4.68E-06	-5.33
NO2-1	4.83E-38	3.76E-38	-37.425
NO3-1	3.86E-49	2.89E-49	-48.54
OH-	1.18E-12	8.9E-13	-12.05
Pb DOM1	1.1E-09	9.36E-10	-9.029
Pb(CO3)2-2	4.51E-29	1.66E-29	-28.781
Pb(HS)2 (aq)	4.82E-83	4.94E-83	-82.306
Pb(HS)3-	2.5E-126	2E-126	-125.706
Pb(NO2)2 (aq)	1.18E-80	1.21E-80	-79.916
Pb(NO3)2 (aq)	1.5E-104	1.5E-104	-103.816
Pb(OH)2 (aq)	1.95E-21	2E-21	-20.699
Pb(OH)3-	5E-30	3.89E-30	-29.41
Pb(SO4)2-2	2.52E-09	9.25E-10	-9.034
Pb+2	1.82E-08	6.66E-09	-8.177
Pb2OH+3	3.28E-20	3.43E-21	-20.464
Pb3(OH)4+2	2.85E-40	1.05E-40	-39.981
Pb4(OH)4+4	5.93E-44	1.07E-45	-44.969
PbCl+	4.56E-09	3.55E-09	-8.45
PbCl2 (aq)	1.2E-10	1.23E-10	-9.911
PbCl3-	2.08E-12	1.62E-12	-11.792
PbCl4-2	2.67E-14	9.79E-15	-14.009
PbCO3 (aq)	1.18E-17	1.21E-17	-16.919
PbF+	9.45E-15	7.35E-15	-14.133
PbF2 (aq)	6.89E-22	7.07E-22	-21.15
PbH2PO4+	1.03E-13	8.02E-14	-13.096
PbHCO3+	3.99E-13	3.1E-13	-12.508
PbHPO4 (aq)	3.84E-17	3.94E-17	-16.404
PbNO2+	1.04E-43	8.1E-44	-43.091
PbNO3+	3.76E-56	2.92E-56	-55.534
PbOH+	3E-14	2.33E-14	-13.632
PbSO4 (aq)	2.18E-08	2.24E-08	-7.65
PO4-3	3.65E-21	3.86E-22	-21.413
S-2	2.1E-60	7.75E-61	-60.111
SO4-2	0.020293	0.00686	-2.164
Zn DOM1	1.8E-08	1.53E-08	-7.815
Zn(CO3)2-2	8.49E-29	3.11E-29	-28.507
Zn(N3)2 (aq)	1.9E-17	1.95E-17	-16.711
Zn(N3)3-	2.77E-23	2.15E-23	-22.667
Zn(NH3)2+2	1.5E-22	5.51E-23	-22.259
Zn(NH3)3+2	6.71E-31	2.46E-31	-30.609
Zn(NH3)4+2	1.47E-39	5.39E-40	-39.269
Zn(NO2)2 (aq)	1.19E-79	1.23E-79	-78.912
Zn(NO3)2 (aq)	2.2E-103	2.3E-103	-102.642
Zn(OH)2 (aq)	2.54E-18	2.6E-18	-17.584

Species	Concentration	Activity	Log activity
Zn(OH)3-	2.06E-27	1.6E-27	-26.796
Zn(OH)4-2	1.35E-37	4.94E-38	-37.307
Zn(SO4)2-2	1.34E-06	4.9E-07	-6.31
Zn+2	1.39E-05	5.47E-06	-5.262
Zn2OH+3	2.27E-17	2.38E-18	-17.624
Zn2S3-2	1.1E-137	3.9E-138	-137.406
Zn4S6-4	1.4E-272	2.6E-274	-273.582
ZnCl+	3.17E-07	2.42E-07	-6.616
ZnCl2 (aq)	2.5E-09	2.57E-09	-8.59
ZnCl3-	5.77E-11	4.49E-11	-10.348
ZnCl4-2	9.36E-13	3.43E-13	-12.464
ZnCO3 (aq)	1.64E-16	1.68E-16	-15.775
ZnF+	9.39E-13	7.31E-13	-12.136
ZnHCO3+	1.3E-11	1.01E-11	-10.995
ZnHPO4 (aq)	5.17E-14	5.31E-14	-13.275
ZnN3+	1.95E-11	1.52E-11	-10.818
ZnNH3+2	4.27E-14	1.57E-14	-13.805
ZnNO2+	1.59E-42	1.24E-42	-41.907
ZnNO3+	5.43E-54	4.23E-54	-53.374
ZnOH+	6.26E-13	4.87E-13	-12.313
ZnS (aq)	7.69E-50	7.89E-50	-49.103
ZnSO4 (aq)	7.33E-06	7.52E-06	-5.124

A2: Species distribution

Component	% of total concentration	Species name
Ni+2	68.723	Ni+2
	0.052	Ni DOM1
	0.194	NiCl+
	31.009	NiSO4 (aq)
	0.021	Ni(SO4)2-2
NH4+1	93.479	NH4+1
	6.521	NH4SO4-
Cl-1	98.028	Cl-1
	0.587	CaCl+
	0.247	FeCl+
	0.743	MgCl+
	0.379	NaCl (aq)
Pb+2	37.616	Pb+2
	2.276	Pb DOM1
	9.442	PbCl+
	0.248	PbCl2 (aq)
	45.188	PbSO4 (aq)
	5.224	Pb(SO4)2-2
Zn+2	60.671	Zn+2
	0.079	Zn DOM1
	1.384	ZnCl+
	0.011	ZnCl2 (aq)
	32.019	ZnSO4 (aq)
	5.836	Zn(SO4)2-2
F-1	0.078	F-1
	0.373	HF (aq)
	99.234	AlF+2
	0.296	AlF2+
	0.011	MgF+
SO4-2	48.735	SO4-2
	8.153	HSO4-
	8.223	AlSO4+
	4.748	Al(SO4)2-
	0.018	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	14.603	FeSO4 (aq)
	5.627	MgSO4 (aq)
	8.709	CaSO4 (aq)
	1.072	NaSO4-
	0.03	KSO4-
	0.064	NH4SO4-
Hg(OH)2	54.824	HgCl2 (aq)
	11.907	HgCl3-1
	1.874	HgCl4-2

Component	% of total concentration	Species name
	31.386	HgN3+
N3-1	0.497	N3-1
	99.503	HN3 (aq)
PO4-3	31.243	H2PO4-
	15.535	H3PO4
	50.432	FeH2PO4+
	1.546	CaH2PO4+
	0.862	AlHPO4+
	0.349	NaH2PO4 (aq)
AsO4-3	41.017	H3AsO4
	58.981	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	27.035	DOM1
	63.137	H DOM1
	7.789	Al DOM1
	1.794	Ca DOM1
	0.078	Fe DOM1
	0.143	Mg DOM1
	0.015	Zn DOM1
Ca+2	62.88	Ca+2
	0.021	Ca DOM1
	1.305	CaCl+
	35.793	CaSO4 (aq)
Mg+2	66.1	Mg+2
	2.26	MgCl+
	31.637	MgSO4 (aq)
K+1	95.673	K+1
	0.615	KCl (aq)
	3.712	KSO4-
Na+1	95.787	Na+1
	0.676	NaCl (aq)
	3.537	NaSO4-
CO3-2	99.989	H2CO3* (aq)
Al+3	7.915	Al+3
	0.195	Al DOM1
	0.272	AlF+2
	0.025	AlCl+2
	71.072	AlSO4+
	20.517	Al(SO4)2-
Cu+2	63.079	Cu+2
	2.052	Cu DOM1
	0.956	CuCl+
	33.66	CuSO4 (aq)
	0.246	CuHSO4+

Component	% of total concentration	Species name
Cd+2	41.315	Cd+2
	0.031	Cd DOM1
	29.961	CdCl+
	1.514	CdCl2 (aq)
	21.031	CdSO4 (aq)
	6.148	Cd(SO4)2-2
CrO4-2	0.014	CrO4-2
	97.474	HCrO4-
	0.143	H2CrO4 (aq)
	0.054	CrO3Cl-
	2.301	CrO3SO4-2
Mn+3	100	Mn+3
Fe+2	63.179	Fe+2
	0.334	FeCl+
	36.481	FeSO4 (aq)
NO2-1	15.374	NO2-1
	84.624	HNO2 (aq)
NO3-1	98.945	NO3-1
	0.848	CaNO3+
	0.013	KNO3 (aq)
	0.191	NaNO3 (aq)
HS-1	97.041	H2S (aq)
	2.955	FeHS+
H3AsO3	100	H3AsO3
Fe+3	3.261	Fe+3
	25.383	Fe DOM1
	1.993	FeOH+2
	0.028	Fe(OH)2+
	0.011	FeF+2
	0.557	FeCl+2
	62.397	FeSO4+
	6.269	Fe(SO4)2-
	0.046	FeN3+2
	0.011	FeH2PO4+2
	0.042	FeHPO4+

A3: Saturation indices

Mineral	log IAP	Sat. index
Al(OH)3 (am)	2.678	-8.797
Al(OH)3 (Soil)	2.678	-6.25
Al2O3(s)	5.366	-15.858
Al4(OH)10SO4(s)	3.977	-18.723
AlAsO4:2H2O(s)	-24.954	-9.154
AlOHF2(s)	-18.108	-18.515
AlOHSO4(s)	-4.057	-0.827
Alunite	-6.773	-6.65
Anglesite	-10.34	-2.477
Anhydrite	-4.746	-0.43
Antlerite	-16.148	-24.936
Aragonite	-17.855	-9.576
Arsenolite	-10.735	-9.172
Artinite	-16.071	-26.402
As2O5(s)	-55.261	-20.552
As2S3(am)	-151.692	-105.307
Atacamite	-10.342	-18.301
Azurite	-49.101	-31.948
Bianchite	-7.446	-5.685
Birnessite	11.044	-7.047
Bixbyite	3.52	3.407
Boehmite	2.681	-6.612
Brochantite	-19.285	-35.741
Brucite	1.892	-15.901
Ca3(AsO4)2:4H2O(s)	-49.297	-30.397
Ca3(PO4)2 (am1)	-50.575	-25.646
Ca3(PO4)2 (am2)	-50.575	-22.854
Ca3(PO4)2 (beta)	-50.575	-21.326
Ca4H(PO4)3:3H2O(s)	-76.87	-29.559
CaCO3xH2O(s)	-17.858	-10.771
CaCrO4(s)	-13.265	-11.163
CaHPO4(s)	-26.285	-6.822
CaHPO4:2H2O(s)	-26.292	-7.157
Calcite	-17.855	-9.425
CaS(s)	-44.993	-56.173
Cd metal (alpha)	-23.085	-37.058
Cd metal (gamma)	-23.085	-37.165
Cd(OH)2(s)	-4.52	-18.74
Cd3(OH)4SO4(s)	-20.296	-42.856
Cd3(PO4)2(s)	-70.103	-37.503
Cd3OH2(SO4)2(s)	-27.032	-33.742
Cd4(OH)6SO4(s)	-24.817	-53.217
CdCl2(s)	-12.654	-12.108
CdCl2:1H2O(s)	-12.657	-11.009

Mineral	log IAP	Sat. index
CdCl2:2.5H2O(s)	-12.662	-10.705
CdF2(s)	-25.306	-24.375
CdOHCl(s)	-8.587	-12.312
CdSO4(s)	-11.256	-11.4
CdSO4:1H2O(s)	-11.259	-9.725
CdSO4:2.67H2O(s)	-11.265	-9.501
Cerrusite	-23.449	-10.098
Chalcanthite	-9.89	-7.213
Chalcopyrite	-94.913	-58.74
Chloropyromorphite(c)	-106.904	-22.474
Chloropyromorphite(soil)	-106.904	-26.504
Cinnabar	-69.446	-22.623
Claudetite	-10.735	-9.222
Cotunnite	-11.738	-6.799
Covellite	-50.12	-27.31
Cr(VI)-Ettringite	-28.56	-91.961
Cr(VI)-Jarosite	-37.305	-18.789
CrO3(s)	-15.258	-12.079
Cryolite	-58.899	-24.828
Cu azide	-21.137	-13.296
Cu(OH)2(s)	-3.137	-12.75
Cu2(OH)3NO3(s)	-57.101	-66.793
Cu3(AsO4)2:2H2O(s)	-64.67	-29.57
Cu3(PO4)2(s)	-65.955	-29.105
Cu3(PO4)2:3H2O(s)	-65.965	-30.845
CuCO3(s)	-22.982	-11.482
CuCrO4(s)	-18.392	-12.952
CuF2(s)	-23.923	-25.445
CuF2:2H2O(s)	-23.93	-19.473
CuOCuSO4(s)	-13.007	-24.148
Cupric Ferrite	-6.764	-14.03
CuSO4(s)	-9.873	-13.257
Diaspore	2.681	-4.818
Dolomite (disordered)	-35.807	-19.549
Dolomite (ordered)	-35.807	-18.957
Epsomite	-4.867	-2.671
Ettringite	-3.002	-62.191
FCO3-Apatite	-166.391	-50.989
Fe(OH)2 (am)	2.189	-11.858
Fe(OH)2 (c)	2.189	-10.701
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-23.847	-21.584
Fe3(OH)8(s)	-1.451	-21.673
FeAsO4:2H2O(s)	-29.452	-9.252
Ferrihydrite	-1.82	-5.63
Ferrihydrite (aged)	-1.82	-5.12

Mineral	log IAP	Sat. index
FeS (ppt)	-44.793	-41.91
Fluorite	-18.796	-8.223
Galena	-50.587	-35.181
Gibbsite (C)	2.678	-5.7
Goethite	-1.817	-2.676
Goslarite	-7.45	-5.352
Greenockite	-51.503	-37.148
Greigite	-189.38	-144.345
Gypsum	-4.753	-0.137
Halite	-3.807	-5.334
Hematite	-3.63	-2.996
Hercynite	7.559	-17.243
Hg(OH)2(s)	-22.464	-18.968
Hg3O2CO3(s)	-87.229	-57.649
HgCl2(s)	-30.597	-8.68
HgSO4(s)	-29.199	-19.691
Hinsdalite	-30.577	-28.077
H-Jarosite	-18.938	-14.905
Huntite	-71.712	-42.399
Hydrocerrusite	-50.502	-31.742
Hydromagnesite	-69.932	-62.494
Hydroxyapatite	-74.867	-30.534
Hydroxylpyromorphite	-102.837	-40.047
Hydrozincite	-43.14	-53.278
K2Cr2O7(s)	-33.185	-15.451
K2CrO4(s)	-17.927	-17.302
K-Alum	-12.17	-6.816
KCl(s)	-5.403	-6.303
K-Jarosite	-20.267	-9.886
Langite	-19.289	-37.784
Larnakite	-13.942	-13.64
Laurionite	-7.671	-8.294
Lepidocrocite	-1.817	-3.188
Lime	1.993	-31.886
Litharge	-3.601	-16.69
Mackinawite	-44.793	-41.193
Maghemite	-3.63	-10.016
Magnesioferrite	-1.735	-20.29
Magnesite	-17.952	-10.371
Magnetite	-1.437	-6.108
Malachite	-26.119	-20.919
Massicot	-3.601	-16.898
Matlockite	-18.064	-8.889
Melanothallite	-11.271	-17.913
Melanterite	-4.57	-2.236
Metacinnabar	-69.446	-23.022

Mineral	log IAP	Sat. index
Mg(OH)2 (active)	1.892	-16.902
Mg2(OH)3Cl:4H2O(s)	-0.297	-26.297
Mg3(PO4)2(s)	-50.868	-27.588
MgCO3:5H2O(s)	-17.969	-13.429
MgCrO4(s)	-13.363	-19.284
MgF2(s)	-18.894	-10.833
MgHPO4:3H2O(s)	-26.393	-8.218
MgS(s)	-45.091	-62.771
Minium	7.764	-68.323
Mirabilite	-6.25	-4.653
Mn2(SO4)3(s)	-16.697	-11.98
Montroydite	-22.46	-18.744
Morenosite	-7.618	-5.4
Na2Cr2O7(s)	-29.993	-19.963
Na2CrO4(s)	-14.735	-17.785
NaF(s)	-10.133	-9.638
Na-Jarosite	-18.671	-14.177
Natron	-19.358	-17.647
Nesquehonite	-17.963	-13.44
Ni(OH)2 (am)	-0.859	-14.333
Ni(OH)2 (c)	-0.859	-11.649
Ni3(AsO4)2:8H2O(s)	-57.856	-32.356
Ni3(PO4)2(s)	-59.12	-27.82
Ni4(OH)6SO4(s)	-10.173	-42.173
NiCO3(s)	-20.703	-9.756
NiS (alpha)	-47.842	-42.322
NiS (beta)	-47.842	-36.822
NiS (gamma)	-47.842	-35.122
Nsutite	11.044	-6.46
Orpiment	-151.692	-103.792
Otavite	-24.364	-12.313
Pb azide (alpha)	-21.605	-12.63
Pb metal	-22.169	-26.41
Pb(OH)2(s)	-3.605	-12.111
Pb10(OH)6O(CO3)6(s)	-155.109	-146.349
Pb2(OH)3Cl(s)	-11.276	-20.069
Pb2O(OH)2(s)	-7.206	-33.396
Pb2O3(s)	11.365	-49.675
Pb2OCO3(s)	-27.05	-26.741
Pb3(AsO4)2(s)	-66.065	-30.565
Pb3(PO4)2(s)	-67.357	-23.827
Pb3O2CO3(s)	-30.652	-42.344
Pb3O2SO4(s)	-17.543	-28.711
Pb4(OH)6SO4(s)	-21.154	-42.254
Pb4O3SO4(s)	-21.144	-43.851
PbCrO4(s)	-18.859	-5.991

Mineral	log IAP	Sat. index
PbF2(s)	-24.39	-16.829
PbHPO4(s)	-31.879	-8.074
PbO:0.3H2O(s)	-3.602	-16.582
Periclase	1.895	-20.609
Phosgenite	-35.187	-15.377
Plattnerite	14.967	-36.435
Plumbgummite	-52.116	-19.326
Portlandite	1.989	-21.497
Pyrite	-73.211	-54.399
Realgar	-61.637	-40.907
Retgersite	-7.615	-5.547
Siderite	-17.655	-7.109
Smithsonite	-20.535	-9.658
Spharelite	-47.673	-36.67
Spinel	7.261	-31.945
Strengite	-30.098	-3.755
Struvite	-27.64	-14.38
Sulfur	-28.418	-26.372
Tenorite(am)	-3.134	-12.018
Tenorite(c)	-3.134	-11.169
Thenardite	-6.216	-6.593
Thermonatrite	-19.328	-20.029
Tsumebite	-38.628	-28.838
Vaterite	-17.855	-10.018
Vivianite	-50.002	-12.211
Wurtzite	-47.673	-38.924
Zincite	-0.687	-12.462
Zincosite	-7.426	-11.858
Zn metal	-19.255	-45.976
Zn(NO3)2:6H2O(s)	-102.362	-105.528
Zn(OH)2 (am)	-0.69	-13.685
Zn(OH)2 (beta)	-0.69	-12.95
Zn(OH)2 (delta)	-0.69	-12.534
Zn(OH)2 (epsilon)	-0.69	-12.702
Zn(OH)2 (gamma)	-0.69	-12.922
Zn2(OH)2SO4(s)	-8.116	-15.616
Zn2(OH)3Cl(s)	-5.447	-20.638
Zn3(PO4)2:4H2O(s)	-58.627	-23.207
Zn3AsO42:2.5H2O(s)	-57.331	-29.831
Zn3O(SO4)2(s)	-15.539	-36.022
Zn4(OH)6SO4(s)	-9.497	-37.897
Zn5(OH)8Cl2(s)	-11.585	-50.085
Zn-Al LDH(s)	-8.625	-28.455
ZnCl2(s)	-8.824	-16.314
ZnCO3(s)	-20.535	-9.735
ZnCO3:1H2O(s)	-20.538	-10.278

Mineral	log IAP	Sat. index
ZnF2(s)	-21.476	-21.305
ZnSO4:1H2O(s)	-7.429	-7.059

A4: Mass distribution

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	8.15E-07	100	0	0	0	0
Ca+2	0.010132	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.022516	86.769	0	0	0.003433	13.231
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.016669	100	0	0	0	0
Fe+3	3.71E-07	0.003	0	0	0.011444	99.997
H+1	0.011703	100	0	0	0	0
H3AsO3	4.13E-06	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	1.5E-40	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	3.14E-37	100	0	0	0	0
NO3-1	3.9E-49	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

A5: Finite solids

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	1.14E-02

Appendix B - Return of reducing conditions in Big Swamp

B1: Aqueous species

B1.1: Eh 100

Species	Concentration	Activity	Log activity
Al DOM1	2.39E-05	2.36E-05	-4.627
Al(OH)2+	3.25E-09	2.53E-09	-8.597
Al(OH)3 (aq)	1.47E-12	1.51E-12	-11.822
Al(OH)4-	2.77E-15	2.13E-15	-14.673
Al(SO4)2-	0.000401	0.000307	-3.512
Al+3	0.000166	2.78E-05	-4.556
Al2(OH)2+4	3.31E-09	5.47E-11	-10.262
Al2(OH)2CO3+2	6.18E-11	2.21E-11	-10.655
Al2PO4+3	6.01E-09	5.98E-10	-9.223
Al3(OH)4+5	2.35E-12	3.87E-15	-14.413
AlCl+2	5.97E-07	2.14E-07	-6.669
AlF+2	1.31E-05	4.83E-06	-5.316
AlF2+	4.44E-08	3.46E-08	-7.461
AlF3 (aq)	7.11E-12	7.31E-12	-11.136
AlF4-	8.66E-17	6.63E-17	-16.178
AlHPO4+	9.42E-08	7.29E-08	-7.137
AlOH+2	1.22E-06	4.52E-07	-6.345
AlSO4+	0.001419	0.001088	-2.963
As3S4(HS)-	1.72E-43	1.33E-43	-42.875
AsO4-3	7.5E-25	7.46E-26	-25.127
AsS(OH)HS-	1.22E-18	9.42E-19	-18.026
Ca DOM1	1.19E-05	1.01E-05	-4.997
Ca(NH3)2+2	1.35E-21	4.83E-22	-21.316
Ca(NO3)2	1.1E-164	1.1E-164	-163.942
Ca+2	0.005878	0.002366	-2.626
CaCl+	0.000137	0.000106	-3.974
CaCO3 (aq)	4.63E-13	4.76E-13	-12.322
CaCrO4 (aq)	4.64E-10	4.77E-10	-9.322
CaF+	6.28E-10	4.86E-10	-9.313
CaH2PO4+	2.24E-08	1.75E-08	-7.758
CaHCO3+	3.79E-08	2.98E-08	-7.525
CaHPO4 (aq)	6.67E-11	6.86E-11	-10.164
CaNH3+2	5.36E-12	1.92E-12	-11.716
CaNO3+	4.08E-81	3.15E-81	-80.501
CaOH+	7.76E-13	6.11E-13	-12.214
CaPO4-	5.92E-16	4.61E-16	-15.336
CaSO4 (aq)	0.003205	0.003295	-2.482
Cd DOM1	9.67E-12	8.21E-12	-11.086
Cd(CO3)2-2	7.23E-28	2.59E-28	-27.586
Cd(HS)2 (aq)	8.14E-22	8.37E-22	-21.077
Cd(HS)3-	1.58E-33	1.22E-33	-32.914
Cd(HS)4-2	1.25E-44	4.47E-45	-44.35

Species	Concentration	Activity	Log activity
Cd(NH3)2+2	6.8E-24	2.44E-24	-23.613
Cd(NH3)3+2	4.3E-32	1.54E-32	-31.812
Cd(NH3)4+2	8.01E-41	2.87E-41	-40.542
Cd(NO2)2 (aq)	1.2E-124	1.2E-124	-123.915
Cd(NO3)2 (aq)	1.8E-166	1.9E-166	-165.731
Cd(OH)2 (aq)	3.78E-23	3.88E-23	-22.411
Cd(OH)3-	1.56E-32	1.21E-32	-31.918
Cd(OH)4-2	1.09E-42	3.92E-43	-42.407
Cd(SO4)2-2	3.05E-10	1.09E-10	-9.961
Cd+2	2.14E-09	7.68E-10	-9.115
Cd2OH+3	3.94E-24	3.92E-25	-24.406
CdCl+	1.74E-09	1.35E-09	-8.87
CdCl2 (aq)	9.97E-11	1.02E-10	-9.989
CdCO3 (aq)	2.47E-18	2.54E-18	-17.596
CdF+	2.65E-16	2.05E-16	-15.688
CdHCO3+	2.99E-14	2.31E-14	-13.636
CdHPO4 (aq)	2.3E-16	2.37E-16	-15.626
CdHS+	2.35E-15	1.81E-15	-14.741
CdNH3+2	2.23E-16	7.98E-17	-16.098
CdNO2+	5.99E-67	4.64E-67	-66.334
CdNO3+	1.65E-87	1.27E-87	-86.895
CdOH+	1.16E-16	8.99E-17	-16.046
CdSO4 (aq)	1.04E-09	1.07E-09	-8.971
Cl-1	0.025415	0.018911	-1.723
CO3-2	3.82E-13	1.41E-13	-12.851
Cr2O7-2	1.47E-11	5.26E-12	-11.279
CrO3Cl-	1.71E-11	1.32E-11	-10.879
CrO3H2PO4-	8.3E-14	6.42E-14	-13.192
CrO3HPO4-2	1.18E-12	4.22E-13	-12.375
CrO3SO4-2	6.33E-10	2.27E-10	-9.644
CrO4-2	1.03E-09	3.42E-10	-9.466
Cu DOM1	9.1E-15	7.72E-15	-14.112
Cu(CO3)2-2	1.59E-29	5.72E-30	-29.243
Cu(N3)2 (aq)	5.1E-21	5.25E-21	-20.28
Cu(N3)3-	9.93E-25	7.69E-25	-24.114
Cu(N3)4-2	1.65E-29	5.91E-30	-29.229
Cu(NH3)2+2	1.38E-25	4.93E-26	-25.307
Cu(NH3)3+2	2.85E-32	1.02E-32	-31.991
Cu(NH3)4+2	1.22E-39	4.37E-40	-39.359
Cu(NO2)2 (aq)	6.8E-130	7E-130	-129.155
Cu(NO3)2 (aq)	1.1E-171	1.1E-171	-170.957
Cu(OH)2 (aq)	2.81E-24	2.89E-24	-23.539
Cu(OH)3-	1.69E-30	1.31E-30	-29.884
Cu(OH)4-2	7.67E-41	2.75E-41	-40.561
Cu+2	4.72E-14	1.81E-14	-13.741

Species	Concentration	Activity	Log activity
Cu2(OH)2+2	1.05E-31	3.76E-32	-31.425
Cu2OH+3	1.39E-30	1.39E-31	-30.858
Cu2S3-2	1.27E-60	4.55E-61	-60.342
Cu3(OH)4+2	6.07E-49	2.18E-49	-48.662
CuCl+	8.03E-16	6.09E-16	-15.215
CuCl2 (aq)	1.87E-18	1.92E-18	-17.717
CuCl3-	3.72E-22	2.82E-22	-21.55
CuCl4-2 1	1.05E-25	3.78E-26	-25.422
CuCO3 (aq)	1.47E-20	1.51E-20	-19.822
CuF+	1.77E-20	1.37E-20	-19.863
CuHCO3+	1.41E-18	1.09E-18	-17.963
CuHPO4 (aq)	1.43E-20	1.47E-20	-19.832
CuHSO4+	1.09E-17	8.43E-18	-17.074
CuN3+	4.96E-17	3.84E-17	-16.416
CuNH3+2	1.74E-19	6.22E-20	-19.206
CuNO2+	1.47E-71	1.14E-71	-70.943
CuNO3+	3.07E-92	2.37E-92	-91.624
CuOH+	1.46E-18	1.1E-18	-17.957
CuS(aq)	2.04E-27	2.1E-27	-26.678
CuSO4 (aq)	2.4E-14	2.47E-14	-13.607
DOC (Gaussian DOM)	0.001399	0.001438	-2.842
DOM1	5.47E-05	7.33E-06	-5.135
F-1	2.41E-08	1.81E-08	-7.742
Fe DOM1	5.4E-12	5.35E-12	-11.272
Fe(N3)2+	8.33E-17	6.45E-17	-16.191
Fe(N3)3 (aq)	3.93E-20	4.04E-20	-19.394
Fe(NH3)2+2	2.55E-19	9.13E-20	-19.04
Fe(NH3)3+2	1.9E-28	6.81E-29	-28.167
Fe(NH3)4+2	6.04E-38	2.17E-38	-37.664
Fe(NO2)2+	4.9E-128	3.8E-128	-127.425
Fe(NO2)3 (aq)	2.5E-185	2.6E-185	-184.587
Fe(OH)2 (aq)	4.04E-17	4.15E-17	-16.382
Fe(OH)2+	2.67E-13	2.08E-13	-12.682
Fe(OH)3-	4.9E-24	3.79E-24	-23.421
Fe(OH)3 (aq)	2.12E-19	2.18E-19	-18.662
Fe(OH)4-	5.78E-24	4.51E-24	-23.346
Fe(SO4)2-	2.13E-13	1.65E-13	-12.784
Fe+2	0.018056	0.006941	-2.159
Fe+3	1.19E-13	1.99E-14	-13.701
Fe2(OH)2+4	1.38E-22	2.28E-24	-23.641
Fe3(OH)4+5	9.83E-32	1.62E-34	-33.792
FeCl+	0.000107	8.28E-05	-4.082
FeCl+2	2.3E-14	8.24E-15	-14.084
FeCrO4+	3.23E-16	2.5E-16	-15.602
FeF+	2.63E-09	2.04E-09	-8.691

Species	Concentration	Activity	Log activity
FeF+2	9.57E-16	3.43E-16	-15.464
FeF2+	3.04E-19	2.35E-19	-18.629
FeF3 (aq)	3.83E-24	3.94E-24	-23.404
FeH2PO4+	1.35E-06	1.06E-06	-5.977
FeH2PO4+2	3.09E-16	1.14E-16	-15.942
FeHCO3+	1.06E-07	8.31E-08	-7.08
FeHPO4 (aq)	1.63E-09	1.68E-09	-8.775
FeHPO4+	1.94E-14	1.51E-14	-13.821
FeHS+	8.64E-11	6.69E-11	-10.175
FeN3+2	2.53E-14	9.07E-15	-14.042
FeNH3+2	1.35E-10	4.82E-11	-10.317
FeNO2+2	5.28E-70	1.89E-70	-69.723
FeOH+	5.19E-09	4.02E-09	-8.396
FeOH+2	1.18E-12	4.22E-13	-12.375
FeSO4 (aq)	0.009949	0.010229	-1.99
FeSO4+	2.16E-12	1.67E-12	-11.776
H DOM1	2.88E-05	1.26E-05	-4.901
H+1	0.000386	0.000316	-3.5
H2AsO3-	9.55E-12	7.39E-12	-11.131
H2AsO4-	8E-14	6.19E-14	-13.208
H2CO3* (aq)	0.000965	0.000993	-3.003
H2CrO4 (aq)	3.94E-11	4.05E-11	-10.393
H2PO4-	5.01E-07	3.9E-07	-6.409
H2S (aq)	1.03E-10	1.06E-10	-9.973
H3AsO3	4.95E-06	5.09E-06	-5.293
H3AsO4	3.4E-15	3.49E-15	-14.457
H3PO4	1.52E-08	1.56E-08	-7.806
HAsO3-2	3.32E-22	1.19E-22	-21.925
HAsO4-2	5.35E-17	1.92E-17	-16.717
HCO3-	1.53E-06	1.2E-06	-5.922
HCrO4-	4.4E-07	3.41E-07	-6.468
HF (aq)	6.99E-09	7.19E-09	-8.143
HF2-	6.52E-16	4.89E-16	-15.31
Hg(CO3)2-2	1.57E-40	5.63E-41	-40.249
Hg(HS)2 (aq)	1.02E-19	1.05E-19	-18.981
Hg(N3)2 (aq)	6.31E-19	6.49E-19	-18.188
Hg(NH3)2+2	5.79E-31	2.08E-31	-30.683
Hg(NH3)4+2	1.65E-48	5.91E-49	-48.228
Hg(NO2)2 (aq)	2.1E-139	2.2E-139	-138.662
Hg(NO2)3-	5.9E-197	4.5E-197	-196.344
Hg(NO2)4-2	1.9E-255	7E-256	-255.156
Hg(NO3)2 (aq)	1.8E-188	1.9E-188	-187.724
Hg(OH)2	4.99E-30	5.13E-30	-29.29
Hg(SO4)2-2	2.83E-31	1.01E-31	-30.994
Hg+2	3.66E-30	1.31E-30	-29.883

Species	Concentration	Activity	Log activity
Hg2OH+3	2.26E-59	2.25E-60	-59.648
Hg3(OH)3+3	5.45E-86	5.42E-87	-86.266
HgCl+	9.1E-25	7.04E-25	-24.152
HgCl2 (aq)	9.94E-20	1.02E-19	-18.991
HgCl3-1	2.48E-20	1.92E-20	-19.716
HgCl4-2	4.54E-21	1.63E-21	-20.789
HgClOH (aq)	1.51E-24	1.55E-24	-23.809
HgCO3 (aq)	1.38E-31	1.42E-31	-30.849
HgF+	1.14E-36	8.85E-37	-36.053
HgHCO3+	9.61E-31	7.44E-31	-30.129
HgHS2-	1.38E-22	1.07E-22	-21.971
HgN3+	4.69E-14	3.63E-14	-13.44
HgNO2+	5.03E-84	3.89E-84	-83.41
HgNO3+	1.5E-109	1.2E-109	-108.935
HgOH+	1.6E-30	1.24E-30	-29.907
HgOHCO3-	6.79E-35	5.25E-35	-34.28
HgS2-2	1.84E-27	6.6E-28	-27.181
HgSO4 (aq)	1.44E-30	1.48E-30	-29.831
HN3 (aq)	4.62E-05	4.75E-05	-4.323
HNO2 (aq)	2.61E-60	2.68E-60	-59.572
HPO4-2	2.09E-10	7.5E-11	-10.125
HS-1	3.08E-14	2.31E-14	-13.636
HSO4-	0.000206	0.000158	-3.802
K+1	0.000318	0.000237	-3.626
K2HPO4 (aq)	4.42E-17	4.54E-17	-16.343
K2PO4-	1.07E-24	8.27E-25	-24.083
KCl (aq)	2.31E-06	2.37E-06	-5.625
KCr2O7-	1.39E-14	1.08E-14	-13.969
KCrO4-	3.89E-13	3.01E-13	-12.521
KF (aq)	1.9E-12	1.96E-12	-11.708
KH2PO4 (aq)	1.39E-10	1.43E-10	-9.844
KHPO4-	1.4E-13	1.09E-13	-12.962
KNO3 (aq)	6.87E-83	7.07E-83	-82.151
KOH (aq)	5.82E-15	5.98E-15	-14.223
KPO4-2	1.17E-21	4.19E-22	-21.378
KSO4-	1.21E-05	9.39E-06	-5.027
Mg DOM1	1.04E-06	8.83E-07	-6.054
Mg(NH3)2+2	5.89E-22	2.11E-22	-21.675
Mg+2	0.004943	0.002073	-2.684
Mg2CO3+2	6.57E-15	2.36E-15	-14.628
MgCl+	0.000191	0.000148	-3.831
MgCO3 (aq)	2.03E-13	2.09E-13	-12.681
MgF+	3.24E-09	2.48E-09	-8.605
MgHCO3+	3.17E-08	2.41E-08	-7.618
MgHPO4 (aq)	8.07E-11	8.29E-11	-10.081

Species	Concentration	Activity	Log activity
MgOH+	1.28E-11	1.02E-11	-10.992
MgPO4-	8.11E-18	6.32E-18	-17.199
MgSO4 (aq)	0.002271	0.002335	-2.632
Mn+3	4.55E-05	7.61E-06	-5.119
N3-1	3.78E-06	2.92E-06	-5.534
Na+1	0.012081	0.009357	-2.029
Na2HPO4 (aq)	4.56E-14	4.69E-14	-13.329
Na2PO4-	3.57E-21	2.76E-21	-20.559
NaCl (aq)	9.65E-05	9.92E-05	-4.004
NaCO3-	4.19E-14	3.27E-14	-13.486
NaCrO4-	2.06E-11	1.59E-11	-10.798
NaF (aq)	1.46E-10	1.5E-10	-9.824
NaH2PO4 (aq)	5.51E-09	5.66E-09	-8.247
NaHCO3 (aq)	6.45E-09	6.63E-09	-8.178
NaHPO4-	8.58E-12	6.68E-12	-11.175
NaNO3 (aq)	1E-81	1.03E-81	-80.987
NaOH (aq)	1.58E-13	1.62E-13	-12.79
NaPO4-2	5.09E-20	1.83E-20	-19.739
NaSO4-	0.000437	0.00034	-3.468
NH3 (aq)	2.38E-10	2.45E-10	-9.612
NH4+1	0.000385	0.000282	-3.55
NH4Cr2O7-	1.92E-14	1.49E-14	-13.827
NH4SO4-	2.62E-05	2.03E-05	-4.693
Ni DOM1	4.62E-08	3.92E-08	-7.407
Ni(N3)2 (aq)	3.01E-15	3.09E-15	-14.51
Ni(NH3)2+2	7.07E-20	2.54E-20	-19.596
Ni(NH3)3+2	1E-27	3.59E-28	-27.445
Ni(NH3)4+2	4.21E-36	1.51E-36	-35.821
Ni(NH3)5+2	5.71E-45	2.05E-45	-44.689
Ni(NH3)6+2	1.65E-54	5.91E-55	-54.228
Ni(NO2)2 (aq)	7.9E-123	8.1E-123	-122.09
Ni(OH)2 (aq)	3.6E-18	3.7E-18	-17.432
Ni(OH)3-	1.52E-25	1.17E-25	-24.93
Ni(SO4)2-2	3.04E-09	1.09E-09	-8.962
Ni+2	1.02E-05	3.66E-06	-5.436
NiCl+	3.23E-08	2.5E-08	-7.602
NiCl2 (aq)	1.64E-11	1.69E-11	-10.773
NiCO3 (aq)	1.87E-14	1.92E-14	-13.717
NiF+	1.55E-12	1.2E-12	-11.922
NiH2PO4+	1.21E-11	9.39E-12	-11.027
NiHCO3+	5.55E-10	4.3E-10	-9.367
NiHPO4 (aq)	1.95E-13	2.01E-13	-12.697
NiHS+	3.38E-14	2.62E-14	-13.582
NiN3+	2.6E-10	2.02E-10	-9.696
NiNH3+2	1.64E-12	5.87E-13	-12.231

Species	Concentration	Activity	Log activity
NiNO2+	6.81E-64	5.27E-64	-63.278
NiNO3+	4.65E-84	3.6E-84	-83.444
NiOH+	9.17E-13	7.09E-13	-12.149
NiSO4 (aq)	4.4E-06	4.52E-06	-5.344
NO2-1	7.75E-60	6E-60	-59.222
NO3-1	5.28E-79	3.91E-79	-78.408
OH-	1.94E-11	1.45E-11	-10.837
Pb DOM1	5.91E-09	5.02E-09	-8.299
Pb(CO3)2-2	2.85E-24	1.02E-24	-23.99
Pb(HS)2 (aq)	5.71E-21	5.87E-21	-20.231
Pb(HS)3-	3.5E-33	2.71E-33	-32.567
Pb(NO2)2 (aq)	2.7E-124	2.7E-124	-123.562
Pb(NO3)2 (aq)	2.4E-164	2.5E-164	-163.604
Pb(OH)2 (aq)	4.61E-19	4.74E-19	-18.325
Pb(OH)3-	1.94E-26	1.5E-26	-25.823
Pb(SO4)2-2	2.19E-09	7.86E-10	-9.105
Pb+2	1.65E-08	5.91E-09	-8.229
Pb2OH+3	4.44E-19	4.41E-20	-19.355
Pb3(OH)4+2	1.45E-35	5.19E-36	-35.285
Pb4(OH)4+4	2.86E-39	4.73E-41	-40.325
PbCl+	4.64E-09	3.59E-09	-8.445
PbCl2 (aq)	1.38E-10	1.42E-10	-9.848
PbCl3-	2.75E-12	2.13E-12	-11.671
PbCl4-2	4.11E-14	1.47E-14	-13.832
PbCO3 (aq)	2.75E-15	2.82E-15	-14.549
PbF+	1.95E-14	1.51E-14	-13.821
PbF2 (aq)	3.27E-21	3.36E-21	-20.473
PbH2PO4+	7.32E-14	5.67E-14	-13.247
PbHCO3+	5.78E-12	4.47E-12	-11.349
PbHPO4 (aq)	4.4E-16	4.52E-16	-15.345
PbNO2+	1.48E-65	1.15E-65	-64.941
PbNO3+	4.54E-86	3.51E-86	-85.454
PbOH+	4.36E-13	3.38E-13	-12.471
PbSO4 (aq)	1.89E-08	1.94E-08	-7.712
PO4-3	8.14E-19	8.11E-20	-19.091
S-2	4.06E-28	1.46E-28	-27.837
SO4-2	0.020507	0.006715	-2.173
Zn DOM1	1.08E-07	9.16E-08	-7.038
Zn(CO3)2-2	5.98E-24	2.14E-24	-23.669
Zn(N3)2 (aq)	4.28E-15	4.4E-15	-14.356
Zn(N3)3-	9.51E-20	7.36E-20	-19.133
Zn(NH3)2+2	3.94E-20	1.41E-20	-19.85
Zn(NH3)3+2	2.84E-27	1.02E-27	-26.992
Zn(NH3)4+2	1E-34	3.59E-35	-34.445
Zn(NO2)2 (aq)	3E-123	3.1E-123	-122.511

Species	Concentration	Activity	Log activity
Zn(NO3)2 (aq)	4E-163	4.1E-163	-162.383
Zn(OH)2 (aq)	6.68E-16	6.87E-16	-15.163
Zn(OH)3-	8.91E-24	6.9E-24	-23.161
Zn(OH)4-2	9.69E-33	3.47E-33	-32.459
Zn(SO4)2-2	1.29E-06	4.64E-07	-6.333
Zn+2	1.41E-05	5.4E-06	-5.267
Zn2OH+3	3.82E-16	3.8E-17	-16.421
Zn2S3-2	7.11E-41	2.55E-41	-40.594
Zn4S6-4	6.68E-79	1.1E-80	-79.957
ZnCl+	3.6E-07	2.73E-07	-6.563
ZnCl2 (aq)	3.22E-09	3.31E-09	-8.48
ZnCl3-	8.53E-11	6.6E-11	-10.18
ZnCl4-2	1.61E-12	5.76E-13	-12.24
ZnCO3 (aq)	4.27E-14	4.39E-14	-13.358
ZnF+	2.16E-12	1.67E-12	-11.777
ZnHCO3+	2.1E-10	1.63E-10	-9.789
ZnHPO4 (aq)	6.6E-13	6.79E-13	-12.168
ZnN3+	2.93E-10	2.27E-10	-9.644
ZnNH3+2	6.96E-13	2.5E-13	-12.603
ZnNO2+	2.52E-64	1.95E-64	-63.709
ZnNO3+	7.31E-84	5.66E-84	-83.247
ZnOH+	1.02E-11	7.86E-12	-11.105
ZnS (aq)	1.43E-17	1.47E-17	-16.834
ZnSO4 (aq)	7.08E-06	7.28E-06	-5.138

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Species	Concentration	Activity	Log activity
Al DOM1	2.93E-05	2.9E-05	-4.538
Al(OH)2+	1.66E-09	1.29E-09	-8.89
Al(OH)3 (aq)	3.74E-13	3.85E-13	-12.415
Al(OH)4-	3.55E-16	2.72E-16	-15.566
Al(SO4)2-	0.000789	0.000604	-3.219
Al+3	0.000339	5.63E-05	-4.249
Al2(OH)2+4	3.48E-09	5.65E-11	-10.248
Al2(OH)2CO3+2	1.61E-11	5.75E-12	-11.24
Al2PO4+3	6.2E-09	6.11E-10	-9.214
Al3(OH)4+5	1.27E-12	2.03E-15	-14.692
AlCl+2	1.21E-06	4.33E-07	-6.363
AlF+2	1.31E-05	4.82E-06	-5.317
AlF2+	2.19E-08	1.7E-08	-7.768
AlF3 (aq)	1.73E-12	1.78E-12	-11.75
AlF4-	1.04E-17	7.95E-18	-17.1
AlHPO4+	9.48E-08	7.33E-08	-7.135
AlOH+2	1.25E-06	4.59E-07	-6.338
AlSO4+	0.002836	0.00217	-2.663
As3S4(HS)-	8.7E-110	6.7E-110	-109.173
AsO4-3	7.55E-23	7.43E-24	-23.129
AsS(OH)HS-	6.12E-41	4.73E-41	-40.325
Ca DOM1	7.22E-06	6.12E-06	-5.213
Ca(NH3)2+2	3.41E-22	1.22E-22	-21.915
Ca(NO3)2	1.1E-142	1.1E-142	-141.955
Ca+2	0.005923	0.002374	-2.624
CaCl+	0.000138	0.000106	-3.973
CaCO3 (aq)	1.17E-13	1.2E-13	-12.92
CaCrO4 (aq)	2.33E-10	2.4E-10	-9.621
CaF+	3.11E-10	2.4E-10	-9.619
CaH2PO4+	2.23E-08	1.73E-08	-7.761
CaHCO3+	1.91E-08	1.5E-08	-7.823
CaHPO4 (aq)	3.32E-11	3.41E-11	-10.467
CaNH3+2	2.71E-12	9.67E-13	-12.015
CaNO3+	4.03E-70	3.11E-70	-69.507
CaOH+	3.91E-13	3.07E-13	-12.512
CaPO4-	1.48E-16	1.15E-16	-15.939
CaSO4 (aq)	0.003164	0.003255	-2.488
Cd DOM1	5.89E-12	4.99E-12	-11.302
Cd(CO3)2-2	4.61E-29	1.65E-29	-28.783
Cd(HS)2 (aq)	2.05E-44	2.11E-44	-43.675
Cd(HS)3-	2E-67	1.54E-67	-66.811
Cd(HS)4-2	7.94E-90	2.83E-90	-89.548
Cd(NH3)2+2	1.72E-24	6.14E-25	-24.212
Cd(NH3)3+2	5.44E-33	1.94E-33	-32.712

Species	Concentration	Activity	Log activity
Cd(NH3)4+2	5.08E-42	1.81E-42	-41.742
Cd(NO2)2 (aq)	1.8E-108	1.9E-108	-107.725
Cd(NO3)2 (aq)	1.8E-144	1.8E-144	-143.744
Cd(OH)2 (aq)	9.52E-24	9.79E-24	-23.009
Cd(OH)3-	1.98E-33	1.53E-33	-32.816
Cd(OH)4-2	6.95E-44	2.48E-44	-43.605
Cd(SO4)2-2	2.98E-10	1.06E-10	-9.973
Cd+2	2.16E-09	7.71E-10	-9.113
Cd2OH+3	2.01E-24	1.98E-25	-24.703
CdCl+	1.75E-09	1.35E-09	-8.869
CdCl2 (aq)	9.96E-11	1.02E-10	-9.989
CdCO3 (aq)	6.23E-19	6.41E-19	-18.193
CdF+	1.31E-16	1.02E-16	-15.993
CdHCO3+	1.51E-14	1.17E-14	-13.933
CdHPO4 (aq)	1.14E-16	1.18E-16	-15.929
CdHS+	1.18E-26	9.14E-27	-26.039
CdNH3+2	1.12E-16	4.01E-17	-16.397
CdNO2+	7.48E-59	5.78E-59	-58.238
CdNO3+	1.63E-76	1.26E-76	-75.901
CdOH+	5.85E-17	4.52E-17	-16.344
CdSO4 (aq)	1.03E-09	1.06E-09	-8.976
Cl-1	0.025414	0.018877	-1.724
CO3-2	9.66E-14	3.55E-14	-13.45
Cr2O7-2	1.47E-11	5.25E-12	-11.28
CrO3Cl-	3.4E-11	2.63E-11	-10.581
CrO3H2PO4-	1.64E-13	1.27E-13	-12.898
CrO3HPO4-2	1.17E-12	4.17E-13	-12.38
CrO3SO4-2	1.25E-09	4.45E-10	-9.351
CrO4-2	5.21E-10	1.71E-10	-9.766
Cu DOM1	5.61E-09	4.75E-09	-8.323
Cu(CO3)2-2	1.03E-24	3.68E-25	-24.434
Cu(N3)2 (aq)	1.41E-15	1.45E-15	-14.839
Cu(N3)3-	1.43E-19	1.11E-19	-18.957
Cu(N3)4-2	1.24E-24	4.43E-25	-24.354
Cu(NH3)2+2	3.52E-20	1.26E-20	-19.901
Cu(NH3)3+2	3.65E-27	1.3E-27	-26.885
Cu(NH3)4+2	7.83E-35	2.79E-35	-34.554
Cu(NO2)2 (aq)	1.1E-107	1.1E-107	-106.96
Cu(NO3)2 (aq)	1.1E-143	1.1E-143	-142.965
Cu(OH)2 (aq)	7.17E-19	7.37E-19	-18.132
Cu(OH)3-	2.16E-25	1.67E-25	-24.777
Cu(OH)4-2	4.94E-36	1.76E-36	-35.754
Cu+2	4.82E-08	1.84E-08	-7.734
Cu2(OH)2+2	2.73E-20	9.76E-21	-20.011
Cu2OH+3	7.29E-19	7.18E-20	-19.144
Cu2S3-2	2.09E-83	7.47E-84	-83.127

Species	Concentration	Activity	Log activity
Cu3(OH)4+2	4.04E-32	1.44E-32	-31.841
CuCl+	8.16E-10	6.18E-10	-9.209
CuCl2 (aq)	1.89E-12	1.94E-12	-11.711
CuCl3-	3.77E-16	2.85E-16	-15.545
CuCl4-2 1	1.07E-19	3.81E-20	-19.419
CuCO3 (aq)	3.74E-15	3.85E-15	-14.414
CuF+	8.89E-15	6.87E-15	-14.163
CuHCO3+	7.19E-13	5.55E-13	-12.255
CuHPO4 (aq)	7.2E-15	7.41E-15	-14.13
CuHSO4+	2.18E-11	1.68E-11	-10.774
CuN3+	2.63E-11	2.03E-11	-10.692
CuNH3+2	8.88E-14	3.17E-14	-13.499
CuNO2+	1.86E-57	1.44E-57	-56.842
CuNO3+	3.07E-75	2.37E-75	-74.625
CuOH+	7.42E-13	5.62E-13	-12.25
CuS(aq)	5.22E-33	5.37E-33	-32.27
CuSO4 (aq)	2.4E-08	2.47E-08	-7.607
DOC (Gaussian DOM)	0.001399	0.001439	-2.842
DOM1	4.83E-05	6.41E-06	-5.193
F-1	1.19E-08	8.92E-09	-8.049
Fe DOM1	1.84E-10	1.82E-10	-9.739
Fe(N3)2+	1.27E-15	9.85E-16	-15.007
Fe(N3)3 (aq)	3.12E-19	3.21E-19	-18.493
Fe(NH3)2+2	6.43E-20	2.3E-20	-19.639
Fe(NH3)3+2	2.4E-29	8.57E-30	-29.067
Fe(NH3)4+2	3.82E-39	1.37E-39	-38.865
Fe(NO2)2+	4.2E-110	3.3E-110	-109.486
Fe(NO2)3 (aq)	2.7E-159	2.8E-159	-158.554
Fe(OH)2 (aq)	1.02E-17	1.05E-17	-16.981
Fe(OH)2+	3.77E-12	2.94E-12	-11.532
Fe(OH)3-	6.19E-25	4.79E-25	-24.32
Fe(OH)3 (aq)	1.5E-18	1.54E-18	-17.812
Fe(OH)4-	2.06E-23	1.6E-23	-22.796
Fe(SO4)2-	1.16E-11	8.97E-12	-11.047
Fe+2	0.018191	0.00696	-2.157
Fe+3	6.75E-12	1.12E-12	-11.951
Fe2(OH)2+4	1.12E-19	1.82E-21	-20.741
Fe3(OH)4+5	1.14E-27	1.82E-30	-29.741
FeCl+	0.000107	8.29E-05	-4.081
FeCl+2	1.3E-12	4.63E-13	-12.335
FeCrO4+	9.12E-15	7.05E-15	-14.152
FeF+	1.3E-09	1.01E-09	-8.997
FeF+2	2.67E-14	9.53E-15	-14.021
FeF2+	4.16E-18	3.21E-18	-17.493
FeF3 (aq)	2.58E-23	2.66E-23	-22.575

Species	Concentration	Activity	Log activity
FeH2PO4+	1.34E-06	1.05E-06	-5.98
FeH2PO4+2	1.73E-14	6.36E-15	-14.197
FeHCO3+	5.32E-08	4.18E-08	-7.378
FeHPO4 (aq)	8.12E-10	8.35E-10	-9.078
FeHPO4+	5.41E-13	4.21E-13	-12.376
FeHS+	4.35E-22	3.36E-22	-21.473
FeN3+2	7.45E-13	2.66E-13	-12.575
FeNH3+2	6.79E-11	2.42E-11	-10.616
FeNO2+2	3.71E-60	1.32E-60	-59.878
FeOH+	2.61E-09	2.02E-09	-8.695
FeOH+2	3.34E-11	1.19E-11	-10.924
FeSO4 (aq)	0.009814	0.010095	-1.996
FeSO4+	1.2E-10	9.28E-11	-10.033
H DOM1	3.5E-05	1.52E-05	-4.819
H+1	0.00077	0.000631	-3.2
H2AsO3-	4.79E-12	3.71E-12	-11.431
H2AsO4-	3.18E-11	2.45E-11	-10.61
H2CO3* (aq)	0.000966	0.000994	-3.003
H2CrO4 (aq)	7.84E-11	8.07E-11	-10.093
H2PO4-	4.96E-07	3.86E-07	-6.413
H2S (aq)	1.03E-21	1.06E-21	-20.973
H3AsO3	4.95E-06	5.09E-06	-5.293
H3AsO4	2.69E-12	2.76E-12	-11.558
H3PO4	3E-08	3.08E-08	-7.511
HAsO3-2	8.37E-23	2.99E-23	-22.524
HAsO4-2	1.07E-14	3.82E-15	-14.418
HCO3-	7.71E-07	6E-07	-6.222
HCrO4-	4.4E-07	3.4E-07	-6.468
HF (aq)	6.88E-09	7.07E-09	-8.15
HF2-	3.17E-16	2.37E-16	-15.625
Hg(CO3)2-2	1.61E-36	5.76E-37	-36.24
Hg(HS)2 (aq)	4.13E-37	4.25E-37	-36.372
Hg(N3)2 (aq)	6.95E-15	7.15E-15	-14.146
Hg(NH3)2+2	2.36E-26	8.41E-27	-26.075
Hg(NH3)4+2	1.68E-44	6E-45	-44.222
Hg(NO2)2 (aq)	5.3E-118	5.4E-118	-117.265
Hg(NO2)3-	1.8E-167	1.4E-167	-166.853
Hg(NO2)4-2	7.5E-218	2.7E-218	-217.57
Hg(NO3)2 (aq)	2.9E-161	2.9E-161	-160.53
Hg(OH)2	2.02E-25	2.08E-25	-24.682
Hg(SO4)2-2	4.45E-26	1.59E-26	-25.799
Hg+2	5.93E-25	2.12E-25	-24.674
Hg2OH+3	2.99E-49	2.94E-50	-49.532
Hg3(OH)3+3	2.92E-71	2.88E-72	-71.541
HgCl+	1.47E-19	1.14E-19	-18.945
HgCl2 (aq)	1.6E-14	1.64E-14	-13.784

Species	Concentration	Activity	Log activity
HgCl3-1	3.99E-15	3.09E-15	-14.51
HgCl4-2	7.31E-16	2.61E-16	-15.583
HgClOH (aq)	1.22E-19	1.26E-19	-18.901
HgCO3 (aq)	5.6E-27	5.76E-27	-26.24
HgF+	9.12E-32	7.05E-32	-31.152
HgHCO3+	7.8E-26	6.03E-26	-25.22
HgHS2-	2.82E-40	2.18E-40	-39.662
HgN3+	2.49E-10	1.93E-10	-9.715
HgNO2+	1.01E-70	7.81E-71	-70.107
HgNO3+	2.39E-93	1.85E-93	-92.734
HgOH+	1.3E-25	1E-25	-24.999
HgOHCO3-	1.38E-30	1.07E-30	-29.971
HgS2-2	1.89E-45	6.73E-46	-45.172
HgSO4 (aq)	2.28E-25	2.35E-25	-24.629
HN3 (aq)	4.8E-05	4.94E-05	-4.306
HNO2 (aq)	6.46E-52	6.64E-52	-51.178
HPO4-2	1.04E-10	3.72E-11	-10.43
HS-1	1.55E-25	1.16E-25	-24.936
HSO4-	0.000405	0.00031	-3.508
K+1	0.000318	0.000236	-3.626
K2HPO4 (aq)	2.18E-17	2.25E-17	-16.648
K2PO4-	2.65E-25	2.05E-25	-24.688
KCl (aq)	2.3E-06	2.37E-06	-5.626
KCr2O7-	1.39E-14	1.07E-14	-13.97
KCrO4-	1.95E-13	1.51E-13	-12.822
KF (aq)	9.38E-13	9.64E-13	-12.016
KH2PO4 (aq)	1.38E-10	1.42E-10	-9.849
KHPO4-	6.94E-14	5.41E-14	-13.267
KNO3 (aq)	6.75E-72	6.94E-72	-71.159
KOH (aq)	2.91E-15	3E-15	-14.524
KPO4-2	2.91E-22	1.04E-22	-21.983
KSO4-	1.19E-05	9.24E-06	-5.035
Mg DOM1	6.32E-07	5.36E-07	-6.271
Mg(NH3)2+2	1.49E-22	5.31E-23	-22.275
Mg+2	0.004974	0.002078	-2.682
Mg2CO3+2	1.67E-15	5.96E-16	-15.225
MgCl+	0.000191	0.000148	-3.831
MgCO3 (aq)	5.11E-14	5.26E-14	-13.279
MgF+	1.6E-09	1.23E-09	-8.911
MgHCO3+	1.6E-08	1.21E-08	-7.917
MgHPO4 (aq)	4.01E-11	4.12E-11	-10.385
MgOH+	6.45E-12	5.12E-12	-11.291
MgPO4-	2.02E-18	1.57E-18	-17.803
MgSO4 (aq)	0.00224	0.002304	-2.637
Mn+3	4.55E-05	7.55E-06	-5.122
N3-1	1.97E-06	1.52E-06	-5.817

Species	Concentration	Activity	Log activity
Na+1	0.012088	0.009351	-2.029
Na2HPO4 (aq)	2.26E-14	2.32E-14	-13.634
Na2PO4-	8.87E-22	6.85E-22	-21.164
NaCl (aq)	9.62E-05	9.9E-05	-4.005
NaCO3-	1.06E-14	8.21E-15	-14.085
NaCrO4-	1.03E-11	7.96E-12	-11.099
NaF (aq)	7.18E-11	7.39E-11	-10.132
NaH2PO4 (aq)	5.44E-09	5.6E-09	-8.252
NaHCO3 (aq)	3.23E-09	3.33E-09	-8.478
NaHPO4-	4.25E-12	3.31E-12	-11.48
NaNO3 (aq)	9.84E-71	1.01E-70	-69.995
NaOH (aq)	7.89E-14	8.11E-14	-13.091
NaPO4-2	1.27E-20	4.53E-21	-20.344
NaSO4-	0.00043	0.000335	-3.475
NH3 (aq)	1.19E-10	1.22E-10	-9.912
NH4+1	0.000386	0.000282	-3.55
NH4Cr2O7-	1.92E-14	1.48E-14	-13.829
NH4SO4-	2.58E-05	1.99E-05	-4.7
Ni DOM1	2.81E-08	2.38E-08	-7.623
Ni(N3)2 (aq)	8.18E-16	8.42E-16	-15.075
Ni(NH3)2+2	1.79E-20	6.38E-21	-20.195
Ni(NH3)3+2	1.27E-28	4.52E-29	-28.345
Ni(NH3)4+2	2.67E-37	9.51E-38	-37.022
Ni(NH3)5+2	1.81E-46	6.46E-47	-46.19
Ni(NH3)6+2	2.62E-56	9.35E-57	-56.029
Ni(NO2)2 (aq)	1.2E-106	1.3E-106	-105.9
Ni(OH)2 (aq)	9.06E-19	9.31E-19	-18.031
Ni(OH)3-	1.92E-26	1.48E-26	-25.829
Ni(SO4)2-2	2.97E-09	1.06E-09	-8.975
Ni+2	1.03E-05	3.67E-06	-5.435
NiCl+	3.24E-08	2.51E-08	-7.601
NiCl2 (aq)	1.64E-11	1.69E-11	-10.773
NiCO3 (aq)	4.71E-15	4.84E-15	-14.315
NiF+	7.66E-13	5.92E-13	-12.227
NiH2PO4+	1.21E-11	9.32E-12	-11.031
NiHCO3+	2.8E-10	2.16E-10	-9.665
NiHPO4 (aq)	9.71E-14	9.98E-14	-13.001
NiHS+	1.7E-25	1.32E-25	-24.881
NiN3+	1.36E-10	1.05E-10	-9.977
NiNH3+2	8.27E-13	2.95E-13	-12.53
NiNO2+	8.5E-56	6.57E-56	-55.183
NiNO3+	4.59E-73	3.55E-73	-72.45
NiOH+	4.61E-13	3.57E-13	-12.448
NiSO4 (aq)	4.34E-06	4.47E-06	-5.35
NO2-1	9.64E-52	7.45E-52	-51.128
NO3-1	5.19E-68	3.84E-68	-67.415

Species	Concentration	Activity	Log activity
OH-	9.73E-12	7.29E-12	-11.137
Pb DOM1	3.79E-09	3.21E-09	-8.493
Pb(CO3)2-2	1.92E-25	6.85E-26	-25.164
Pb(HS)2 (aq)	1.52E-43	1.56E-43	-42.806
Pb(HS)3-	4.67E-67	3.61E-67	-66.443
Pb(NO2)2 (aq)	4.3E-108	4.5E-108	-107.35
Pb(NO3)2 (aq)	2.5E-142	2.5E-142	-141.595
Pb(OH)2 (aq)	1.22E-19	1.26E-19	-18.9
Pb(OH)3-	2.59E-27	2E-27	-26.698
Pb(SO4)2-2	2.26E-09	8.05E-10	-9.094
Pb+2	1.75E-08	6.25E-09	-8.204
Pb2OH+3	2.51E-19	2.47E-20	-19.607
Pb3(OH)4+2	1.09E-36	3.88E-37	-36.412
Pb4(OH)4+4	2.3E-40	3.74E-42	-41.428
PbCl+	4.9E-09	3.79E-09	-8.421
PbCl2 (aq)	1.45E-10	1.49E-10	-9.825
PbCl3-	2.9E-12	2.24E-12	-11.65
PbCl4-2	4.33E-14	1.55E-14	-13.811
PbCO3 (aq)	7.3E-16	7.51E-16	-15.124
PbF+	1.02E-14	7.87E-15	-14.104
PbF2 (aq)	8.4E-22	8.64E-22	-21.063
PbH2PO4+	7.67E-14	5.93E-14	-13.227
PbHCO3+	3.07E-12	2.37E-12	-11.624
PbHPO4 (aq)	2.3E-16	2.37E-16	-15.625
PbNO2+	1.95E-57	1.51E-57	-56.822
PbNO3+	4.72E-75	3.65E-75	-74.438
PbOH+	2.32E-13	1.79E-13	-12.747
PbSO4 (aq)	1.97E-08	2.02E-08	-7.694
PO4-3	2.05E-19	2.01E-20	-19.696
S-2	1.03E-39	3.66E-40	-39.436
SO4-2	0.020314	0.006609	-2.18
Zn DOM1	6.58E-08	5.58E-08	-7.253
Zn(CO3)2-2	3.82E-25	1.36E-25	-24.865
Zn(N3)2 (aq)	1.17E-15	1.2E-15	-14.92
Zn(N3)3-	1.35E-20	1.05E-20	-19.98
Zn(NH3)2+2	9.99E-21	3.56E-21	-20.448
Zn(NH3)3+2	3.6E-28	1.28E-28	-27.891
Zn(NH3)4+2	6.35E-36	2.27E-36	-35.645
Zn(NO2)2 (aq)	4.7E-107	4.8E-107	-106.32
Zn(NO3)2 (aq)	3.9E-141	4E-141	-140.396
Zn(OH)2 (aq)	1.69E-16	1.73E-16	-15.761
Zn(OH)3-	1.13E-24	8.73E-25	-24.059
Zn(OH)4-2	6.17E-34	2.2E-34	-33.657
Zn(SO4)2-2	1.27E-06	4.52E-07	-6.345
Zn+2	1.42E-05	5.43E-06	-5.265
Zn2OH+3	1.95E-16	1.92E-17	-16.716

Species	Concentration	Activity	Log activity
Zn2S3-2	1.15E-75	4.09E-76	-75.388
Zn4S6-4	1.8E-148	2.8E-150	-149.546
ZnCl+	3.62E-07	2.74E-07	-6.562
ZnCl2 (aq)	3.22E-09	3.31E-09	-8.48
ZnCl3-	8.54E-11	6.6E-11	-10.18
ZnCl4-2	1.61E-12	5.75E-13	-12.24
ZnCO3 (aq)	1.08E-14	1.11E-14	-13.955
ZnF+	1.07E-12	8.29E-13	-12.081
ZnHCO3+	1.06E-10	8.2E-11	-10.086
ZnHPO4 (aq)	3.29E-13	3.38E-13	-12.471
ZnN3+	1.54E-10	1.19E-10	-9.925
ZnNH3+2	3.52E-13	1.26E-13	-12.901
ZnNO2+	3.16E-56	2.44E-56	-55.613
ZnNO3+	7.24E-73	5.59E-73	-72.252
ZnOH+	5.12E-12	3.96E-12	-11.402
ZnS (aq)	3.6E-29	3.71E-29	-28.431
ZnSO4 (aq)	7E-06	7.2E-06	-5.143

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Species	Concentration	Activity	Log activity
Al DOM1	2.31E-05	2.28E-05	-4.641
Al(OH)2+	4.47E-10	3.5E-10	-9.456
Al(OH)3 (aq)	4.97E-14	5.11E-14	-13.292
Al(OH)4-	2.29E-17	1.77E-17	-16.753
Al(SO4)2-	0.001005	0.000774	-3.111
Al+3	0.000374	6.39E-05	-4.194
Al2(OH)2+4	1E-09	1.74E-11	-10.759
Al2(OH)2CO3+2	1.18E-12	4.28E-13	-12.369
Al2PO4+3	2.22E-09	2.27E-10	-9.643
Al3(OH)4+5	9.54E-14	1.7E-16	-15.77
AlCl+2	1.27E-06	4.6E-07	-6.337
AlF+2	1.31E-05	4.92E-06	-5.308
AlF2+	2E-08	1.56E-08	-7.806
AlF3 (aq)	1.43E-12	1.46E-12	-11.834
AlF4-	7.65E-18	5.89E-18	-17.23
AlHPO4+	6.3E-08	4.89E-08	-7.311
AlOH+2	6.81E-07	2.55E-07	-6.594
AlSO4+	0.0034	0.002617	-2.582
As3S4(HS)-	2.5E-175	1.9E-175	-174.72
AsO4-3	6.52E-21	6.67E-22	-21.176
AsS(OH)HS-	5.34E-63	4.15E-63	-62.382
Ca DOM1	4.94E-06	4.2E-06	-5.376
Ca(NH3)2+2	8.07E-23	2.93E-23	-22.533
Ca(NO3)2	6.9E-121	7.1E-121	-120.148
Ca+2	0.005769	0.002348	-2.629

Species	Concentration	Activity	Log activity
CaCl+	0.000127	9.86E-05	-4.006
CaCO3 (aq)	2.8E-14	2.87E-14	-13.542
CaCrO4 (aq)	1.14E-10	1.17E-10	-9.933
CaF+	2.75E-10	2.14E-10	-9.67
CaH2PO4+	2.62E-08	2.05E-08	-7.688
CaHCO3+	9.24E-09	7.3E-09	-8.136
CaHPO4 (aq)	1.93E-11	1.99E-11	-10.702
CaNH3+2	1.3E-12	4.72E-13	-12.326
CaNO3+	3.19E-59	2.48E-59	-58.606
CaOH+	1.88E-13	1.49E-13	-12.828
CaPO4-	4.21E-17	3.29E-17	-16.482
CaSO4 (aq)	0.003331	0.003421	-2.466
Cd DOM1	4.13E-12	3.51E-12	-11.454
Cd(CO3)2-2	2.68E-30	9.75E-31	-30.011
Cd(HS)2 (aq)	8.94E-67	9.18E-67	-66.037
Cd(HS)3-	5.7E-101	4.4E-101	-100.357
Cd(HS)4-2	1.5E-134	5.3E-135	-134.277
Cd(NH3)2+2	4.17E-25	1.52E-25	-24.819
Cd(NH3)3+2	6.52E-34	2.37E-34	-33.626
Cd(NH3)4+2	3E-43	1.09E-43	-42.962
Cd(NO2)2 (aq)	2.1E-92	2.16E-92	-91.666
Cd(NO3)2 (aq)	1.2E-122	1.2E-122	-121.926
Cd(OH)2 (aq)	2.31E-24	2.37E-24	-23.624
Cd(OH)3-	2.33E-34	1.81E-34	-33.742
Cd(OH)4-2	3.97E-45	1.44E-45	-44.841
Cd(SO4)2-2	3.36E-10	1.22E-10	-9.914
Cd+2	2.15E-09	7.81E-10	-9.107
Cd2OH+3	9.72E-25	9.96E-26	-25.002
CdCl+	1.65E-09	1.28E-09	-8.892
CdCl2 (aq)	8.87E-11	9.11E-11	-10.041
CdCO3 (aq)	1.53E-19	1.57E-19	-18.804
CdF+	1.19E-16	9.26E-17	-16.034
CdHCO3+	7.48E-15	5.81E-15	-14.236
CdHPO4 (aq)	6.84E-17	7.02E-17	-16.154
CdHS+	7.81E-38	6.06E-38	-37.217
CdNH3+2	5.52E-17	2.01E-17	-16.698
CdNO2+	8.02E-51	6.23E-51	-50.206
CdNO3+	1.32E-65	1.03E-65	-64.989
CdOH+	2.89E-17	2.24E-17	-16.649
CdSO4 (aq)	1.11E-09	1.14E-09	-8.944
Cl-1	0.023635	0.017675	-1.753
CO3-2	2.29E-14	8.57E-15	-14.067
Cr2O7-2	1.46E-11	5.3E-12	-11.276
CrO3Cl-	6.49E-11	5.04E-11	-10.298
CrO3H2PO4-	4E-13	3.1E-13	-12.508
CrO3HPO4-2	1.38E-12	5.02E-13	-12.299

Species	Concentration	Activity	Log activity
CrO3SO4-2	2.67E-09	9.69E-10	-9.013
CrO4-2	2.51E-10	8.45E-11	-10.073
Cu DOM1	3.94E-09	3.35E-09	-8.475
Cu(CO3)2-2	6E-26	2.18E-26	-25.662
Cu(N3)2 (aq)	3.59E-16	3.69E-16	-15.433
Cu(N3)3-	1.82E-20	1.41E-20	-19.851
Cu(N3)4-2	7.79E-26	2.83E-26	-25.548
Cu(NH3)2+2	8.55E-21	3.1E-21	-20.508
Cu(NH3)3+2	4.38E-28	1.59E-28	-27.799
Cu(NH3)4+2	4.63E-36	1.68E-36	-35.774
Cu(NO2)2 (aq)	1.22E-91	1.26E-91	-90.901
Cu(NO3)2 (aq)	6.9E-122	7.1E-122	-121.147
Cu(OH)2 (aq)	1.74E-19	1.79E-19	-18.747
Cu(OH)3-	2.55E-26	1.98E-26	-25.703
Cu(OH)4-2	2.82E-37	1.02E-37	-36.99
Cu+2	4.8E-08	1.87E-08	-7.728
Cu2(OH)2+2	6.61E-21	2.4E-21	-20.62
Cu2OH+3	3.53E-19	3.61E-20	-19.442
Cu2S3-2	7.1E-118	2.6E-118	-117.591
Cu3(OH)4+2	2.37E-33	8.61E-34	-33.065
CuCl+	7.7E-10	5.87E-10	-9.231
CuCl2 (aq)	1.68E-12	1.73E-12	-11.762
CuCl3-	3.12E-16	2.37E-16	-15.625
CuCl4-2 1	8.16E-20	2.97E-20	-19.527
CuCO3 (aq)	9.19E-16	9.44E-16	-15.025
CuF+	8.07E-15	6.26E-15	-14.203
CuHCO3+	3.56E-13	2.77E-13	-12.558
CuHPO4 (aq)	4.31E-15	4.42E-15	-14.354
CuHSO4+	4.75E-11	3.68E-11	-10.434
CuN3+	1.33E-11	1.03E-11	-10.986
CuNH3+2	4.37E-14	1.59E-14	-13.8
CuNO2+	2E-49	1.55E-49	-48.809
CuNO3+	2.5E-64	1.94E-64	-63.713
CuOH+	3.66E-13	2.79E-13	-12.555
CuS(aq)	1.71E-44	1.75E-44	-43.756
CuSO4 (aq)	2.59E-08	2.66E-08	-7.575
DOC (Gaussian DOM)	0.001399	0.001436	-2.843
DOM1	4.33E-05	5.94E-06	-5.226
F-1	1.06E-08	8.02E-09	-8.096
Fe DOM1	5.55E-09	5.49E-09	-8.26
Fe(N3)2+	1.38E-14	1.07E-14	-13.969
Fe(N3)3 (aq)	1.71E-18	1.76E-18	-17.756
Fe(NH3)2+2	1.19E-20	4.33E-21	-20.364
Fe(NH3)3+2	2.2E-30	7.97E-31	-30.098
Fe(NH3)4+2	1.73E-40	6.27E-41	-40.203

Species	Concentration	Activity	Log activity
Fe(NO2)2+	2.06E-92	1.6E-92	-91.795
Fe(NO2)3 (aq)	1.4E-133	1.5E-133	-132.836
Fe(OH)2 (aq)	1.89E-18	1.94E-18	-17.713
Fe(OH)2+	3.9E-11	3.05E-11	-10.515
Fe(OH)3-	5.58E-26	4.33E-26	-25.363
Fe(OH)3 (aq)	7.64E-18	7.84E-18	-17.105
Fe(OH)4-	5.09E-23	3.98E-23	-22.4
Fe(SO4)2-	5.67E-10	4.4E-10	-9.357
Fe+2	0.013821	0.005384	-2.269
Fe+3	2.85E-10	4.86E-11	-10.313
Fe2(OH)2+4	4.71E-17	8.2E-19	-18.086
Fe3(OH)4+5	4.78E-24	8.51E-27	-26.07
FeCl+	7.73E-05	6E-05	-4.222
FeCl+2	5.16E-11	1.88E-11	-10.726
FeCrO4+	1.94E-13	1.51E-13	-12.822
FeF+	9.02E-10	7E-10	-9.155
FeF+2	1.02E-12	3.72E-13	-12.43
FeF2+	1.45E-16	1.13E-16	-15.948
FeF3 (aq)	8.16E-22	8.38E-22	-21.077
FeH2PO4+	1.24E-06	9.68E-07	-6.014
FeH2PO4+2	8.82E-13	3.3E-13	-12.481
FeHCO3+	2.01E-08	1.59E-08	-7.799
FeHPO4 (aq)	3.7E-10	3.8E-10	-9.42
FeHPO4+	1.37E-11	1.08E-11	-10.969
FeHS+	2.19E-33	1.7E-33	-32.769
FeN3+2	1.59E-11	5.79E-12	-11.238
FeNH3+2	2.55E-11	9.25E-12	-11.034
FeNO2+2	1.68E-50	6.11E-51	-50.214
FeOH+	9.84E-10	7.64E-10	-9.117
FeOH+2	6.94E-10	2.53E-10	-9.597
FeSO4 (aq)	0.008083	0.0083	-2.081
FeSO4+	5.51E-09	4.28E-09	-8.369
H DOM1	4.87E-05	2.14E-05	-4.669
H+1	0.001561	0.001283	-2.892
H2AsO3-	2.34E-12	1.81E-12	-11.741
H2AsO4-	1.17E-08	9.11E-09	-8.04
H2CO3* (aq)	0.000967	0.000993	-3.003
H2CrO4 (aq)	1.6E-10	1.64E-10	-9.784
H2PO4-	5.9E-07	4.62E-07	-6.336
H2S (aq)	1.38E-32	1.42E-32	-31.849
H3AsO3	4.93E-06	5.07E-06	-5.295
H3AsO4	2.03E-09	2.09E-09	-8.681
H3PO4	7.3E-08	7.5E-08	-7.125
HAsO3-2	1.98E-23	7.2E-24	-23.143
HAsO4-2	1.92E-12	6.97E-13	-12.157
HCO3-	3.77E-07	2.95E-07	-6.53

Species	Concentration	Activity	Log activity
HCrO4-	4.39E-07	3.41E-07	-6.467
HF (aq)	1.26E-08	1.29E-08	-7.888
HF2-	5.17E-16	3.9E-16	-15.409
Hg(CO3)2-2	3.2E-36	1.16E-36	-35.935
Hg(HS)2 (aq)	6.13E-58	6.29E-58	-57.201
Hg(N3)2 (aq)	1.44E-14	1.48E-14	-13.829
Hg(NH3)2+2	1.95E-25	7.08E-26	-25.15
Hg(NH3)4+2	3.39E-44	1.23E-44	-43.91
Hg(NO2)2 (aq)	2.1E-100	2.1E-100	-99.674
Hg(NO2)3-	7.5E-142	5.8E-142	-141.235
Hg(NO2)4-2	3.3E-184	1.2E-184	-183.926
Hg(NO3)2 (aq)	6.4E-138	6.6E-138	-137.18
Hg(OH)2	1.67E-24	1.72E-24	-23.765
Hg(SO4)2-2	1.7E-24	6.19E-25	-24.208
Hg+2	2.01E-23	7.31E-24	-23.136
Hg2OH+3	1.67E-46	1.71E-47	-46.766
Hg3(OH)3+3	1.35E-67	1.39E-68	-67.858
HgCl+	4.73E-18	3.67E-18	-17.435
HgCl2 (aq)	4.85E-13	4.98E-13	-12.303
HgCl3-1	1.13E-13	8.75E-14	-13.058
HgCl4-2	1.91E-14	6.93E-15	-14.16
HgClOH (aq)	1.93E-18	1.99E-18	-17.702
HgCO3 (aq)	4.68E-26	4.8E-26	-25.318
HgF+	2.82E-30	2.19E-30	-29.66
HgHCO3+	1.32E-24	1.02E-24	-23.99
HgHS2-	2.04E-61	1.59E-61	-60.799
HgN3+	2.49E-10	1.93E-10	-9.714
HgNO2+	3.69E-61	2.87E-61	-60.543
HgNO3+	6.61E-81	5.13E-81	-80.289
HgOH+	2.18E-24	1.69E-24	-23.771
HgOHCO3-	5.63E-30	4.37E-30	-29.36
HgS2-2	6.64E-67	2.41E-67	-66.618
HgSO4 (aq)	8.39E-24	8.61E-24	-23.065
HN3 (aq)	4.9E-05	5.03E-05	-4.298
HNO2 (aq)	1.4E-43	1.44E-43	-42.843
HPO4-2	6.01E-11	2.19E-11	-10.66
HS-1	1.01E-36	7.59E-37	-36.12
HSO4-	0.000871	0.00067	-3.174
K+1	0.000318	0.000238	-3.624
K2HPO4 (aq)	1.3E-17	1.34E-17	-16.874
K2PO4-	7.72E-26	5.99E-26	-25.223
KCl (aq)	2.17E-06	2.23E-06	-5.652
KCr2O7-	1.4E-14	1.09E-14	-13.964
KCrO4-	9.6E-14	7.45E-14	-13.128
KF (aq)	8.48E-13	8.71E-13	-12.06
KH2PO4 (aq)	1.66E-10	1.7E-10	-9.769

Species	Concentration	Activity	Log activity
KHPO4-	4.09E-14	3.2E-14	-13.495
KNO3 (aq)	5.47E-61	5.62E-61	-60.25
KOH (aq)	1.43E-15	1.47E-15	-14.832
KPO4-2	8.32E-23	3.02E-23	-22.52
KSO4-	1.26E-05	9.87E-06	-5.006
Mg DOM1	4.34E-07	3.69E-07	-6.433
Mg(NH3)2+2	3.53E-23	1.28E-23	-22.892
Mg+2	0.004865	0.00206	-2.686
Mg2CO3+2	3.9E-16	1.42E-16	-15.849
MgCl+	0.000177	0.000137	-3.863
MgCO3 (aq)	1.23E-14	1.26E-14	-13.9
MgF+	1.42E-09	1.09E-09	-8.961
MgHCO3+	7.74E-09	5.9E-09	-8.229
MgHPO4 (aq)	2.34E-11	2.4E-11	-10.619
MgOH+	3.12E-12	2.48E-12	-11.605
MgPO4-	5.77E-19	4.52E-19	-18.345
MgSO4 (aq)	0.002364	0.002428	-2.615
Mn+3	4.55E-05	7.77E-06	-5.11
N3-1	9.83E-07	7.63E-07	-6.117
Na+1	0.012067	0.009379	-2.028
Na2HPO4 (aq)	1.34E-14	1.37E-14	-13.862
Na2PO4-	2.57E-22	2E-22	-21.7
NaCl (aq)	9.05E-05	9.29E-05	-4.032
NaCO3-	2.54E-15	1.99E-15	-14.701
NaCrO4-	5.07E-12	3.94E-12	-11.405
NaF (aq)	6.49E-11	6.66E-11	-10.177
NaH2PO4 (aq)	6.54E-09	6.72E-09	-8.173
NaHCO3 (aq)	1.6E-09	1.64E-09	-8.785
NaHPO4-	2.5E-12	1.95E-12	-11.709
NaNO3 (aq)	7.97E-60	8.18E-60	-59.087
NaOH (aq)	3.88E-14	3.98E-14	-13.4
NaPO4-2	3.62E-21	1.32E-21	-20.881
NaSO4-	0.000456	0.000357	-3.447
NH3 (aq)	5.89E-11	6.04E-11	-10.219
NH4+1	0.000384	0.000283	-3.549
NH4Cr2O7-	1.94E-14	1.5E-14	-13.823
NH4SO4-	2.74E-05	2.13E-05	-4.672
Ni DOM1	1.93E-08	1.64E-08	-7.784
Ni(N3)2 (aq)	2.05E-16	2.1E-16	-15.678
Ni(NH3)2+2	4.25E-21	1.54E-21	-20.811
Ni(NH3)3+2	1.49E-29	5.41E-30	-29.267
Ni(NH3)4+2	1.55E-38	5.61E-39	-38.251
Ni(NH3)5+2	5.18E-48	1.88E-48	-47.725
Ni(NH3)6+2	3.7E-58	1.34E-58	-57.871
Ni(NO2)2 (aq)	1.38E-90	1.41E-90	-89.85
Ni(OH)2 (aq)	2.16E-19	2.22E-19	-18.655

Species	Concentration	Activity	Log activity
Ni(OH)3-	2.22E-27	1.73E-27	-26.763
Ni(SO4)2-2	3.28E-09	1.19E-09	-8.924
Ni+2	1.01E-05	3.65E-06	-5.438
NiCl+	3E-08	2.33E-08	-7.632
NiCl2 (aq)	1.43E-11	1.47E-11	-10.833
NiCO3 (aq)	1.13E-15	1.16E-15	-14.934
NiF+	6.82E-13	5.29E-13	-12.276
NiH2PO4+	1.43E-11	1.11E-11	-10.956
NiHCO3+	1.36E-10	1.06E-10	-9.976
NiHPO4 (aq)	5.69E-14	5.84E-14	-13.234
NiHS+	1.1E-36	8.56E-37	-36.068
NiN3+	6.76E-11	5.25E-11	-10.28
NiNH3+2	3.98E-13	1.45E-13	-12.839
NiNO2+	8.94E-48	6.94E-48	-47.159
NiNO3+	3.66E-62	2.84E-62	-61.547
NiOH+	2.23E-13	1.73E-13	-12.761
NiSO4 (aq)	4.59E-06	4.72E-06	-5.326
NO2-1	1.02E-43	7.92E-44	-43.101
NO3-1	4.16E-57	3.1E-57	-56.509
OH-	4.73E-12	3.57E-12	-11.448
Pb DOM1	2.64E-09	2.25E-09	-8.649
Pb(CO3)2-2	1.11E-26	4.02E-27	-26.395
Pb(HS)2 (aq)	6.56E-66	6.74E-66	-65.171
Pb(HS)3-	1.3E-100	1E-100	-99.991
Pb(NO2)2 (aq)	4.95E-92	5.08E-92	-91.294
Pb(NO3)2 (aq)	1.6E-120	1.7E-120	-119.78
Pb(OH)2 (aq)	2.95E-20	3.03E-20	-19.519
Pb(OH)3-	3.04E-28	2.36E-28	-27.627
Pb(SO4)2-2	2.52E-09	9.15E-10	-9.038
Pb+2	1.73E-08	6.29E-09	-8.202
Pb2OH+3	1.2E-19	1.23E-20	-19.912
Pb3(OH)4+2	6.23E-38	2.26E-38	-37.646
Pb4(OH)4+4	1.26E-41	2.19E-43	-42.659
PbCl+	4.6E-09	3.57E-09	-8.447
PbCl2 (aq)	1.28E-10	1.32E-10	-9.88
PbCl3-	2.38E-12	1.85E-12	-11.733
PbCl4-2	3.29E-14	1.2E-14	-13.922
PbCO3 (aq)	1.78E-16	1.83E-16	-15.738
PbF+	9.17E-15	7.12E-15	-14.147
PbF2 (aq)	6.85E-22	7.03E-22	-21.153
PbH2PO4+	9.19E-14	7.13E-14	-13.147
PbHCO3+	1.51E-12	1.17E-12	-11.93
PbHPO4 (aq)	1.37E-16	1.4E-16	-15.853
PbNO2+	2.08E-49	1.61E-49	-48.793
PbNO3+	3.81E-64	2.96E-64	-63.529
PbOH+	1.14E-13	8.81E-14	-13.055

Species	Concentration	Activity	Log activity
PbSO4 (aq)	2.11E-08	2.16E-08	-7.665
PO4-3	5.66E-20	5.83E-21	-20.234
S-2	3.24E-51	1.18E-51	-50.928
SO4-2	0.021069	0.007025	-2.153
Zn DOM1	4.5E-08	3.82E-08	-7.417
Zn(CO3)2-2	2.17E-26	7.87E-27	-26.104
Zn(N3)2 (aq)	2.9E-16	2.98E-16	-15.526
Zn(N3)3-	1.68E-21	1.3E-21	-20.886
Zn(NH3)2+2	2.36E-21	8.57E-22	-21.067
Zn(NH3)3+2	4.2E-29	1.53E-29	-28.817
Zn(NH3)4+2	3.66E-37	1.33E-37	-36.876
Zn(NO2)2 (aq)	5.2E-91	5.34E-91	-90.273
Zn(NO3)2 (aq)	2.5E-119	2.6E-119	-118.589
Zn(OH)2 (aq)	3.99E-17	4.1E-17	-16.388
Zn(OH)3-	1.3E-25	1.01E-25	-24.996
Zn(OH)4-2	3.43E-35	1.25E-35	-34.904
Zn(SO4)2-2	1.39E-06	5.04E-07	-6.297
Zn+2	1.38E-05	5.36E-06	-5.271
Zn2OH+3	8.96E-17	9.17E-18	-17.037
Zn2S3-2	3.7E-110	1.3E-110	-109.875
Zn4S6-4	1.7E-217	3E-219	-218.52
ZnCl+	3.33E-07	2.54E-07	-6.596
ZnCl2 (aq)	2.79E-09	2.87E-09	-8.542
ZnCl3-	6.89E-11	5.35E-11	-10.272
ZnCl4-2	1.2E-12	4.36E-13	-12.36
ZnCO3 (aq)	2.58E-15	2.65E-15	-14.577
ZnF+	9.48E-13	7.36E-13	-12.133
ZnHCO3+	5.13E-11	3.98E-11	-10.4
ZnHPO4 (aq)	1.91E-13	1.97E-13	-12.707
ZnN3+	7.58E-11	5.89E-11	-10.23
ZnNH3+2	1.69E-13	6.13E-14	-13.213
ZnNO2+	3.3E-48	2.56E-48	-47.592
ZnNO3+	5.73E-62	4.45E-62	-61.352
ZnOH+	2.46E-12	1.91E-12	-11.718
ZnS (aq)	1.15E-40	1.18E-40	-39.929
ZnSO4 (aq)	7.36E-06	7.56E-06	-5.122

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Species	Concentration	Activity	Log activity
Al DOM1	9.27E-06	9.18E-06	-5.037
Al(OH)2+	2.76E-11	2.17E-11	-10.664
Al(OH)3 (aq)	7.53E-16	7.73E-16	-15.112
Al(OH)4-	8.46E-20	6.53E-20	-19.185
Al(SO4)2-	0.000986	0.000761	-3.119
Al+3	0.000383	6.63E-05	-4.178
Al2(OH)2+4	6.2E-11	1.12E-12	-11.951
Al2(OH)2CO3+2	4.48E-15	1.64E-15	-14.785
Al2PO4+3	1.44E-10	1.51E-11	-10.822
Al3(OH)4+5	3.58E-16	6.77E-19	-18.17
AlCl+2	1.24E-06	4.53E-07	-6.343
AlF+2	1.31E-05	4.96E-06	-5.305
AlF2+	1.95E-08	1.53E-08	-7.816
AlF3 (aq)	1.35E-12	1.39E-12	-11.857
AlF4-	7.02E-18	5.42E-18	-17.266
AlHPO4+	1.64E-08	1.28E-08	-7.894
AlOH+2	1.71E-07	6.46E-08	-7.189
AlSO4+	0.003426	0.002644	-2.578
As3S4(HS)-	1.8E-223	1.4E-223	-222.852
AsO4-3	1.48E-20	1.54E-21	-20.811
AsS(OH)HS-	1.88E-79	1.46E-79	-78.834
Ca DOM1	1.94E-06	1.65E-06	-5.782
Ca(NH3)2+2	4.9E-24	1.8E-24	-23.746
Ca(NO3)2	3.9E-105	4E-105	-104.393
Ca+2	0.005812	0.002384	-2.623
CaCl+	0.000122	9.5E-05	-4.022
CaCO3 (aq)	1.7E-15	1.74E-15	-14.759
CaCrO4 (aq)	2.78E-11	2.85E-11	-10.545
CaF+	2.7E-10	2.11E-10	-9.676
CaH2PO4+	2.74E-08	2.15E-08	-7.668
CaHCO3+	2.29E-09	1.81E-09	-8.742
CaHPO4 (aq)	4.94E-12	5.07E-12	-11.295
CaNH3+2	3.21E-13	1.18E-13	-12.929
CaNO3+	2.42E-51	1.88E-51	-50.725
CaOH+	4.66E-14	3.69E-14	-13.433
CaPO4-	2.62E-18	2.05E-18	-17.687
CaSO4 (aq)	0.003296	0.003381	-2.471
Cd DOM1	1.65E-12	1.4E-12	-11.853
Cd(CO3)2-2	9.76E-33	3.58E-33	-32.446
Cd(HS)2 (aq)	9.43E-84	9.67E-84	-83.014
Cd(HS)3-	1.9E-126	1.5E-126	-125.83
Cd(HS)4-2	1.6E-168	5.7E-169	-168.245
Cd(NH3)2+2	2.58E-26	9.44E-27	-26.025
Cd(NH3)3+2	9.89E-36	3.62E-36	-35.441

Species	Concentration	Activity	Log activity
Cd(NH3)4+2	1.12E-45	4.1E-46	-45.387
Cd(NO2)2 (aq)	3.44E-81	3.53E-81	-80.452
Cd(NO3)2 (aq)	6.7E-107	6.9E-107	-106.164
Cd(OH)2 (aq)	1.43E-25	1.46E-25	-24.835
Cd(OH)3-	3.5E-36	2.73E-36	-35.564
Cd(OH)4-2	1.44E-47	5.3E-48	-47.276
Cd(SO4)2-2	3.25E-10	1.19E-10	-9.924
Cd+2	2.2E-09	8.06E-10	-9.094
Cd2OH+3	2.48E-25	2.59E-26	-25.586
CdCl+	1.61E-09	1.26E-09	-8.901
CdCl2 (aq)	8.26E-11	8.47E-11	-10.072
CdCO3 (aq)	9.42E-21	9.66E-21	-20.015
CdF+	1.19E-16	9.27E-17	-16.033
CdHCO3+	1.88E-15	1.46E-15	-14.835
CdHPO4 (aq)	1.78E-17	1.82E-17	-16.739
CdHS+	2.57E-46	2E-46	-45.699
CdNH3+2	1.39E-17	5.09E-18	-17.293
CdNO2+	3.29E-45	2.56E-45	-44.592
CdNO3+	1.02E-57	7.92E-58	-57.101
CdOH+	7.27E-18	5.66E-18	-17.247
CdSO4 (aq)	1.12E-09	1.14E-09	-8.942
Cl-1	0.022357	0.016778	-1.775
CO3-2	1.35E-15	5.11E-16	-15.291
Cr2O7-2	1.4E-11	5.13E-12	-11.29
CrO3Cl-	2.47E-10	1.93E-10	-9.715
CrO3H2PO4-	1.65E-12	1.29E-12	-11.891
CrO3HPO4-2	1.39E-12	5.09E-13	-12.294
CrO3SO4-2	1.04E-08	3.8E-09	-8.42
CrO4-2	5.95E-11	2.03E-11	-10.693
Cu DOM1	1.59E-09	1.35E-09	-8.868
Cu(CO3)2-2	2.21E-28	8.1E-29	-28.092
Cu(N3)2 (aq)	2.31E-17	2.37E-17	-16.626
Cu(N3)3-	2.88E-22	2.24E-22	-21.649
Cu(N3)4-2	3.04E-28	1.12E-28	-27.953
Cu(NH3)2+2	5.35E-22	1.96E-22	-21.708
Cu(NH3)3+2	6.72E-30	2.46E-30	-29.608
Cu(NH3)4+2	1.75E-38	6.41E-39	-38.193
Cu(NO2)2 (aq)	2.03E-80	2.08E-80	-79.681
Cu(NO3)2 (aq)	4.1E-106	4.2E-106	-105.379
Cu(OH)2 (aq)	1.09E-20	1.12E-20	-19.952
Cu(OH)3-	3.88E-28	3.02E-28	-27.52
Cu(OH)4-2	1.04E-39	3.81E-40	-39.419
Cu+2	4.97E-08	1.95E-08	-7.709
Cu2(OH)2+2	4.27E-22	1.57E-22	-21.805
Cu2OH+3	9.23E-20	9.65E-21	-20.016
Cu2S3-2	3.6E-145	1.3E-145	-144.875

Species	Concentration	Activity	Log activity
Cu3(OH)4+2	9.56E-36	3.51E-36	-35.455
CuCl+	7.62E-10	5.83E-10	-9.235
CuCl2 (aq)	1.59E-12	1.63E-12	-11.788
CuCl3-	2.78E-16	2.12E-16	-15.673
CuCl4-2 1	6.86E-20	2.52E-20	-19.598
CuCO3 (aq)	5.74E-17	5.88E-17	-16.23
CuF+	8.17E-15	6.36E-15	-14.197
CuHCO3+	9.08E-14	7.06E-14	-13.151
CuHPO4 (aq)	1.13E-15	1.16E-15	-14.934
CuHSO4+	1.97E-10	1.54E-10	-9.814
CuN3+	3.44E-12	2.68E-12	-11.572
CuNH3+2	1.11E-14	4.07E-15	-14.39
CuNO2+	8.3E-44	6.46E-44	-43.19
CuNO3+	1.95E-56	1.52E-56	-55.819
CuOH+	9.32E-14	7.12E-14	-13.147
CuS(aq)	1.39E-53	1.43E-53	-52.845
CuSO4 (aq)	2.64E-08	2.71E-08	-7.567
DOC (Gaussian DOM)	0.001399	0.001435	-2.843
DOM1	3.24E-05	4.54E-06	-5.343
F-1	1.03E-08	7.79E-09	-8.109
Fe DOM1	9.81E-08	9.71E-08	-7.013
Fe(N3)2+	3.87E-14	3.01E-14	-13.522
Fe(N3)3 (aq)	1.19E-18	1.22E-18	-17.914
Fe(NH3)2+2	5.8E-22	2.12E-22	-21.673
Fe(NH3)3+2	2.62E-32	9.62E-33	-32.017
Fe(NH3)4+2	5.07E-43	1.86E-43	-42.731
Fe(NO2)2+	1.49E-79	1.16E-79	-78.936
Fe(NO2)3 (aq)	4.1E-115	4.2E-115	-114.377
Fe(OH)2 (aq)	9.16E-20	9.4E-20	-19.027
Fe(OH)2+	1.06E-10	8.32E-11	-10.08
Fe(OH)3-	6.6E-28	5.14E-28	-27.289
Fe(OH)3 (aq)	5.09E-18	5.22E-18	-17.282
Fe(OH)4-	8.25E-24	6.47E-24	-23.189
Fe(SO4)2-	2.45E-08	1.9E-08	-7.721
Fe+2	0.01114	0.00438	-2.359
Fe+3	1.28E-08	2.22E-09	-8.654
Fe2(OH)2+4	5.65E-15	1.02E-16	-15.992
Fe3(OH)4+5	1.53E-21	2.88E-24	-23.54
FeCl+	5.96E-05	4.64E-05	-4.334
FeCl+2	2.21E-09	8.15E-10	-9.089
FeCrO4+	2.13E-12	1.65E-12	-11.781
FeF+	7.11E-10	5.53E-10	-9.257
FeF+2	4.48E-11	1.65E-11	-10.783
FeF2+	6.22E-15	4.85E-15	-14.314
FeF3 (aq)	3.41E-20	3.5E-20	-19.456

Species	Concentration	Activity	Log activity
FeH2PO4+	1.03E-06	8.11E-07	-6.091
FeH2PO4+2	4.1E-11	1.55E-11	-10.809
FeHCO3+	3.99E-09	3.16E-09	-8.501
FeHPO4 (aq)	7.58E-11	7.78E-11	-10.109
FeHPO4+	1.57E-10	1.23E-10	-9.908
FeHS+	5.69E-42	4.43E-42	-41.354
FeN3+2	1.79E-10	6.54E-11	-10.184
FeNH3+2	5.04E-12	1.85E-12	-11.733
FeNO2+2	3.03E-43	1.11E-43	-42.955
FeOH+	1.95E-10	1.52E-10	-9.818
FeOH+2	7.66E-09	2.82E-09	-8.55
FeSO4 (aq)	0.006407	0.006573	-2.182
FeSO4+	2.44E-07	1.9E-07	-6.721
H DOM1	7.66E-05	3.4E-05	-4.469
H+1	0.00638	0.005251	-2.28
H2AsO3-	4.81E-13	3.74E-13	-12.427
H2AsO4-	4.54E-07	3.53E-07	-6.452
H2CO3* (aq)	0.000967	0.000992	-3.003
H2CrO4 (aq)	6.45E-10	6.62E-10	-9.179
H2PO4-	6.06E-07	4.75E-07	-6.323
H2S (aq)	1.81E-40	1.85E-40	-39.732
H3AsO3	4.17E-06	4.28E-06	-5.369
H3AsO4	3.23E-07	3.31E-07	-6.48
H3PO4	3.08E-07	3.16E-07	-6.5
HAsO3-2	9.9E-25	3.63E-25	-24.44
HAsO4-2	1.8E-11	6.6E-12	-11.18
HCO3-	9.18E-08	7.2E-08	-7.143
HCrO4-	4.31E-07	3.35E-07	-6.475
HF (aq)	5.01E-08	5.14E-08	-7.289
HF2-	1.99E-15	1.5E-15	-14.823
Hg(CO3)2-2	3.66E-36	1.34E-36	-35.873
Hg(HS)2 (aq)	2.03E-72	2.09E-72	-71.681
Hg(N3)2 (aq)	1.72E-14	1.76E-14	-13.754
Hg(NH3)2+2	3.78E-24	1.39E-24	-23.858
Hg(NH3)4+2	3.97E-44	1.46E-44	-43.837
Hg(NO2)2 (aq)	1.06E-86	1.09E-86	-85.962
Hg(NO2)3-	1.5E-122	1.2E-122	-121.923
Hg(NO2)4-2	2.6E-159	9.7E-160	-159.014
Hg(NO3)2 (aq)	1.2E-119	1.2E-119	-118.92
Hg(OH)2	3.25E-23	3.33E-23	-22.477
Hg(SO4)2-2	5.2E-22	1.9E-22	-21.72
Hg+2	6.48E-21	2.37E-21	-20.625
Hg2OH+3	4.22E-42	4.42E-43	-42.355
Hg3(OH)3+3	6.62E-62	6.92E-63	-62.16
HgCl+	1.45E-15	1.13E-15	-14.946
HgCl2 (aq)	1.42E-10	1.46E-10	-9.837

Species	Concentration	Activity	Log activity
HgCl3-1	3.12E-11	2.43E-11	-10.614
HgCl4-2	4.98E-12	1.83E-12	-11.739
HgClOH (aq)	1.46E-16	1.5E-16	-15.825
HgCO3 (aq)	9.07E-25	9.3E-25	-24.031
HgF+	8.86E-28	6.89E-28	-27.162
HgHCO3+	1.04E-22	8.11E-23	-22.091
HgHS2-	1.65E-76	1.29E-76	-75.891
HgN3+	7.11E-11	5.53E-11	-10.257
HgNO2+	4.76E-53	3.71E-53	-52.431
HgNO3+	1.6E-70	1.25E-70	-69.904
HgOH+	1.73E-22	1.34E-22	-21.872
HgOHCO3-	2.65E-29	2.07E-29	-28.685
HgS2-2	1.3E-82	4.77E-83	-82.321
HgSO4 (aq)	2.65E-21	2.72E-21	-20.565
HN3 (aq)	4.98E-05	5.1E-05	-4.292
HNO2 (aq)	2.28E-37	2.34E-37	-36.631
HPO4-2	1.5E-11	5.5E-12	-11.259
HS-1	3.21E-45	2.42E-45	-44.615
HSO4-	0.00346	0.002671	-2.573
K+1	0.000318	0.000239	-3.622
K2HPO4 (aq)	3.31E-18	3.39E-18	-17.47
K2PO4-	4.78E-27	3.72E-27	-26.43
KCl (aq)	2.07E-06	2.12E-06	-5.673
KCr2O7-	1.36E-14	1.06E-14	-13.976
KCrO4-	2.31E-14	1.8E-14	-13.745
KF (aq)	8.28E-13	8.5E-13	-12.071
KH2PO4 (aq)	1.72E-10	1.76E-10	-9.754
KHPO4-	1.03E-14	8.08E-15	-14.093
KNO3 (aq)	4.12E-53	4.22E-53	-52.374
KOH (aq)	3.52E-16	3.61E-16	-15.442
KPO4-2	5.09E-24	1.87E-24	-23.729
KSO4-	1.23E-05	9.65E-06	-5.016
Mg DOM1	1.7E-07	1.45E-07	-6.839
Mg(NH3)2+2	2.14E-24	7.85E-25	-24.105
Mg+2	0.0049	0.002089	-2.68
Mg2CO3+2	2.37E-17	8.68E-18	-17.061
MgCl+	0.00017	0.000132	-3.88
MgCO3 (aq)	7.43E-16	7.62E-16	-15.118
MgF+	1.4E-09	1.08E-09	-8.968
MgHCO3+	1.91E-09	1.46E-09	-8.835
MgHPO4 (aq)	5.98E-12	6.13E-12	-11.212
MgOH+	7.7E-13	6.15E-13	-12.211
MgPO4-	3.59E-20	2.81E-20	-19.551
MgSO4 (aq)	0.002336	0.002397	-2.62
Mn+3	4.55E-05	7.88E-06	-5.103
N3-1	2.43E-07	1.89E-07	-6.723

Species	Concentration	Activity	Log activity
Na+1	0.012083	0.009414	-2.026
Na2HPO4 (aq)	3.4E-15	3.48E-15	-14.458
Na2PO4-	1.59E-23	1.24E-23	-22.908
NaCl (aq)	8.63E-05	8.85E-05	-4.053
NaCO3-	1.52E-16	1.19E-16	-15.924
NaCrO4-	1.22E-12	9.49E-13	-12.023
NaF (aq)	6.32E-11	6.49E-11	-10.188
NaH2PO4 (aq)	6.77E-09	6.94E-09	-8.159
NaHCO3 (aq)	3.92E-10	4.02E-10	-9.396
NaHPO4-	6.29E-13	4.93E-13	-12.307
NaNO3 (aq)	5.99E-52	6.15E-52	-51.211
NaOH (aq)	9.52E-15	9.76E-15	-14.01
NaPO4-2	2.21E-22	8.12E-23	-22.091
NaSO4-	0.000445	0.000349	-3.457
NH3 (aq)	1.45E-11	1.48E-11	-10.828
NH4+1	0.000385	0.000284	-3.546
NH4Cr2O7-	1.88E-14	1.46E-14	-13.835
NH4SO4-	2.68E-05	2.08E-05	-4.681
Ni DOM1	7.58E-09	6.46E-09	-8.19
Ni(N3)2 (aq)	1.28E-17	1.31E-17	-16.883
Ni(NH3)2+2	2.58E-22	9.46E-23	-22.024
Ni(NH3)3+2	2.22E-31	8.14E-32	-31.089
Ni(NH3)4+2	5.66E-41	2.08E-41	-40.683
Ni(NH3)5+2	4.66E-51	1.71E-51	-50.767
Ni(NH3)6+2	8.18E-62	3E-62	-61.523
Ni(NO2)2 (aq)	2.22E-79	2.28E-79	-78.643
Ni(OH)2 (aq)	1.31E-20	1.34E-20	-19.872
Ni(OH)3-	3.28E-29	2.55E-29	-28.593
Ni(SO4)2-2	3.12E-09	1.15E-09	-8.941
Ni+2	1.01E-05	3.71E-06	-5.431
NiCl+	2.89E-08	2.25E-08	-7.648
NiCl2 (aq)	1.31E-11	1.34E-11	-10.871
NiCO3 (aq)	6.87E-17	7.04E-17	-16.152
NiF+	6.7E-13	5.21E-13	-12.283
NiH2PO4+	1.49E-11	1.16E-11	-10.936
NiHCO3+	3.36E-11	2.62E-11	-10.582
NiHPO4 (aq)	1.45E-14	1.49E-14	-13.826
NiHS+	3.57E-45	2.78E-45	-44.556
NiN3+	1.7E-11	1.32E-11	-10.879
NiNH3+2	9.85E-14	3.61E-14	-13.442
NiNO2+	3.61E-42	2.81E-42	-41.552
NiNO3+	2.77E-54	2.16E-54	-53.666
NiOH+	5.53E-14	4.3E-14	-13.367
NiSO4 (aq)	4.55E-06	4.66E-06	-5.331
NO2-1	4.05E-38	3.16E-38	-37.501
NO3-1	3.1E-49	2.32E-49	-48.635

Species	Concentration	Activity	Log activity
OH-	1.15E-12	8.71E-13	-12.06
Pb DOM1	1.08E-09	9.21E-10	-9.036
Pb(CO3)2-2	4.14E-29	1.52E-29	-28.819
Pb(HS)2 (aq)	7.11E-83	7.29E-83	-82.137
Pb(HS)3-	4.5E-126	3.5E-126	-125.453
Pb(NO2)2 (aq)	8.33E-81	8.55E-81	-80.068
Pb(NO3)2 (aq)	9.6E-105	9.9E-105	-104.006
Pb(OH)2 (aq)	1.87E-21	1.92E-21	-20.718
Pb(OH)3-	4.69E-30	3.65E-30	-29.438
Pb(SO4)2-2	2.51E-09	9.19E-10	-9.036
Pb+2	1.82E-08	6.66E-09	-8.176
Pb2OH+3	3.22E-20	3.36E-21	-20.473
Pb3(OH)4+2	2.62E-40	9.59E-41	-40.018
Pb4(OH)4+4	5.46E-44	9.86E-46	-45.006
PbCl+	4.62E-09	3.59E-09	-8.444
PbCl2 (aq)	1.23E-10	1.26E-10	-9.9
PbCl3-	2.16E-12	1.68E-12	-11.775
PbCl4-2	2.81E-14	1.03E-14	-13.987
PbCO3 (aq)	1.13E-17	1.15E-17	-16.938
PbF+	9.42E-15	7.33E-15	-14.135
PbF2 (aq)	6.84E-22	7.02E-22	-21.154
PbH2PO4+	1E-13	7.79E-14	-13.109
PbHCO3+	3.9E-13	3.04E-13	-12.517
PbHPO4 (aq)	3.65E-17	3.74E-17	-16.427
PbNO2+	8.74E-44	6.8E-44	-43.167
PbNO3+	3.02E-56	2.35E-56	-55.629
PbOH+	2.93E-14	2.28E-14	-13.642
PbSO4 (aq)	2.18E-08	2.23E-08	-7.651
PO4-3	3.39E-21	3.58E-22	-21.446
S-2	2.5E-60	9.21E-61	-60.036
SO4-2	0.020246	0.006838	-2.165
Zn DOM1	1.77E-08	1.51E-08	-7.821
Zn(CO3)2-2	7.79E-29	2.85E-29	-28.545
Zn(N3)2 (aq)	1.82E-17	1.87E-17	-16.729
Zn(N3)3-	2.59E-23	2.02E-23	-22.695
Zn(NH3)2+2	1.44E-22	5.28E-23	-22.278
Zn(NH3)3+2	6.29E-31	2.31E-31	-30.637
Zn(NH3)4+2	1.35E-39	4.94E-40	-39.307
Zn(NO2)2 (aq)	8.41E-80	8.63E-80	-79.064
Zn(NO3)2 (aq)	1.4E-103	1.5E-103	-102.832
Zn(OH)2 (aq)	2.43E-18	2.49E-18	-17.603
Zn(OH)3-	1.93E-27	1.5E-27	-26.824
Zn(OH)4-2	1.23E-37	4.53E-38	-37.344
Zn(SO4)2-2	1.33E-06	4.87E-07	-6.312
Zn+2	1.39E-05	5.47E-06	-5.262
Zn2OH+3	2.23E-17	2.33E-18	-17.632

Species	Concentration	Activity	Log activity
Zn2S3-2	1.8E-137	6.6E-138	-137.181
Zn4S6-4	4.1E-272	7.4E-274	-273.131
ZnCl+	3.21E-07	2.45E-07	-6.61
ZnCl2 (aq)	2.57E-09	2.64E-09	-8.579
ZnCl3-	6E-11	4.67E-11	-10.331
ZnCl4-2	9.86E-13	3.61E-13	-12.442
ZnCO3 (aq)	1.57E-16	1.61E-16	-15.793
ZnF+	9.36E-13	7.29E-13	-12.138
ZnHCO3+	1.27E-11	9.91E-12	-11.004
ZnHPO4 (aq)	4.91E-14	5.04E-14	-13.297
ZnN3+	1.91E-11	1.49E-11	-10.828
ZnNH3+2	4.19E-14	1.54E-14	-13.814
ZnNO2+	1.34E-42	1.04E-42	-41.983
ZnNO3+	4.36E-54	3.4E-54	-53.469
ZnOH+	6.13E-13	4.77E-13	-12.322
ZnS (aq)	9.15E-50	9.39E-50	-49.028
ZnSO4 (aq)	7.31E-06	7.5E-06	-5.125

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Species	Concentration	Activity	Log activity
Al DOM1	4.05E-06	4.01E-06	-5.397
Al(OH)2+	3.24E-12	2.56E-12	-11.591
Al(OH)3 (aq)	2.94E-17	3.01E-17	-16.521
Al(OH)4-	1.08E-21	8.4E-22	-21.076
Al(SO4)2-	0.000935	0.000727	-3.138
Al+3	0.0004	7.21E-05	-4.142
Al2(OH)2+4	7.19E-12	1.44E-13	-12.842
Al2(OH)2CO3+2	6.09E-17	2.29E-17	-16.64
Al2PO4+3	1.78E-11	1.97E-12	-11.705
Al3(OH)4+5	4.65E-18	1.03E-20	-19.988
AlCl+2	1.13E-06	4.24E-07	-6.372
AlF+2	1.3E-05	5.06E-06	-5.296
AlF2+	1.85E-08	1.46E-08	-7.834
AlF3 (aq)	1.22E-12	1.25E-12	-11.903
AlF4-	5.89E-18	4.58E-18	-17.339
AlHPO4+	5.96E-09	4.66E-09	-8.331
AlOH+2	5.96E-08	2.32E-08	-7.635
AlSO4+	0.003465	0.002695	-2.569
As3S4(HS)-	9.4E-284	7.4E-284	-283.131
AsO4-3	5.11E-21	5.66E-22	-21.247
AsS(OH)HS-	7.2E-100	5.6E-100	-99.249
Ca DOM1	8.06E-07	6.89E-07	-6.162
Ca(NH3)2+2	5.55E-25	2.09E-25	-24.68
Ca(NO3)2	9.48E-87	9.71E-87	-86.013
Ca+2	0.005906	0.002476	-2.606

Species	Concentration	Activity	Log activity
CaCl+	0.000108	8.49E-05	-4.071
CaCO3 (aq)	1.92E-16	1.96E-16	-15.707
CaCrO4 (aq)	9.18E-12	9.39E-12	-11.027
CaF+	2.62E-10	2.05E-10	-9.687
CaH2PO4+	2.87E-08	2.27E-08	-7.644
CaHCO3+	7.77E-10	6.19E-10	-9.208
CaHPO4 (aq)	1.73E-12	1.77E-12	-11.752
CaNH3+2	1.09E-13	4.09E-14	-13.388
CaNO3+	3.8E-42	2.97E-42	-41.527
CaOH+	1.59E-14	1.26E-14	-13.898
CaPO4-	2.99E-19	2.36E-19	-18.626
CaSO4 (aq)	0.003217	0.003293	-2.482
Cd DOM1	7.16E-13	6.13E-13	-12.213
Cd(CO3)2-2	1.22E-34	4.58E-35	-34.339
Cd(HS)2 (aq)	4.4E-103	4.5E-103	-102.349
Cd(HS)3-	1.8E-155	1.4E-155	-154.849
Cd(HS)4-2	3E-207	1.1E-207	-206.95
Cd(NH3)2+2	3.06E-27	1.15E-27	-26.94
Cd(NH3)3+2	3.92E-37	1.48E-37	-36.831
Cd(NH3)4+2	1.49E-47	5.59E-48	-47.253
Cd(NO2)2 (aq)	7.38E-68	7.55E-68	-67.122
Cd(NO3)2 (aq)	1.68E-88	1.72E-88	-87.764
Cd(OH)2 (aq)	1.69E-26	1.73E-26	-25.762
Cd(OH)3-	1.36E-37	1.06E-37	-36.974
Cd(OH)4-2	1.81E-49	6.81E-50	-49.167
Cd(SO4)2-2	3.03E-10	1.14E-10	-9.944
Cd+2	2.33E-09	8.76E-10	-9.058
Cd2OH+3	9.12E-26	1.01E-26	-25.996
CdCl+	1.5E-09	1.17E-09	-8.93
CdCl2 (aq)	6.66E-11	6.81E-11	-10.167
CdCO3 (aq)	1.11E-21	1.14E-21	-20.943
CdF+	1.21E-16	9.46E-17	-16.024
CdHCO3+	6.68E-16	5.23E-16	-15.281
CdHPO4 (aq)	6.5E-18	6.65E-18	-17.177
CdHS+	5.73E-56	4.49E-56	-55.348
CdNH3+2	4.92E-18	1.85E-18	-17.733
CdNO2+	1.58E-38	1.23E-38	-37.909
CdNO3+	1.67E-48	1.31E-48	-47.883
CdOH+	2.59E-18	2.03E-18	-17.693
CdSO4 (aq)	1.14E-09	1.17E-09	-8.933
Cl-1	0.019054	0.014436	-1.841
CO3-2	1.43E-16	5.55E-17	-16.256
Cr2O7-2	1.26E-11	4.75E-12	-11.323
CrO3Cl-	6.17E-10	4.83E-10	-9.316
CrO3H2PO4-	4.88E-12	3.82E-12	-11.418
CrO3HPO4-2	1.33E-12	4.98E-13	-12.302

Species	Concentration	Activity	Log activity
CrO3SO4-2	2.77E-08	1.04E-08	-7.983
CrO4-2	1.83E-11	6.44E-12	-11.191
Cu DOM1	6.66E-10	5.7E-10	-9.244
Cu(CO3)2-2	2.66E-30	9.99E-31	-30
Cu(N3)2 (aq)	2.64E-18	2.7E-18	-17.568
Cu(N3)3-	1.08E-23	8.45E-24	-23.073
Cu(N3)4-2	3.69E-30	1.39E-30	-29.858
Cu(NH3)2+2	6.11E-23	2.3E-23	-22.639
Cu(NH3)3+2	2.57E-31	9.67E-32	-31.015
Cu(NH3)4+2	2.24E-40	8.41E-41	-40.075
Cu(NO2)2 (aq)	4.2E-67	4.3E-67	-66.367
Cu(NO3)2 (aq)	9.87E-88	1.01E-87	-86.996
Cu(OH)2 (aq)	1.24E-21	1.27E-21	-20.896
Cu(OH)3-	1.45E-29	1.14E-29	-28.945
Cu(OH)4-2	1.26E-41	4.73E-42	-41.326
Cu+2	5.07E-08	2.05E-08	-7.689
Cu2(OH)2+2	4.97E-23	1.87E-23	-22.729
Cu2OH+3	3.15E-20	3.49E-21	-20.457
Cu2S3-2	1.2E-175	4.6E-176	-175.336
Cu3(OH)4+2	1.27E-37	4.76E-38	-37.322
CuCl+	6.81E-10	5.25E-10	-9.28
CuCl2 (aq)	1.23E-12	1.26E-12	-11.899
CuCl3-	1.84E-16	1.42E-16	-15.849
CuCl4-2 1	3.82E-20	1.45E-20	-19.839
CuCO3 (aq)	6.53E-18	6.69E-18	-17.175
CuF+	7.98E-15	6.25E-15	-14.204
CuHCO3+	3.11E-14	2.43E-14	-13.614
CuHPO4 (aq)	4E-16	4.09E-16	-15.388
CuHSO4+	5.84E-10	4.57E-10	-9.34
CuN3+	1.18E-12	9.26E-13	-12.034
CuNH3+2	3.8E-15	1.43E-15	-14.845
CuNO2+	3.83E-37	3E-37	-36.523
CuNO3+	3.08E-47	2.41E-47	-46.617
CuOH+	3.19E-14	2.46E-14	-13.609
CuS(aq)	9.96E-64	1.02E-63	-62.991
CuSO4 (aq)	2.6E-08	2.66E-08	-7.575
DOC (Gaussian DOM)	0.001399	0.001432	-2.844
DOM1	2.34E-05	3.44E-06	-5.463
F-1	9.58E-09	7.31E-09	-8.136
Fe DOM1	8.23E-07	8.15E-07	-6.089
Fe(N3)2+	8.76E-14	6.86E-14	-13.164
Fe(N3)3 (aq)	8.96E-19	9.17E-19	-18.038
Fe(NH3)2+2	2.36E-23	8.86E-24	-23.053
Fe(NH3)3+2	3.57E-34	1.34E-34	-33.872
Fe(NH3)4+2	2.31E-45	8.68E-46	-45.062

Species	Concentration	Activity	Log activity
Fe(NO2)2+	6.09E-65	4.77E-65	-64.321
Fe(NO2)3 (aq)	7.49E-94	7.67E-94	-93.115
Fe(OH)2 (aq)	3.72E-21	3.81E-21	-20.419
Fe(OH)2+	2.39E-10	1.89E-10	-9.723
Fe(OH)3-	8.76E-30	6.87E-30	-29.163
Fe(OH)3 (aq)	3.82E-18	3.92E-18	-17.407
Fe(OH)4-	2.03E-24	1.6E-24	-23.796
Fe(SO4)2-	4.47E-07	3.5E-07	-6.456
Fe+2	0.004045	0.001632	-2.787
Fe+3	2.57E-07	4.64E-08	-7.333
Fe2(OH)2+4	2.42E-13	4.85E-15	-14.314
Fe3(OH)4+5	1.41E-19	3.12E-22	-21.506
FeCl+	1.9E-05	1.49E-05	-4.828
FeCl+2	3.87E-08	1.47E-08	-7.834
FeCrO4+	1.4E-11	1.1E-11	-10.959
FeF+	2.47E-10	1.93E-10	-9.713
FeF+2	8.53E-10	3.23E-10	-9.49
FeF2+	1.14E-13	8.94E-14	-13.049
FeF3 (aq)	5.91E-19	6.06E-19	-18.218
FeH2PO4+	3.9E-07	3.08E-07	-6.512
FeH2PO4+2	8.5E-10	3.31E-10	-9.481
FeHCO3+	4.86E-10	3.87E-10	-9.412
FeHPO4 (aq)	9.51E-12	9.73E-12	-11.012
FeHPO4+	1.1E-09	8.67E-10	-9.062
FeHS+	4.35E-52	3.4E-52	-51.468
FeN3+2	1.2E-09	4.52E-10	-9.345
FeNH3+2	6.13E-13	2.3E-13	-12.637
FeNO2+2	2.74E-35	1.03E-35	-34.987
FeOH+	2.38E-11	1.87E-11	-10.729
FeOH+2	5.13E-08	1.94E-08	-7.711
FeSO4 (aq)	0.002243	0.002296	-2.639
FeSO4+	4.75E-06	3.73E-06	-5.428
H DOM1	9.13E-05	4.14E-05	-4.383
H+1	0.019259	0.015921	-1.798
H2AsO3-	4.7E-15	3.68E-15	-14.434
H2AsO4-	1.52E-06	1.19E-06	-5.924
H2CO3* (aq)	0.000967	0.00099	-3.004
H2CrO4 (aq)	1.89E-09	1.93E-09	-8.714
H2PO4-	6.13E-07	4.84E-07	-6.315
H2S (aq)	1.13E-49	1.16E-49	-48.936
H3AsO3	1.25E-07	1.28E-07	-6.894
H3AsO4	3.3E-06	3.38E-06	-5.471
H3PO4	9.53E-07	9.76E-07	-6.011
HAsO3-2	3.13E-27	1.18E-27	-26.929
HAsO4-2	1.95E-11	7.33E-12	-11.135
HCO3-	3E-08	2.37E-08	-7.625

Species	Concentration	Activity	Log activity
HCrO4-	4.12E-07	3.23E-07	-6.491
HF (aq)	1.43E-07	1.46E-07	-6.835
HF2-	5.27E-15	4.02E-15	-14.396
Hg(CO3)2-2	8.18E-38	3.07E-38	-37.512
Hg(HS)2 (aq)	1.69E-91	1.73E-91	-90.762
Hg(N3)2 (aq)	3.98E-16	4.07E-16	-15.39
Hg(NH3)2+2	8.04E-25	3.02E-25	-24.52
Hg(NH3)4+2	9.44E-46	3.55E-46	-45.45
Hg(NO2)2 (aq)	4.09E-73	4.18E-73	-72.379
Hg(NO2)3-	2.6E-102	2E-102	-101.693
Hg(NO2)4-2	1.9E-132	7.3E-133	-132.136
Hg(NO3)2 (aq)	5.3E-101	5.4E-101	-100.267
Hg(OH)2	6.89E-24	7.06E-24	-23.151
Hg(SO4)2-2	8.67E-22	3.26E-22	-21.487
Hg+2	1.23E-20	4.62E-21	-20.335
Hg2OH+3	4.98E-42	5.52E-43	-42.258
Hg3(OH)3+3	1.65E-62	1.83E-63	-62.737
HgCl+	2.42E-15	1.9E-15	-14.722
HgCl2 (aq)	2.05E-10	2.1E-10	-9.678
HgCl3-1	3.85E-11	3.01E-11	-10.521
HgCl4-2	5.18E-12	1.95E-12	-11.71
HgClOH (aq)	8.07E-17	8.26E-17	-16.083
HgCO3 (aq)	1.92E-25	1.97E-25	-24.706
HgF+	1.61E-27	1.26E-27	-26.9
HgHCO3+	6.63E-23	5.19E-23	-22.284
HgHS2-	4.49E-96	3.52E-96	-95.454
HgN3+	5.37E-13	4.2E-13	-12.376
HgNO2+	4.09E-46	3.2E-46	-45.495
HgNO3+	4.71E-61	3.69E-61	-60.433
HgOH+	1.1E-22	8.63E-23	-22.064
HgOHCO3-	1.84E-30	1.44E-30	-29.842
HgS2-2	1.1E-102	4.3E-103	-102.366
HgSO4 (aq)	4.85E-21	4.97E-21	-20.304
HN3 (aq)	4.99E-05	5.11E-05	-4.292
HNO2 (aq)	3.08E-30	3.15E-30	-29.502
HPO4-2	4.88E-12	1.85E-12	-11.733
HS-1	6.56E-55	5E-55	-54.301
HSO4-	0.009759	0.007592	-2.12
K+1	0.000319	0.000242	-3.617
K2HPO4 (aq)	1.14E-18	1.17E-18	-17.933
K2PO4-	5.39E-28	4.22E-28	-27.375
KCl (aq)	1.81E-06	1.85E-06	-5.733
KCr2O7-	1.27E-14	9.91E-15	-14.004
KCrO4-	7.39E-15	5.79E-15	-14.238
KF (aq)	7.89E-13	8.08E-13	-12.093
KH2PO4 (aq)	1.77E-10	1.82E-10	-9.741

Species	Concentration	Activity	Log activity
KHPO4-	3.48E-15	2.75E-15	-14.561
KNO3 (aq)	6.35E-44	6.5E-44	-43.187
KOH (aq)	1.18E-16	1.21E-16	-15.918
KPO4-2	5.57E-25	2.09E-25	-24.679
KSO4-	1.16E-05	9.16E-06	-5.038
Mg DOM1	7.05E-08	6.03E-08	-7.22
Mg(NH3)2+2	2.42E-25	9.11E-26	-25.04
Mg+2	0.00498	0.002165	-2.664
Mg2CO3+2	2.69E-18	1.01E-18	-17.995
MgCl+	0.00015	0.000118	-3.929
MgCO3 (aq)	8.37E-17	8.57E-17	-16.067
MgF+	1.35E-09	1.05E-09	-8.98
MgHCO3+	6.47E-10	4.98E-10	-9.302
MgHPO4 (aq)	2.09E-12	2.13E-12	-11.671
MgOH+	2.62E-13	2.1E-13	-12.678
MgPO4-	4.09E-21	3.23E-21	-20.491
MgSO4 (aq)	0.002275	0.002329	-2.633
Mn+3	4.55E-05	8.2E-06	-5.086
N3-1	7.97E-08	6.24E-08	-7.205
Na+1	0.012121	0.009508	-2.022
Na2HPO4 (aq)	1.17E-15	1.19E-15	-14.923
Na2PO4-	1.78E-24	1.4E-24	-23.855
NaCl (aq)	7.52E-05	7.69E-05	-4.114
NaCO3-	1.65E-17	1.31E-17	-16.884
NaCrO4-	3.89E-13	3.04E-13	-12.517
NaF (aq)	6.01E-11	6.15E-11	-10.211
NaH2PO4 (aq)	6.97E-09	7.14E-09	-8.146
NaHCO3 (aq)	1.3E-10	1.34E-10	-9.874
NaHPO4-	2.12E-13	1.67E-13	-12.776
NaNO3 (aq)	9.22E-43	9.43E-43	-42.025
NaOH (aq)	3.18E-15	3.25E-15	-14.488
NaPO4-2	2.41E-23	9.08E-24	-23.042
NaSO4-	0.000418	0.00033	-3.481
NH3 (aq)	4.85E-12	4.97E-12	-11.304
NH4+1	0.000386	0.000288	-3.54
NH4Cr2O7-	1.76E-14	1.37E-14	-13.862
NH4SO4-	2.53E-05	1.98E-05	-4.703
Ni DOM1	3.15E-09	2.69E-09	-8.57
Ni(N3)2 (aq)	1.45E-18	1.48E-18	-17.829
Ni(NH3)2+2	2.92E-23	1.1E-23	-22.959
Ni(NH3)3+2	8.42E-33	3.17E-33	-32.5
Ni(NH3)4+2	7.18E-43	2.7E-43	-42.568
Ni(NH3)5+2	1.98E-53	7.45E-54	-53.128
Ni(NH3)6+2	1.16E-64	4.37E-65	-64.359
Ni(NO2)2 (aq)	4.54E-66	4.65E-66	-65.333
Ni(OH)2 (aq)	1.48E-21	1.52E-21	-20.819

Species	Concentration	Activity	Log activity
Ni(OH)3-	1.21E-30	9.51E-31	-30.022
Ni(SO4)2-2	2.78E-09	1.05E-09	-8.981
Ni+2	1.02E-05	3.85E-06	-5.415
NiCl+	2.56E-08	2.01E-08	-7.697
NiCl2 (aq)	1.01E-11	1.03E-11	-10.986
NiCO3 (aq)	7.75E-18	7.94E-18	-17.1
NiF+	6.49E-13	5.08E-13	-12.294
NiH2PO4+	1.56E-11	1.22E-11	-10.912
NiHCO3+	1.14E-11	8.94E-12	-11.048
NiHPO4 (aq)	5.08E-15	5.2E-15	-14.284
NiHS+	7.6E-55	5.95E-55	-54.225
NiN3+	5.78E-12	4.52E-12	-11.345
NiNH3+2	3.33E-14	1.25E-14	-13.902
NiNO2+	1.65E-35	1.29E-35	-34.889
NiNO3+	4.35E-45	3.4E-45	-44.468
NiOH+	1.88E-14	1.47E-14	-13.832
NiSO4 (aq)	4.43E-06	4.54E-06	-5.343
NO2-1	1.79E-31	1.4E-31	-30.854
NO3-1	4.66E-40	3.52E-40	-39.453
OH-	3.76E-13	2.87E-13	-12.542
Pb DOM1	4.66E-10	3.99E-10	-9.399
Pb(CO3)2-2	5.12E-31	1.93E-31	-30.715
Pb(HS)2 (aq)	3.3E-102	3.3E-102	-101.475
Pb(HS)3-	4.3E-155	3.3E-155	-154.476
Pb(NO2)2 (aq)	1.77E-67	1.81E-67	-66.742
Pb(NO3)2 (aq)	2.4E-86	2.45E-86	-85.61
Pb(OH)2 (aq)	2.19E-22	2.25E-22	-21.648
Pb(OH)3-	1.8E-31	1.41E-31	-30.851
Pb(SO4)2-2	2.32E-09	8.71E-10	-9.06
Pb+2	1.91E-08	7.18E-09	-8.144
Pb2OH+3	1.16E-20	1.29E-21	-20.89
Pb3(OH)4+2	3.78E-42	1.42E-42	-41.848
Pb4(OH)4+4	7.87E-46	1.57E-47	-46.803
PbCl+	4.26E-09	3.33E-09	-8.477
PbCl2 (aq)	9.82E-11	1E-10	-9.998
PbCl3-	1.47E-12	1.15E-12	-11.938
PbCl4-2	1.62E-14	6.08E-15	-14.216
PbCO3 (aq)	1.32E-18	1.35E-18	-17.87
PbF+	9.47E-15	7.42E-15	-14.13
PbF2 (aq)	6.52E-22	6.67E-22	-21.176
PbH2PO4+	1.09E-13	8.55E-14	-13.068
PbHCO3+	1.38E-13	1.08E-13	-12.968
PbHPO4 (aq)	1.32E-17	1.35E-17	-16.868
PbNO2+	4.15E-37	3.25E-37	-36.488
PbNO3+	4.91E-47	3.85E-47	-46.415
PbOH+	1.04E-14	8.11E-15	-14.091

Species	Concentration	Activity	Log activity
PbSO4 (aq)	2.2E-08	2.26E-08	-7.647
PO4-3	3.52E-22	3.97E-23	-22.401
S-2	1.65E-70	6.27E-71	-70.203
SO4-2	0.018337	0.006411	-2.193
Zn DOM1	7.43E-09	6.35E-09	-8.197
Zn(CO3)2-2	9.37E-31	3.52E-31	-30.453
Zn(N3)2 (aq)	2.08E-18	2.13E-18	-17.672
Zn(N3)3-	9.71E-25	7.61E-25	-24.119
Zn(NH3)2+2	1.65E-23	6.19E-24	-23.208
Zn(NH3)3+2	2.41E-32	9.06E-33	-32.043
Zn(NH3)4+2	1.72E-41	6.48E-42	-41.188
Zn(NO2)2 (aq)	1.74E-66	1.78E-66	-65.75
Zn(NO3)2 (aq)	3.48E-85	3.56E-85	-84.448
Zn(OH)2 (aq)	2.78E-19	2.84E-19	-18.546
Zn(OH)3-	7.2E-29	5.64E-29	-28.249
Zn(OH)4-2	1.49E-39	5.61E-40	-39.251
Zn(SO4)2-2	1.19E-06	4.49E-07	-6.348
Zn+2	1.42E-05	5.73E-06	-5.242
Zn2OH+3	7.62E-18	8.44E-19	-18.074
Zn2S3-2	6.1E-168	2.3E-168	-167.641
ZnCl+	2.87E-07	2.21E-07	-6.655
ZnCl2 (aq)	2E-09	2.05E-09	-8.689
ZnCl3-	3.98E-11	3.11E-11	-10.507
ZnCl4-2	5.52E-13	2.07E-13	-12.683
ZnCO3 (aq)	1.79E-17	1.83E-17	-16.737
ZnF+	9.15E-13	7.17E-13	-12.145
ZnHCO3+	4.36E-12	3.42E-12	-11.466
ZnHPO4 (aq)	1.73E-14	1.77E-14	-13.751
ZnN3+	6.57E-12	5.15E-12	-11.289
ZnNH3+2	1.43E-14	5.38E-15	-14.269
ZnNO2+	6.17E-36	4.83E-36	-35.316
ZnNO3+	6.9E-45	5.41E-45	-44.267
ZnOH+	2.1E-13	1.65E-13	-12.783
ZnS (aq)	6.54E-60	6.69E-60	-59.174
ZnSO4 (aq)	7.2E-06	7.37E-06	-5.132

B1.6: Eh 600

Species	Concentration	Activity	Log activity
Al DOM1	3.21E-06	3.17E-06	-5.498
Al(OH)2+	1.79E-12	1.42E-12	-11.848
Al(OH)3 (aq)	1.19E-17	1.22E-17	-16.915
Al(OH)4-	3.16E-22	2.47E-22	-21.607
Al(SO4)2-	0.000911	0.000712	-3.148
Al+3	0.000407	7.52E-05	-4.124

Species	Concentration	Activity	Log activity
Al2(OH)2+4	3.91E-12	8.3E-14	-13.081
Al2(OH)2CO3+2	1.84E-17	7.01E-18	-17.154
Al2PO4+3	1E-11	1.15E-12	-11.94
Al3(OH)4+5	1.35E-18	3.29E-21	-20.483
AlCl+2	1.06E-06	4.03E-07	-6.395
AlF+2	1.3E-05	5.12E-06	-5.291
AlF2+	1.82E-08	1.44E-08	-7.842
AlF3 (aq)	1.17E-12	1.19E-12	-11.923
AlF4-	5.44E-18	4.25E-18	-17.372
AlHPO4+	4.55E-09	3.58E-09	-8.447
AlOH+2	4.46E-08	1.76E-08	-7.754
AlSO4+	0.003483	0.002721	-2.565
AsO4-3	2.15E-21	2.46E-22	-21.609
AsS(OH)HS-	1.9E-128	1.5E-128	-127.828
Ca DOM1	6.24E-07	5.35E-07	-6.272
Ca(NH3)2+2	3.01E-25	1.15E-25	-24.94
Ca(NO3)2	1.71E-61	1.75E-61	-60.757
Ca+2	0.005948	0.002525	-2.598
CaCl+	0.0001	7.9E-05	-4.103
CaCO3 (aq)	1.04E-16	1.06E-16	-15.974
CaCrO4 (aq)	6.71E-12	6.86E-12	-11.164
CaF+	2.58E-10	2.03E-10	-9.691
CaH2PO4+	2.95E-08	2.34E-08	-7.632
CaHCO3+	5.75E-10	4.6E-10	-9.338
CaHPO4 (aq)	1.3E-12	1.33E-12	-11.877
CaNH3+2	8.03E-14	3.06E-14	-13.514
CaNO3+	1.62E-29	1.28E-29	-28.894
CaOH+	1.17E-14	9.4E-15	-14.027
CaPO4-	1.63E-19	1.29E-19	-18.888
CaSO4 (aq)	0.003183	0.003254	-2.488
Cd DOM1	5.69E-13	4.88E-13	-12.312
Cd(CO3)2-2	3.54E-35	1.35E-35	-34.869
Cd(HS)2 (aq)	1.3E-128	1.3E-128	-127.872
Cd(HS)3-	9.1E-194	7.2E-194	-193.144
Cd(HS)4-2	2.5E-258	9.6E-259	-258.016
Cd(NH3)2+2	1.7E-27	6.49E-28	-27.188
Cd(NH3)3+2	1.61E-37	6.13E-38	-37.213
Cd(NH3)4+2	4.46E-48	1.7E-48	-47.769
Cd(NO2)2 (aq)	4.88E-49	4.99E-49	-48.302
Cd(NO3)2 (aq)	3.12E-63	3.19E-63	-62.496
Cd(OH)2 (aq)	9.41E-27	9.62E-27	-26.017
Cd(OH)3-	5.49E-38	4.31E-38	-37.365
Cd(OH)4-2	5.28E-50	2.01E-50	-49.696
Cd(SO4)2-2	2.93E-10	1.12E-10	-9.951
Cd+2	2.4E-09	9.17E-10	-9.038
Cd2OH+3	7.04E-26	8.07E-27	-26.093

Species	Concentration	Activity	Log activity
CdCl+	1.43E-09	1.12E-09	-8.95
CdCl2 (aq)	5.8E-11	5.94E-11	-10.227
CdCO3 (aq)	6.19E-22	6.33E-22	-21.198
CdF+	1.22E-16	9.62E-17	-16.017
CdHCO3+	5.07E-16	3.99E-16	-15.399
CdHPO4 (aq)	5.01E-18	5.13E-18	-17.29
CdHS+	1.01E-68	7.95E-69	-68.1
CdNH3+2	3.73E-18	1.42E-18	-17.847
CdNO2+	4.13E-29	3.25E-29	-28.489
CdNO3+	7.33E-36	5.76E-36	-35.239
CdOH+	1.97E-18	1.55E-18	-17.81
CdSO4 (aq)	1.16E-09	1.18E-09	-8.927
Cl-1	0.017287	0.013168	-1.88
CO3-2	7.46E-17	2.95E-17	-16.531
Cr2O7-2	1.2E-11	4.58E-12	-11.339
CrO3Cl-	7.56E-10	5.94E-10	-9.226
CrO3H2PO4-	6.61E-12	5.2E-12	-11.284
CrO3HPO4-2	1.29E-12	4.94E-13	-12.306
CrO3SO4-2	3.56E-08	1.36E-08	-7.867
CrO4-2	1.28E-11	4.61E-12	-11.336
Cu DOM1	5.16E-10	4.42E-10	-9.355
Cu(CO3)2-2	7.53E-31	2.87E-31	-30.542
Cu(N3)2 (aq)	1.43E-18	1.46E-18	-17.835
Cu(N3)3-	4.24E-24	3.33E-24	-23.477
Cu(N3)4-2	1.04E-30	3.98E-31	-30.4
Cu(NH3)2+2	3.32E-23	1.27E-23	-22.898
Cu(NH3)3+2	1.02E-31	3.91E-32	-31.408
Cu(NH3)4+2	6.55E-41	2.5E-41	-40.602
Cu(NO2)2 (aq)	2.71E-48	2.77E-48	-47.558
Cu(NO3)2 (aq)	1.78E-62	1.82E-62	-61.739
Cu(OH)2 (aq)	6.74E-22	6.89E-22	-21.162
Cu(OH)3-	5.71E-30	4.49E-30	-29.348
Cu(OH)4-2	3.57E-42	1.36E-42	-41.866
Cu+2	5.1E-08	2.09E-08	-7.68
Cu2(OH)2+2	2.71E-23	1.03E-23	-22.986
Cu2OH+3	2.31E-20	2.65E-21	-20.577
Cu2S3-2	2.4E-214	9E-215	-214.044
Cu3(OH)4+2	3.74E-38	1.43E-38	-37.845
CuCl+	6.31E-10	4.88E-10	-9.311
CuCl2 (aq)	1.05E-12	1.07E-12	-11.97
CuCl3-	1.42E-16	1.1E-16	-15.96
CuCl4-2 1	2.65E-20	1.02E-20	-19.99
CuCO3 (aq)	3.54E-18	3.62E-18	-17.441
CuF+	7.88E-15	6.19E-15	-14.208
CuHCO3+	2.3E-14	1.81E-14	-13.743
CuHPO4 (aq)	3E-16	3.07E-16	-15.513

Species	Concentration	Activity	Log activity
CuHSO4+	7.88E-10	6.2E-10	-9.208
CuN3+	8.75E-13	6.88E-13	-12.163
CuNH3+2	2.8E-15	1.07E-15	-14.971
CuNO2+	9.78E-28	7.69E-28	-27.114
CuNO3+	1.32E-34	1.04E-34	-33.985
CuOH+	2.36E-14	1.83E-14	-13.738
CuS(aq)	1.26E-76	1.28E-76	-75.892
CuSO4 (aq)	2.57E-08	2.63E-08	-7.58
DOC (Gaussian DOM)	0.001399	0.00143	-2.845
DOM1	2.1E-05	3.17E-06	-5.498
F-1	9.26E-09	7.1E-09	-8.149
Fe DOM1	1.51E-06	1.5E-06	-5.825
Fe(N3)2+	1.12E-13	8.78E-14	-13.056
Fe(N3)3 (aq)	8.37E-19	8.55E-19	-18.068
Fe(NH3)2+2	5.39E-25	2.06E-25	-24.687
Fe(NH3)3+2	6E-36	2.29E-36	-35.64
Fe(NH3)4+2	2.85E-47	1.09E-47	-46.964
Fe(NO2)2+	9.25E-46	7.27E-46	-45.138
Fe(NO2)3 (aq)	2.87E-65	2.94E-65	-64.532
Fe(OH)2 (aq)	8.51E-23	8.7E-23	-22.06
Fe(OH)2+	3.06E-10	2.43E-10	-9.615
Fe(OH)3-	1.45E-31	1.14E-31	-30.941
Fe(OH)3 (aq)	3.58E-18	3.66E-18	-17.436
Fe(OH)4-	1.38E-24	1.09E-24	-23.962
Fe(SO4)2-	1.01E-06	7.92E-07	-6.101
Fe+2	0.000171	7.02E-05	-4.154
Fe+3	6.07E-07	1.12E-07	-6.951
Fe2(OH)2+4	7.07E-13	1.5E-14	-13.824
Fe3(OH)4+5	5.09E-19	1.24E-21	-20.908
FeCl+	7.42E-07	5.83E-07	-6.234
FeCl+2	8.37E-08	3.23E-08	-7.491
FeCrO4+	2.41E-11	1.9E-11	-10.722
FeF+	1.03E-11	8.08E-12	-11.093
FeF+2	1.97E-09	7.58E-10	-9.12
FeF2+	2.58E-13	2.03E-13	-12.692
FeF3 (aq)	1.31E-18	1.34E-18	-17.873
FeH2PO4+	1.68E-08	1.34E-08	-7.874
FeH2PO4+2	2.04E-09	8.05E-10	-9.094
FeHCO3+	1.52E-11	1.21E-11	-10.916
FeHPO4 (aq)	3.01E-13	3.08E-13	-12.512
FeHPO4+	1.94E-09	1.54E-09	-8.813
FeHS+	3.15E-66	2.48E-66	-65.606
FeN3+2	2.08E-09	7.94E-10	-9.1
FeNH3+2	1.91E-14	7.28E-15	-14.138
FeNO2+2	1.64E-25	6.24E-26	-25.205

Species	Concentration	Activity	Log activity
FeOH+	7.43E-13	5.85E-13	-12.233
FeOH+2	8.87E-08	3.42E-08	-7.466
FeSO4 (aq)	9.36E-05	9.57E-05	-4.019
FeSO4+	1.11E-05	8.72E-06	-5.06
H DOM1	9.41E-05	4.31E-05	-4.365
H+1	0.026349	0.021837	-1.661
H2AsO3-	2.29E-18	1.8E-18	-17.745
H2AsO4-	1.24E-06	9.73E-07	-6.012
H2CO3* (aq)	0.000967	0.000989	-3.005
H2CrO4 (aq)	2.55E-09	2.6E-09	-8.585
H2PO4-	6.16E-07	4.89E-07	-6.311
H2S (aq)	2.63E-62	2.69E-62	-61.57
H3AsO3	8.36E-11	8.55E-11	-10.068
H3AsO4	3.71E-06	3.79E-06	-5.421
H3PO4	1.32E-06	1.35E-06	-5.869
HAsO3-2	1.1E-30	4.19E-31	-30.378
HAsO4-2	1.15E-11	4.37E-12	-11.359
HCO3-	2.18E-08	1.73E-08	-7.763
HCrO4-	4.03E-07	3.17E-07	-6.499
HF (aq)	1.91E-07	1.95E-07	-6.71
HF2-	6.78E-15	5.2E-15	-14.284
Hg(CO3)2-2	2.78E-38	1.06E-38	-37.974
Hg(HS)2 (aq)	5.9E-117	6.1E-117	-116.217
Hg(N3)2 (aq)	1.38E-16	1.41E-16	-15.852
Hg(NH3)2+2	5.24E-25	2E-25	-24.699
Hg(NH3)4+2	3.32E-46	1.27E-46	-45.897
Hg(NO2)2 (aq)	3.16E-54	3.23E-54	-53.49
Hg(NO2)3-	5.02E-74	3.94E-74	-73.404
Hg(NO2)4-2	9.34E-95	3.57E-95	-94.448
Hg(NO3)2 (aq)	1.14E-75	1.17E-75	-74.932
Hg(OH)2	4.49E-24	4.59E-24	-23.338
Hg(SO4)2-2	9.82E-22	3.75E-22	-21.426
Hg+2	1.48E-20	5.66E-21	-20.247
Hg2OH+3	5.27E-42	6.03E-43	-42.22
Hg3(OH)3+3	1.14E-62	1.3E-63	-62.885
HgCl+	2.69E-15	2.12E-15	-14.674
HgCl2 (aq)	2.09E-10	2.14E-10	-9.67
HgCl3-1	3.56E-11	2.8E-11	-10.553
HgCl4-2	4.33E-12	1.65E-12	-11.782
HgClOH (aq)	6.58E-17	6.73E-17	-16.172
HgCO3 (aq)	1.25E-25	1.28E-25	-24.894
HgF+	1.91E-27	1.5E-27	-26.824
HgHCO3+	5.89E-23	4.63E-23	-22.334
HgHS2-	1.1E-121	9E-122	-121.046
HgN3+	1.35E-13	1.06E-13	-12.975
HgNO2+	1.25E-36	9.85E-37	-36.007

Species	Concentration	Activity	Log activity
HgNO3+	2.42E-48	1.9E-48	-47.721
HgOH+	9.8E-23	7.7E-23	-22.114
HgOHCO3-	8.68E-31	6.82E-31	-30.166
HgS2-2	2.1E-128	8E-129	-128.095
HgSO4 (aq)	5.77E-21	5.9E-21	-20.229
HN3 (aq)	4.99E-05	5.11E-05	-4.292
HNO2 (aq)	1.06E-20	1.09E-20	-19.965
HPO4-2	3.53E-12	1.36E-12	-11.866
HS-1	1.1E-67	8.47E-68	-67.072
HSO4-	0.012915	0.010091	-1.996
K+1	0.00032	0.000243	-3.614
K2HPO4 (aq)	8.52E-19	8.71E-19	-18.06
K2PO4-	2.92E-28	2.3E-28	-27.639
KCl (aq)	1.66E-06	1.7E-06	-5.77
KCr2O7-	1.23E-14	9.63E-15	-14.016
KCrO4-	5.31E-15	4.17E-15	-14.38
KF (aq)	7.73E-13	7.9E-13	-12.102
KH2PO4 (aq)	1.8E-10	1.84E-10	-9.734
KHPO4-	2.57E-15	2.04E-15	-14.691
KNO3 (aq)	2.69E-31	2.75E-31	-30.56
KOH (aq)	8.67E-17	8.86E-17	-16.053
KPO4-2	2.96E-25	1.13E-25	-24.947
KSO4-	1.13E-05	8.94E-06	-5.049
Mg DOM1	5.45E-08	4.67E-08	-7.331
Mg(NH3)2+2	1.31E-25	5.01E-26	-25.3
Mg+2	0.005018	0.002206	-2.656
Mg2CO3+2	1.46E-18	5.58E-19	-18.253
MgCl+	0.000139	0.000109	-3.961
MgCO3 (aq)	4.53E-17	4.64E-17	-16.334
MgF+	1.33E-09	1.04E-09	-8.984
MgHCO3+	4.77E-10	3.7E-10	-9.432
MgHPO4 (aq)	1.57E-12	1.6E-12	-11.796
MgOH+	1.94E-13	1.56E-13	-12.807
MgPO4-	2.23E-21	1.77E-21	-20.753
MgSO4 (aq)	0.002249	0.0023	-2.638
Mn+3	4.55E-05	8.39E-06	-5.076
N3-1	5.78E-08	4.55E-08	-7.342
Na+1	0.012139	0.009559	-2.02
Na2HPO4 (aq)	8.68E-16	8.88E-16	-15.052
Na2PO4-	9.63E-25	7.57E-25	-24.121
NaCl (aq)	6.9E-05	7.06E-05	-4.151
NaCO3-	8.79E-18	6.97E-18	-17.157
NaCrO4-	2.79E-13	2.19E-13	-12.659
NaF (aq)	5.88E-11	6.01E-11	-10.221
NaH2PO4 (aq)	7.09E-09	7.24E-09	-8.14
NaHCO3 (aq)	9.56E-11	9.78E-11	-10.01

Species	Concentration	Activity	Log activity
NaHPO4-	1.56E-13	1.24E-13	-12.907
NaNO3 (aq)	3.9E-30	3.99E-30	-29.399
NaOH (aq)	2.33E-15	2.38E-15	-14.623
NaPO4-2	1.28E-23	4.9E-24	-23.31
NaSO4-	0.000406	0.000322	-3.492
NH3 (aq)	3.57E-12	3.65E-12	-11.438
NH4+1	0.000387	0.000291	-3.537
NH4Cr2O7-	1.7E-14	1.34E-14	-13.874
NH4SO4-	2.46E-05	1.93E-05	-4.713
Ni DOM1	2.43E-09	2.09E-09	-8.68
Ni(N3)2 (aq)	7.84E-19	8.02E-19	-18.096
Ni(NH3)2+2	1.59E-23	6.05E-24	-23.218
Ni(NH3)3+2	3.35E-33	1.28E-33	-32.893
Ni(NH3)4+2	2.1E-43	8.03E-44	-43.095
Ni(NH3)5+2	4.26E-54	1.63E-54	-53.789
Ni(NH3)6+2	1.84E-65	7.02E-66	-65.154
Ni(NO2)2 (aq)	2.93E-47	2.99E-47	-46.524
Ni(OH)2 (aq)	8.04E-22	8.22E-22	-21.085
Ni(OH)3-	4.78E-31	3.76E-31	-30.425
Ni(SO4)2-2	2.62E-09	1E-09	-9
Ni+2	1.03E-05	3.92E-06	-5.406
NiCl+	2.38E-08	1.87E-08	-7.729
NiCl2 (aq)	8.57E-12	8.77E-12	-11.057
NiCO3 (aq)	4.2E-18	4.3E-18	-17.367
NiF+	6.41E-13	5.04E-13	-12.298
NiH2PO4+	1.6E-11	1.26E-11	-10.9
NiHCO3+	8.45E-12	6.64E-12	-11.178
NiHPO4 (aq)	3.82E-15	3.9E-15	-14.409
NiHS+	1.31E-67	1.03E-67	-66.988
NiN3+	4.28E-12	3.36E-12	-11.474
NiNH3+2	2.46E-14	9.4E-15	-14.027
NiNO2+	4.21E-26	3.31E-26	-25.48
NiNO3+	1.86E-32	1.46E-32	-31.836
NiOH+	1.39E-14	1.09E-14	-13.961
NiSO4 (aq)	4.39E-06	4.49E-06	-5.348
NO2-1	4.48E-22	3.52E-22	-21.454
NO3-1	1.95E-27	1.48E-27	-26.829
OH-	2.73E-13	2.09E-13	-12.679
Pb DOM1	3.66E-10	3.14E-10	-9.503
Pb(CO3)2-2	1.47E-31	5.62E-32	-31.25
Pb(HS)2 (aq)	9.7E-128	9.9E-128	-127.003
Pb(HS)3-	2.1E-193	1.7E-193	-192.775
Pb(NO2)2 (aq)	1.16E-48	1.18E-48	-47.926
Pb(NO3)2 (aq)	4.39E-61	4.49E-61	-60.348
Pb(OH)2 (aq)	1.21E-22	1.24E-22	-21.908
Pb(OH)3-	7.19E-32	5.65E-32	-31.248

Species	Concentration	Activity	Log activity
Pb(SO4)2-2	2.22E-09	8.47E-10	-9.072
Pb+2	1.95E-08	7.43E-09	-8.129
Pb2OH+3	8.79E-21	1.01E-21	-20.997
Pb3(OH)4+2	1.17E-42	4.45E-43	-42.352
Pb4(OH)4+4	2.4E-46	5.1E-48	-47.292
PbCl+	4E-09	3.15E-09	-8.502
PbCl2 (aq)	8.46E-11	8.65E-11	-10.063
PbCl3-	1.15E-12	9.05E-13	-12.043
PbCl4-2	1.14E-14	4.36E-15	-14.361
PbCO3 (aq)	7.26E-19	7.42E-19	-18.13
PbF+	9.48E-15	7.45E-15	-14.128
PbF2 (aq)	6.37E-22	6.51E-22	-21.186
PbH2PO4+	1.14E-13	8.93E-14	-13.049
PbHCO3+	1.03E-13	8.12E-14	-13.09
PbHPO4 (aq)	1.01E-17	1.03E-17	-16.987
PbNO2+	1.08E-27	8.46E-28	-27.073
PbNO3+	2.13E-34	1.67E-34	-33.776
PbOH+	7.79E-15	6.12E-15	-14.213
PbSO4 (aq)	2.21E-08	2.26E-08	-7.646
PO4-3	1.82E-22	2.13E-23	-22.672
S-2	2.01E-83	7.73E-84	-83.112
SO4-2	0.017427	0.006213	-2.207
Zn DOM1	5.77E-09	4.95E-09	-8.306
Zn(CO3)2-2	2.66E-31	1.02E-31	-30.993
Zn(N3)2 (aq)	1.13E-18	1.16E-18	-17.936
Zn(N3)3-	3.83E-25	3.01E-25	-24.521
Zn(NH3)2+2	8.97E-24	3.42E-24	-23.466
Zn(NH3)3+2	9.64E-33	3.68E-33	-32.434
Zn(NH3)4+2	5.07E-42	1.94E-42	-41.713
Zn(NO2)2 (aq)	1.13E-47	1.15E-47	-46.939
Zn(NO3)2 (aq)	6.31E-60	6.45E-60	-59.19
Zn(OH)2 (aq)	1.51E-19	1.55E-19	-18.811
Zn(OH)3-	2.85E-29	2.24E-29	-28.65
Zn(OH)4-2	4.25E-40	1.62E-40	-39.79
Zn(SO4)2-2	1.13E-06	4.32E-07	-6.365
Zn+2	1.43E-05	5.87E-06	-5.231
Zn2OH+3	5.63E-18	6.45E-19	-18.19
Zn2S3-2	1.2E-206	4.5E-207	-206.347
ZnCl+	2.67E-07	2.07E-07	-6.685
ZnCl2 (aq)	1.7E-09	1.74E-09	-8.759
ZnCl3-	3.08E-11	2.42E-11	-10.616
ZnCl4-2	3.85E-13	1.47E-13	-12.832
ZnCO3 (aq)	9.73E-18	9.95E-18	-17.002
ZnF+	9.07E-13	7.13E-13	-12.147
ZnHCO3+	3.24E-12	2.55E-12	-11.594
ZnHPO4 (aq)	1.31E-14	1.34E-14	-13.874

Species	Concentration	Activity	Log activity
ZnN3+	4.88E-12	3.84E-12	-11.416
ZnNH3+2	1.06E-14	4.05E-15	-14.393
ZnNO2+	1.58E-26	1.24E-26	-25.905
ZnNO3+	2.96E-32	2.33E-32	-31.633
ZnOH+	1.56E-13	1.23E-13	-12.91
ZnS (aq)	8.27E-73	8.46E-73	-72.073
ZnSO4 (aq)	7.15E-06	7.31E-06	-5.136

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Species	Concentration	Activity	Log activity
Al DOM1	3.18E-06	3.15E-06	-5.502
Al(OH)2+	1.75E-12	1.39E-12	-11.857
Al(OH)3 (aq)	1.15E-17	1.18E-17	-16.929
Al(OH)4-	3.02E-22	2.36E-22	-21.627
Al(SO4)2-	0.00091	0.000711	-3.148
Al+3	0.000408	7.53E-05	-4.123
Al2(OH)2+4	3.82E-12	8.13E-14	-13.09
Al2(OH)2CO3+2	1.76E-17	6.71E-18	-17.173
Al2PO4+3	9.82E-12	1.13E-12	-11.948
Al3(OH)4+5	1.29E-18	3.15E-21	-20.501
AlCl+2	1.05E-06	4.02E-07	-6.396
AlF+2	1.3E-05	5.12E-06	-5.29
AlF2+	1.81E-08	1.44E-08	-7.842
AlF3 (aq)	1.17E-12	1.19E-12	-11.924
AlF4-	5.42E-18	4.24E-18	-17.373
AlHPO4+	4.51E-09	3.54E-09	-8.451
AlOH+2	4.41E-08	1.74E-08	-7.759
AlSO4+	0.003484	0.002723	-2.565
AsO4-3	2.08E-21	2.38E-22	-21.623
AsS(OH)HS-	7.9E-160	6.2E-160	-159.205
Ca DOM1	6.18E-07	5.3E-07	-6.276
Ca(NH3)2+2	2.94E-25	1.12E-25	-24.949
Ca(NO3)2	1.31E-33	1.34E-33	-32.872
Ca+2	0.00595	0.002527	-2.597
CaCl+	0.0001	7.87E-05	-4.104
CaCO3 (aq)	1.02E-16	1.04E-16	-15.984
CaCrO4 (aq)	6.63E-12	6.78E-12	-11.169
CaF+	2.58E-10	2.03E-10	-9.692
CaH2PO4+	2.95E-08	2.34E-08	-7.631
CaHCO3+	5.68E-10	4.55E-10	-9.342
CaHPO4 (aq)	1.28E-12	1.31E-12	-11.882
CaNH3+2	7.94E-14	3.03E-14	-13.518
CaNO3+	1.42E-15	1.12E-15	-14.952
CaOH+	1.16E-14	9.29E-15	-14.032
CaPO4-	1.59E-19	1.26E-19	-18.898

Species	Concentration	Activity	Log activity
CaSO4 (aq)	0.003181	0.003253	-2.488
Cd DOM1	5.64E-13	4.84E-13	-12.316
Cd(CO3)2-2	3.38E-35	1.29E-35	-34.889
Cd(HS)2 (aq)	1.7E-156	1.7E-156	-155.766
Cd(HS)3-	1.3E-235	1E-235	-234.985
Cd(NH3)2+2	1.66E-27	6.36E-28	-27.197
Cd(NH3)3+2	1.55E-37	5.93E-38	-37.227
Cd(NH3)4+2	4.27E-48	1.63E-48	-47.788
Cd(NO2)2 (aq)	3.96E-28	4.04E-28	-27.393
Cd(NO3)2 (aq)	2.39E-35	2.44E-35	-34.612
Cd(OH)2 (aq)	9.21E-27	9.42E-27	-26.026
Cd(OH)3-	5.3E-38	4.17E-38	-37.38
Cd(OH)4-2	5.04E-50	1.93E-50	-49.716
Cd(SO4)2-2	2.93E-10	1.12E-10	-9.951
Cd+2	2.41E-09	9.19E-10	-9.037
Cd2OH+3	6.98E-26	8E-27	-26.097
CdCl+	1.42E-09	1.12E-09	-8.951
CdCl2 (aq)	5.77E-11	5.9E-11	-10.229
CdCO3 (aq)	6.06E-22	6.2E-22	-21.208
CdF+	1.23E-16	9.63E-17	-16.016
CdHCO3+	5.02E-16	3.95E-16	-15.403
CdHPO4 (aq)	4.97E-18	5.08E-18	-17.294
CdHS+	1.14E-82	8.99E-83	-82.046
CdNH3+2	3.69E-18	1.41E-18	-17.851
CdNO2+	1.18E-18	9.25E-19	-18.034
CdNO3+	6.43E-22	5.05E-22	-21.297
CdOH+	1.95E-18	1.53E-18	-17.815
CdSO4 (aq)	1.16E-09	1.18E-09	-8.927
Cl-1	0.017211	0.013113	-1.882
CO3-2	7.28E-17	2.88E-17	-16.541
Cr2O7-2	1.2E-11	4.58E-12	-11.339
CrO3Cl-	7.61E-10	5.98E-10	-9.223
CrO3H2PO4-	6.69E-12	5.26E-12	-11.279
CrO3HPO4-2	1.29E-12	4.94E-13	-12.306
CrO3SO4-2	3.59E-08	1.37E-08	-7.863
CrO4-2	1.27E-11	4.56E-12	-11.341
Cu DOM1	5.11E-10	4.38E-10	-9.359
Cu(CO3)2-2	7.18E-31	2.74E-31	-30.562
Cu(N3)2 (aq)	1.4E-18	1.43E-18	-17.845
Cu(N3)3-	4.09E-24	3.22E-24	-23.492
Cu(N3)4-2	9.96E-31	3.8E-31	-30.42
Cu(NH3)2+2	3.24E-23	1.24E-23	-22.907
Cu(NH3)3+2	9.9E-32	3.78E-32	-31.422
Cu(NH3)4+2	6.26E-41	2.39E-41	-40.622
Cu(NO2)2 (aq)	2.19E-27	2.24E-27	-26.65
Cu(NO3)2 (aq)	1.37E-34	1.4E-34	-33.855

Species	Concentration	Activity	Log activity
Cu(OH)2 (aq)	6.59E-22	6.74E-22	-21.171
Cu(OH)3-	5.51E-30	4.33E-30	-29.363
Cu(OH)4-2	3.4E-42	1.3E-42	-41.886
Cu+2	5.1E-08	2.09E-08	-7.68
Cu2(OH)2+2	2.65E-23	1.01E-23	-22.995
Cu2OH+3	2.28E-20	2.62E-21	-20.582
Cu2S3-2	3.3E-256	1.3E-256	-255.901
Cu3(OH)4+2	3.58E-38	1.37E-38	-37.865
CuCl+	6.28E-10	4.87E-10	-9.313
CuCl2 (aq)	1.04E-12	1.06E-12	-11.973
CuCl3-	1.4E-16	1.08E-16	-15.965
CuCl4-2 1	2.61E-20	1.01E-20	-19.997
CuCO3 (aq)	3.46E-18	3.54E-18	-17.451
CuF+	7.88E-15	6.19E-15	-14.208
CuHCO3+	2.27E-14	1.79E-14	-13.748
CuHPO4 (aq)	2.97E-16	3.04E-16	-15.517
CuHSO4+	7.97E-10	6.27E-10	-9.203
CuN3+	8.65E-13	6.8E-13	-12.167
CuNH3+2	2.77E-15	1.06E-15	-14.975
CuNO2+	2.78E-17	2.19E-17	-16.66
CuNO3+	1.15E-20	9.07E-21	-20.043
CuOH+	2.34E-14	1.81E-14	-13.742
CuS(aq)	1.4E-90	1.43E-90	-89.844
CuSO4 (aq)	2.57E-08	2.63E-08	-7.58
DOC (Gaussian DOM)	0.001399	0.00143	-2.845
DOM1	2.09E-05	3.16E-06	-5.5
F-1	9.24E-09	7.09E-09	-8.149
Fe DOM1	1.54E-06	1.53E-06	-5.815
Fe(N3)2+	1.13E-13	8.86E-14	-13.052
Fe(N3)3 (aq)	8.35E-19	8.53E-19	-18.069
Fe(NH3)2+2	9.69E-27	3.7E-27	-26.432
Fe(NH3)3+2	1.07E-37	4.07E-38	-37.39
Fe(NH3)4+2	5.01E-49	1.91E-49	-48.718
Fe(NO2)2+	7.73E-25	6.08E-25	-24.216
Fe(NO2)3 (aq)	6.83E-34	6.98E-34	-33.156
Fe(OH)2 (aq)	1.53E-24	1.57E-24	-23.805
Fe(OH)2+	3.09E-10	2.45E-10	-9.611
Fe(OH)3-	2.58E-33	2.03E-33	-32.691
Fe(OH)3 (aq)	3.57E-18	3.65E-18	-17.437
Fe(OH)4-	1.36E-24	1.08E-24	-23.968
Fe(SO4)2-	1.04E-06	8.17E-07	-6.088
Fe+2	3.16E-06	1.29E-06	-5.889
Fe+3	6.27E-07	1.16E-07	-6.937
Fe2(OH)2+4	7.36E-13	1.57E-14	-13.805
Fe3(OH)4+5	5.34E-19	1.3E-21	-20.885

Species	Concentration	Activity	Log activity
FeCl+	1.36E-08	1.07E-08	-7.971
FeCl+2	8.61E-08	3.32E-08	-7.479
FeCrO4+	2.46E-11	1.94E-11	-10.713
FeF+	1.89E-13	1.49E-13	-12.828
FeF+2	2.03E-09	7.83E-10	-9.106
FeF2+	2.66E-13	2.1E-13	-12.678
FeF3 (aq)	1.35E-18	1.38E-18	-17.86
FeH2PO4+	3.1E-10	2.46E-10	-9.609
FeH2PO4+2	2.11E-09	8.32E-10	-9.08
FeHCO3+	2.76E-13	2.21E-13	-12.656
FeHPO4 (aq)	5.48E-15	5.61E-15	-14.251
FeHPO4+	1.98E-09	1.57E-09	-8.803
FeHS+	6.55E-82	5.15E-82	-81.288
FeN3+2	2.12E-09	8.11E-10	-9.091
FeNH3+2	3.47E-16	1.33E-16	-15.878
FeNO2+2	4.8E-15	1.84E-15	-14.736
FeOH+	1.35E-14	1.06E-14	-13.973
FeOH+2	9.06E-08	3.49E-08	-7.457
FeSO4 (aq)	1.72E-06	1.76E-06	-5.755
FeSO4+	1.14E-05	9E-06	-5.046
H DOM1	9.42E-05	4.32E-05	-4.364
H+1	0.026658	0.022096	-1.656
H2AsO3-	7.37E-22	5.8E-22	-21.237
H2AsO4-	1.23E-06	9.65E-07	-6.016
H2CO3* (aq)	0.000967	0.000989	-3.005
H2CrO4 (aq)	2.57E-09	2.63E-09	-8.58
H2PO4-	6.17E-07	4.89E-07	-6.311
H2S (aq)	3.01E-76	3.08E-76	-75.512
H3AsO3	2.73E-14	2.79E-14	-13.555
H3AsO4	3.72E-06	3.8E-06	-5.42
H3PO4	1.34E-06	1.37E-06	-5.864
HAsO3-2	3.5E-34	1.34E-34	-33.874
HAsO4-2	1.12E-11	4.28E-12	-11.368
HCO3-	2.15E-08	1.71E-08	-7.768
HCrO4-	4.03E-07	3.17E-07	-6.499
HF (aq)	1.93E-07	1.97E-07	-6.706
HF2-	6.84E-15	5.25E-15	-14.28
Hg(CO3)2-2	2.67E-38	1.02E-38	-37.991
Hg(HS)2 (aq)	7.6E-145	7.8E-145	-144.108
Hg(N3)2 (aq)	1.32E-16	1.35E-16	-15.869
Hg(NH3)2+2	5.16E-25	1.97E-25	-24.705
Hg(NH3)4+2	3.2E-46	1.22E-46	-45.913
Hg(NO2)2 (aq)	2.58E-33	2.64E-33	-32.578
Hg(NO2)3-	1.16E-42	9.15E-43	-42.038
Hg(NO2)4-2	6.16E-53	2.35E-53	-52.628
Hg(NO3)2 (aq)	8.84E-48	9.04E-48	-47.044

Species	Concentration	Activity	Log activity
Hg(OH)2	4.43E-24	4.53E-24	-23.344
Hg(SO4)2-2	9.88E-22	3.77E-22	-21.423
Hg+2	1.5E-20	5.71E-21	-20.243
Hg2OH+3	5.29E-42	6.07E-43	-42.217
Hg3(OH)3+3	1.13E-62	1.29E-63	-62.888
HgCl+	2.71E-15	2.13E-15	-14.672
HgCl2 (aq)	2.09E-10	2.14E-10	-9.67
HgCl3-1	3.55E-11	2.79E-11	-10.554
HgCl4-2	4.29E-12	1.64E-12	-11.786
HgClOH (aq)	6.54E-17	6.68E-17	-16.175
HgCO3 (aq)	1.23E-25	1.26E-25	-24.9
HgF+	1.92E-27	1.51E-27	-26.821
HgHCO3+	5.88E-23	4.62E-23	-22.335
HgHS2-	1.5E-149	1.1E-149	-148.942
HgN3+	1.28E-13	1.01E-13	-12.997
HgNO2+	3.6E-26	2.83E-26	-25.549
HgNO3+	2.14E-34	1.68E-34	-33.775
HgOH+	9.77E-23	7.68E-23	-22.115
HgOHCO3-	8.45E-31	6.65E-31	-30.177
HgS2-2	2.6E-156	1E-156	-155.996
HgSO4 (aq)	5.81E-21	5.94E-21	-20.226
HN3 (aq)	4.99E-05	5.11E-05	-4.292
HNO2 (aq)	3.05E-10	3.12E-10	-9.506
HPO4-2	3.49E-12	1.34E-12	-11.871
HS-1	1.25E-81	9.56E-82	-81.02
HSO4-	0.013048	0.010197	-1.992
K+1	0.00032	0.000243	-3.614
K2HPO4 (aq)	8.43E-19	8.62E-19	-18.065
K2PO4-	2.86E-28	2.24E-28	-27.649
KCl (aq)	1.66E-06	1.69E-06	-5.772
KCr2O7-	1.22E-14	9.62E-15	-14.017
KCrO4-	5.24E-15	4.12E-15	-14.385
KF (aq)	7.72E-13	7.89E-13	-12.103
KH2PO4 (aq)	1.81E-10	1.85E-10	-9.734
KHPO4-	2.54E-15	2.01E-15	-14.696
KNO3 (aq)	2.36E-17	2.41E-17	-16.618
KOH (aq)	8.57E-17	8.76E-17	-16.058
KPO4-2	2.89E-25	1.11E-25	-24.957
KSO4-	1.13E-05	8.93E-06	-5.049
Mg DOM1	5.4E-08	4.63E-08	-7.335
Mg(NH3)2+2	1.28E-25	4.9E-26	-25.31
Mg+2	0.005019	0.002208	-2.656
Mg2CO3+2	1.43E-18	5.46E-19	-18.263
MgCl+	0.000139	0.000109	-3.963
MgCO3 (aq)	4.43E-17	4.53E-17	-16.344
MgF+	1.33E-09	1.04E-09	-8.984

Species	Concentration	Activity	Log activity
MgHCO3+	4.72E-10	3.66E-10	-9.437
MgHPO4 (aq)	1.55E-12	1.58E-12	-11.8
MgOH+	1.92E-13	1.54E-13	-12.812
MgPO4-	2.18E-21	1.73E-21	-20.763
MgSO4 (aq)	0.002248	0.002299	-2.639
Mn+3	4.55E-05	8.4E-06	-5.076
N3-1	5.72E-08	4.49E-08	-7.347
Na+1	0.01214	0.009561	-2.019
Na2HPO4 (aq)	8.59E-16	8.78E-16	-15.056
Na2PO4-	9.41E-25	7.4E-25	-24.131
NaCl (aq)	6.87E-05	7.03E-05	-4.153
NaCO3-	8.59E-18	6.81E-18	-17.167
NaCrO4-	2.75E-13	2.17E-13	-12.665
NaF (aq)	5.87E-11	6E-11	-10.222
NaH2PO4 (aq)	7.09E-09	7.25E-09	-8.14
NaHCO3 (aq)	9.45E-11	9.66E-11	-10.015
NaHPO4-	1.54E-13	1.22E-13	-12.912
NaNO3 (aq)	3.41E-16	3.49E-16	-15.457
NaOH (aq)	2.3E-15	2.36E-15	-14.628
NaPO4-2	1.25E-23	4.79E-24	-23.32
NaSO4-	0.000405	0.000321	-3.493
NH3 (aq)	3.53E-12	3.61E-12	-11.443
NH4+1	0.000387	0.000291	-3.537
NH4Cr2O7-	1.7E-14	1.34E-14	-13.874
NH4SO4-	2.46E-05	1.93E-05	-4.714
Ni DOM1	2.41E-09	2.07E-09	-8.685
Ni(N3)2 (aq)	7.67E-19	7.84E-19	-18.106
Ni(NH3)2+2	1.55E-23	5.92E-24	-23.227
Ni(NH3)3+2	3.24E-33	1.24E-33	-32.907
Ni(NH3)4+2	2.01E-43	7.68E-44	-43.115
Ni(NH3)5+2	4.02E-54	1.54E-54	-53.813
Ni(NH3)6+2	1.72E-65	6.56E-66	-65.183
Ni(NO2)2 (aq)	2.37E-26	2.42E-26	-25.616
Ni(OH)2 (aq)	7.86E-22	8.03E-22	-21.095
Ni(OH)3-	4.62E-31	3.63E-31	-30.44
Ni(SO4)2-2	2.62E-09	9.99E-10	-9
Ni+2	1.03E-05	3.93E-06	-5.406
NiCl+	2.37E-08	1.86E-08	-7.73
NiCl2 (aq)	8.51E-12	8.7E-12	-11.06
NiCO3 (aq)	4.11E-18	4.2E-18	-17.377
NiF+	6.4E-13	5.03E-13	-12.298
NiH2PO4+	1.61E-11	1.26E-11	-10.899
NiHCO3+	8.36E-12	6.57E-12	-11.182
NiHPO4 (aq)	3.78E-15	3.86E-15	-14.413
NiHS+	1.48E-81	1.16E-81	-80.935
NiN3+	4.23E-12	3.32E-12	-11.478

Species	Concentration	Activity	Log activity
NiNH3+2	2.43E-14	9.3E-15	-14.032
NiNO2+	1.2E-15	9.43E-16	-15.026
NiNO3+	1.63E-18	1.28E-18	-17.893
NiOH+	1.38E-14	1.08E-14	-13.966
NiSO4 (aq)	4.39E-06	4.48E-06	-5.348
NO2-1	1.27E-11	1E-11	-11
NO3-1	1.71E-13	1.3E-13	-12.888
OH-	2.7E-13	2.07E-13	-12.684
Pb DOM1	3.63E-10	3.11E-10	-9.507
Pb(CO3)2-2	1.41E-31	5.37E-32	-31.27
Pb(HS)2 (aq)	1.2E-155	1.3E-155	-154.897
Pb(HS)3-	3.1E-235	2.4E-235	-234.617
Pb(NO2)2 (aq)	9.38E-28	9.59E-28	-27.018
Pb(NO3)2 (aq)	3.37E-33	3.44E-33	-32.463
Pb(OH)2 (aq)	1.18E-22	1.21E-22	-21.918
Pb(OH)3-	6.95E-32	5.47E-32	-31.262
Pb(SO4)2-2	2.21E-09	8.46E-10	-9.073
Pb+2	1.95E-08	7.44E-09	-8.128
Pb2OH+3	8.7E-21	9.97E-22	-21.001
Pb3(OH)4+2	1.12E-42	4.26E-43	-42.37
Pb4(OH)4+4	2.3E-46	4.9E-48	-47.31
PbCl+	3.99E-09	3.14E-09	-8.503
PbCl2 (aq)	8.4E-11	8.59E-11	-10.066
PbCl3-	1.14E-12	8.95E-13	-12.048
PbCl4-2	1.12E-14	4.29E-15	-14.367
PbCO3 (aq)	7.1E-19	7.26E-19	-18.139
PbF+	9.49E-15	7.46E-15	-14.127
PbF2 (aq)	6.36E-22	6.51E-22	-21.187
PbH2PO4+	1.14E-13	8.94E-14	-13.048
PbHCO3+	1.02E-13	8.04E-14	-13.095
PbHPO4 (aq)	9.99E-18	1.02E-17	-16.991
PbNO2+	3.06E-17	2.41E-17	-16.618
PbNO3+	1.87E-20	1.47E-20	-19.834
PbOH+	7.7E-15	6.06E-15	-14.218
PbSO4 (aq)	2.21E-08	2.26E-08	-7.646
PO4-3	1.78E-22	2.08E-23	-22.682
S-2	2.24E-97	8.63E-98	-97.064
SO4-2	0.017389	0.006205	-2.207
Zn DOM1	5.72E-09	4.9E-09	-8.31
Zn(CO3)2-2	2.54E-31	9.71E-32	-31.013
Zn(N3)2 (aq)	1.11E-18	1.13E-18	-17.946
Zn(N3)3-	3.7E-25	2.91E-25	-24.536
Zn(NH3)2+2	8.77E-24	3.35E-24	-23.475
Zn(NH3)3+2	9.31E-33	3.56E-33	-32.449
Zn(NH3)4+2	4.85E-42	1.85E-42	-41.733
Zn(NO2)2 (aq)	9.11E-27	9.32E-27	-26.031

Species	Concentration	Activity	Log activity
Zn(NO3)2 (aq)	4.83E-32	4.94E-32	-31.306
Zn(OH)2 (aq)	1.48E-19	1.51E-19	-18.82
Zn(OH)3-	2.75E-29	2.16E-29	-28.665
Zn(OH)4-2	4.06E-40	1.55E-40	-39.81
Zn(SO4)2-2	1.13E-06	4.31E-07	-6.366
Zn+2	1.43E-05	5.88E-06	-5.231
Zn2OH+3	5.57E-18	6.39E-19	-18.195
Zn2S3-2	1.6E-248	6.3E-249	-248.203
ZnCl+	2.66E-07	2.06E-07	-6.686
ZnCl2 (aq)	1.69E-09	1.73E-09	-8.762
ZnCl3-	3.04E-11	2.39E-11	-10.621
ZnCl4-2	3.79E-13	1.45E-13	-12.839
ZnCO3 (aq)	9.52E-18	9.73E-18	-17.012
ZnF+	9.07E-13	7.13E-13	-12.147
ZnHCO3+	3.21E-12	2.52E-12	-11.599
ZnHPO4 (aq)	1.29E-14	1.32E-14	-13.879
ZnN3+	4.83E-12	3.8E-12	-11.421
ZnNH3+2	1.05E-14	4.01E-15	-14.397
ZnNO2+	4.5E-16	3.54E-16	-15.451
ZnNO3+	2.59E-18	2.04E-18	-17.691
ZnOH+	1.55E-13	1.22E-13	-12.915
ZnS (aq)	9.24E-87	9.44E-87	-86.025
ZnSO4 (aq)	7.15E-06	7.31E-06	-5.136

B1.8: Eh 800

Species	Concentration	Activity	Log activity
Al DOM1	3.14E-06	3.11E-06	-5.507
Al(OH)2+	1.7E-12	1.35E-12	-11.871
Al(OH)3 (aq)	1.09E-17	1.12E-17	-16.951
Al(OH)4-	2.82E-22	2.2E-22	-21.657
Al(SO4)2-	0.000904	0.000707	-3.151
Al+3	0.000411	7.58E-05	-4.12
Al2(OH)2+4	3.74E-12	7.94E-14	-13.1
Al2(OH)2CO3+2	1.65E-17	6.31E-18	-17.2
Al2PO4+3	9.47E-12	1.09E-12	-11.964
Al3(OH)4+5	1.23E-18	2.98E-21	-20.525
AlCl+2	1.06E-06	4.05E-07	-6.393
AlF+2	1.3E-05	5.12E-06	-5.291
AlF2+	1.8E-08	1.43E-08	-7.846
AlF3 (aq)	1.15E-12	1.17E-12	-11.93
AlF4-	5.3E-18	4.14E-18	-17.383
AlHPO4+	4.4E-09	3.46E-09	-8.462
AlOH+2	4.36E-08	1.72E-08	-7.764
AlSO4+	0.003486	0.002724	-2.565
AsO4-3	1.97E-21	2.26E-22	-21.646

Species	Concentration	Activity	Log activity
AsS(OH)HS-	3.9E-191	3E-191	-190.519
Ca DOM1	6.08E-07	5.21E-07	-6.283
Ca(NH3)2+2	9.33E-35	3.56E-35	-34.449
Ca(NO3)2	2.86E-15	2.92E-15	-14.535
Ca+2	0.005962	0.002532	-2.597
CaCl+	0.0001	7.88E-05	-4.103
CaCO3 (aq)	9.79E-17	1E-16	-15.999
CaCrO4 (aq)	6.51E-12	6.66E-12	-11.177
CaF+	2.57E-10	2.02E-10	-9.694
CaH2PO4+	2.92E-08	2.31E-08	-7.636
CaHCO3+	5.59E-10	4.47E-10	-9.35
CaHPO4 (aq)	1.25E-12	1.27E-12	-11.895
CaNH3+2	1.41E-18	5.4E-19	-18.268
CaNO3+	2.1E-06	1.65E-06	-5.783
CaOH+	1.14E-14	9.14E-15	-14.039
CaPO4-	1.52E-19	1.2E-19	-18.919
CaSO4 (aq)	0.003167	0.003238	-2.49
Cd DOM1	5.55E-13	4.76E-13	-12.323
Cd(CO3)2-2	3.14E-35	1.2E-35	-34.921
Cd(HS)2 (aq)	2.4E-184	2.5E-184	-183.608
Cd(HS)3-	2.3E-277	1.8E-277	-276.749
Cd(NH3)2+2	5.27E-37	2.01E-37	-36.696
Cd(NH3)3+2	8.75E-52	3.34E-52	-51.476
Cd(NH3)4+2	4.27E-67	1.63E-67	-66.787
Cd(NO2)2 (aq)	9.37E-17	9.58E-17	-16.019
Cd(NO3)2 (aq)	5.2E-17	5.32E-17	-16.274
Cd(OH)2 (aq)	8.88E-27	9.08E-27	-26.042
Cd(OH)3-	5.02E-38	3.95E-38	-37.404
Cd(OH)4-2	4.68E-50	1.79E-50	-49.748
Cd(SO4)2-2	2.9E-10	1.11E-10	-9.956
Cd+2	2.41E-09	9.2E-10	-9.036
Cd2OH+3	6.88E-26	7.88E-27	-26.104
CdCl+	1.43E-09	1.12E-09	-8.951
CdCl2 (aq)	5.78E-11	5.9E-11	-10.229
CdCO3 (aq)	5.85E-22	5.98E-22	-21.223
CdF+	1.22E-16	9.58E-17	-16.019
CdHCO3+	4.94E-16	3.88E-16	-15.411
CdHPO4 (aq)	4.82E-18	4.93E-18	-17.307
CdHS+	1.37E-96	1.08E-96	-95.967
CdNH3+2	6.58E-23	2.51E-23	-22.6
CdNO2+	5.73E-13	4.51E-13	-12.346
CdNO3+	9.49E-13	7.46E-13	-12.127
CdOH+	1.92E-18	1.51E-18	-17.822
CdSO4 (aq)	1.15E-09	1.18E-09	-8.929
Cl-1	0.017209	0.01311	-1.882
CO3-2	7.01E-17	2.77E-17	-16.557

Species	Concentration	Activity	Log activity
Cr2O7-2	1.2E-11	4.57E-12	-11.341
CrO3Cl-	7.75E-10	6.09E-10	-9.215
CrO3H2PO4-	6.72E-12	5.29E-12	-11.277
CrO3HPO4-2	1.28E-12	4.87E-13	-12.312
CrO3SO4-2	3.63E-08	1.39E-08	-7.858
CrO4-2	1.24E-11	4.47E-12	-11.35
Cu DOM1	5.02E-10	4.31E-10	-9.366
Cu(CO3)2-2	6.67E-31	2.55E-31	-30.594
Cu(N3)2 (aq)	1.35E-18	1.38E-18	-17.861
Cu(N3)3-	3.88E-24	3.05E-24	-23.516
Cu(N3)4-2	9.25E-31	3.53E-31	-30.452
Cu(NH3)2+2	1.03E-32	3.92E-33	-32.407
Cu(NH3)3+2	5.58E-46	2.13E-46	-45.672
Cu(NH3)4+2	6.26E-60	2.39E-60	-59.621
Cu(NO2)2 (aq)	5.19E-16	5.3E-16	-15.275
Cu(NO3)2 (aq)	2.97E-16	3.04E-16	-15.517
Cu(OH)2 (aq)	6.36E-22	6.5E-22	-21.187
Cu(OH)3-	5.22E-30	4.1E-30	-29.387
Cu(OH)4-2	3.16E-42	1.21E-42	-41.918
Cu+2	5.11E-08	2.09E-08	-7.679
Cu2(OH)2+2	2.56E-23	9.76E-24	-23.011
Cu2OH+3	2.25E-20	2.58E-21	-20.589
Cu2S3-2	5.4E-298	2E-298	-297.689
Cu3(OH)4+2	3.33E-38	1.27E-38	-37.896
CuCl+	6.29E-10	4.87E-10	-9.312
CuCl2 (aq)	1.04E-12	1.06E-12	-11.973
CuCl3-	1.4E-16	1.08E-16	-15.965
CuCl4-2 1	2.61E-20	1.01E-20	-19.997
CuCO3 (aq)	3.34E-18	3.41E-18	-17.467
CuF+	7.83E-15	6.16E-15	-14.211
CuHCO3+	2.24E-14	1.76E-14	-13.755
CuHPO4 (aq)	2.88E-16	2.95E-16	-15.531
CuHSO4+	8.09E-10	6.36E-10	-9.197
CuN3+	8.5E-13	6.68E-13	-12.175
CuNH3+2	4.94E-20	1.88E-20	-19.725
CuNO2+	1.36E-11	1.07E-11	-10.972
CuNO3+	1.7E-11	1.34E-11	-10.873
CuOH+	2.3E-14	1.78E-14	-13.75
CuS(aq)	1.7E-104	1.7E-104	-103.773
CuSO4 (aq)	2.56E-08	2.62E-08	-7.582
DOC (Gaussian DOM)	0.001399	0.00143	-2.845
DOM1	2.07E-05	3.14E-06	-5.503
F-1	9.18E-09	7.04E-09	-8.152
Fe DOM1	1.6E-06	1.58E-06	-5.801
Fe(N3)2+	1.14E-13	8.98E-14	-13.047

Species	Concentration	Activity	Log activity
Fe(N3)3 (aq)	8.3E-19	8.49E-19	-18.071
Fe(NH3)2+2	5.75E-38	2.19E-38	-37.659
Fe(NH3)3+2	1.12E-53	4.29E-54	-53.367
Fe(NH3)4+2	9.39E-70	3.58E-70	-69.446
Fe(NO2)2+	1.92E-13	1.51E-13	-12.82
Fe(NO2)3 (aq)	8.26E-17	8.45E-17	-16.073
Fe(OH)2 (aq)	2.77E-26	2.83E-26	-25.549
Fe(OH)2+	3.13E-10	2.48E-10	-9.605
Fe(OH)3-	4.58E-35	3.61E-35	-34.443
Fe(OH)3 (aq)	3.55E-18	3.63E-18	-17.44
Fe(OH)4-	1.32E-24	1.05E-24	-23.979
Fe(SO4)2-	1.08E-06	8.49E-07	-6.071
Fe+2	5.92E-08	2.42E-08	-7.615
Fe+3	6.6E-07	1.22E-07	-6.914
Fe2(OH)2+4	7.86E-13	1.67E-14	-13.777
Fe3(OH)4+5	5.79E-19	1.41E-21	-20.851
FeCl+	2.55E-10	2.01E-10	-9.698
FeCl+2	9.07E-08	3.5E-08	-7.456
FeCrO4+	2.54E-11	2E-11	-10.699
FeF+	3.52E-15	2.77E-15	-14.558
FeF+2	2.12E-09	8.18E-10	-9.087
FeF2+	2.76E-13	2.18E-13	-12.662
FeF3 (aq)	1.39E-18	1.42E-18	-17.848
FeH2PO4+	5.75E-12	4.56E-12	-11.341
FeH2PO4+2	2.19E-09	8.65E-10	-9.063
FeHCO3+	5.08E-15	4.06E-15	-14.391
FeHPO4 (aq)	9.97E-17	1.02E-16	-15.992
FeHPO4+	2.02E-09	1.6E-09	-8.795
FeHS+	1.47E-97	1.16E-97	-96.936
FeN3+2	2.19E-09	8.38E-10	-9.077
FeNH3+2	1.16E-22	4.42E-23	-22.355
FeNO2+2	2.46E-09	9.39E-10	-9.027
FeOH+	2.49E-16	1.96E-16	-15.708
FeOH+2	9.36E-08	3.61E-08	-7.443
FeSO4 (aq)	3.21E-08	3.28E-08	-7.484
FeSO4+	1.19E-05	9.41E-06	-5.026
H DOM1	9.44E-05	4.33E-05	-4.364
H+1	0.02717	0.02252	-1.647
H2AsO3-	2.4E-25	1.88E-25	-24.725
H2AsO4-	1.21E-06	9.51E-07	-6.022
H2CO3* (aq)	0.000967	0.000989	-3.005
H2CrO4 (aq)	2.62E-09	2.68E-09	-8.572
H2PO4-	6.09E-07	4.83E-07	-6.316
H2S (aq)	3.67E-90	3.76E-90	-89.425
H3AsO3	9.04E-18	9.24E-18	-17.034
H3AsO4	3.74E-06	3.82E-06	-5.418

Species	Concentration	Activity	Log activity
H3PO4	1.35E-06	1.38E-06	-5.861
HAsO3-2	1.12E-37	4.26E-38	-37.371
HAsO4-2	1.09E-11	4.14E-12	-11.383
HCO3-	2.11E-08	1.67E-08	-7.776
HCrO4-	4.03E-07	3.16E-07	-6.5
HF (aq)	1.95E-07	1.99E-07	-6.701
HF2-	6.87E-15	5.27E-15	-14.278
Hg(CO3)2-2	2.48E-38	9.47E-39	-38.023
Hg(HS)2 (aq)	1.1E-172	1.1E-172	-171.95
Hg(N3)2 (aq)	1.23E-16	1.26E-16	-15.901
Hg(NH3)2+2	1.63E-34	6.23E-35	-34.205
Hg(NH3)4+2	3.2E-65	1.22E-65	-64.913
Hg(NO2)2 (aq)	6.11E-22	6.24E-22	-21.205
Hg(NO2)3-	1.34E-25	1.05E-25	-24.978
Hg(NO2)4-2	3.45E-30	1.32E-30	-29.881
Hg(NO3)2 (aq)	1.92E-29	1.97E-29	-28.707
Hg(OH)2	4.26E-24	4.36E-24	-23.36
Hg(SO4)2-2	9.76E-22	3.73E-22	-21.429
Hg+2	1.5E-20	5.71E-21	-20.243
Hg2OH+3	5.2E-42	5.96E-43	-42.225
Hg3(OH)3+3	1.07E-62	1.22E-63	-62.913
HgCl+	2.71E-15	2.13E-15	-14.672
HgCl2 (aq)	2.09E-10	2.14E-10	-9.669
HgCl3-1	3.55E-11	2.79E-11	-10.554
HgCl4-2	4.29E-12	1.64E-12	-11.786
HgClOH (aq)	6.41E-17	6.56E-17	-16.183
HgCO3 (aq)	1.19E-25	1.21E-25	-24.916
HgF+	1.91E-27	1.5E-27	-26.824
HgHCO3+	5.77E-23	4.53E-23	-22.343
HgHS2-	2E-177	1.6E-177	-176.793
HgN3+	1.17E-13	9.17E-14	-13.037
HgNO2+	1.75E-20	1.38E-20	-19.862
HgNO3+	3.15E-25	2.48E-25	-24.606
HgOH+	9.59E-23	7.54E-23	-22.123
HgOHCO3-	7.99E-31	6.28E-31	-30.202
HgS2-2	3.7E-184	1.4E-184	-183.856
HgSO4 (aq)	5.78E-21	5.91E-21	-20.229
HN3 (aq)	4.99E-05	5.11E-05	-4.292
HNO2 (aq)	0.000151	0.000155	-3.81
HPO4-2	3.38E-12	1.3E-12	-11.885
HS-1	1.49E-95	1.15E-95	-94.941
HSO4-	0.013215	0.010326	-1.986
K+1	0.00032	0.000243	-3.614
K2HPO4 (aq)	8.17E-19	8.35E-19	-18.078
K2PO4-	2.71E-28	2.13E-28	-27.671
KCl (aq)	1.65E-06	1.69E-06	-5.772

Species	Concentration	Activity	Log activity
KCr2O7-	1.22E-14	9.6E-15	-14.018
KCrO4-	5.14E-15	4.04E-15	-14.394
KF (aq)	7.66E-13	7.84E-13	-12.106
KH2PO4 (aq)	1.78E-10	1.82E-10	-9.739
KHPO4-	2.46E-15	1.95E-15	-14.71
KNO3 (aq)	3.47E-08	3.55E-08	-7.45
KOH (aq)	8.41E-17	8.59E-17	-16.066
KPO4-2	2.75E-25	1.05E-25	-24.979
KSO4-	1.12E-05	8.87E-06	-5.052
Mg DOM1	5.31E-08	4.55E-08	-7.342
Mg(NH3)2+2	4.07E-35	1.55E-35	-34.809
Mg+2	0.005029	0.002212	-2.655
Mg2CO3+2	1.38E-18	5.27E-19	-18.278
MgCl+	0.000139	0.000109	-3.962
MgCO3 (aq)	4.28E-17	4.37E-17	-16.359
MgF+	1.32E-09	1.03E-09	-8.987
MgHCO3+	4.64E-10	3.59E-10	-9.444
MgHPO4 (aq)	1.5E-12	1.54E-12	-11.813
MgOH+	1.88E-13	1.52E-13	-12.819
MgPO4-	2.07E-21	1.64E-21	-20.784
MgSO4 (aq)	0.002238	0.002288	-2.641
Mn+3	4.55E-05	8.4E-06	-5.076
N3-1	5.61E-08	4.41E-08	-7.356
Na+1	0.012142	0.009562	-2.019
Na2HPO4 (aq)	8.32E-16	8.51E-16	-15.07
Na2PO4-	8.95E-25	7.04E-25	-24.153
NaCl (aq)	6.87E-05	7.03E-05	-4.153
NaCO3-	8.27E-18	6.56E-18	-17.183
NaCrO4-	2.7E-13	2.12E-13	-12.673
NaF (aq)	5.83E-11	5.96E-11	-10.225
NaH2PO4 (aq)	7E-09	7.16E-09	-8.145
NaHCO3 (aq)	9.27E-11	9.48E-11	-10.023
NaHPO4-	1.5E-13	1.19E-13	-12.926
NaNO3 (aq)	5.03E-07	5.15E-07	-6.288
NaOH (aq)	2.26E-15	2.31E-15	-14.636
NaPO4-2	1.19E-23	4.55E-24	-23.342
NaSO4-	0.000403	0.000319	-3.496
NH3 (aq)	6.27E-17	6.42E-17	-16.193
NH4+1	7.02E-09	5.27E-09	-8.278
NH4Cr2O7-	3.07E-19	2.41E-19	-18.617
NH4SO4-	4.43E-10	3.48E-10	-9.458
Ni DOM1	2.37E-09	2.03E-09	-8.692
Ni(N3)2 (aq)	7.39E-19	7.56E-19	-18.122
Ni(NH3)2+2	4.91E-33	1.87E-33	-32.727
Ni(NH3)3+2	1.83E-47	6.97E-48	-47.157
Ni(NH3)4+2	2.01E-62	7.68E-63	-62.115

Species	Concentration	Activity	Log activity
Ni(NH3)5+2	7.16E-78	2.73E-78	-77.563
Ni(NH3)6+2	5.43E-94	2.07E-94	-93.683
Ni(NO2)2 (aq)	5.61E-15	5.74E-15	-14.241
Ni(OH)2 (aq)	7.57E-22	7.74E-22	-21.111
Ni(OH)3-	4.37E-31	3.44E-31	-30.464
Ni(SO4)2-2	2.59E-09	9.88E-10	-9.005
Ni+2	1.03E-05	3.93E-06	-5.405
NiCl+	2.37E-08	1.86E-08	-7.73
NiCl2 (aq)	8.52E-12	8.71E-12	-11.06
NiCO3 (aq)	3.96E-18	4.05E-18	-17.393
NiF+	6.37E-13	5E-13	-12.301
NiH2PO4+	1.59E-11	1.25E-11	-10.904
NiHCO3+	8.21E-12	6.46E-12	-11.19
NiHPO4 (aq)	3.66E-15	3.75E-15	-14.426
NiHS+	1.77E-95	1.39E-95	-94.856
NiN3+	4.16E-12	3.27E-12	-11.486
NiNH3+2	4.34E-19	1.66E-19	-18.781
NiNO2+	5.84E-10	4.59E-10	-9.338
NiNO3+	2.4E-09	1.89E-09	-8.724
NiOH+	1.35E-14	1.06E-14	-13.973
NiSO4 (aq)	4.36E-06	4.46E-06	-5.35
NO2-1	6.19E-06	4.86E-06	-5.313
NO3-1	0.000252	0.000191	-3.719
OH-	2.65E-13	2.03E-13	-12.692
Pb DOM1	3.57E-10	3.06E-10	-9.514
Pb(CO3)2-2	1.31E-31	4.99E-32	-31.302
Pb(HS)2 (aq)	1.8E-183	1.8E-183	-182.739
Pb(HS)3-	5.3E-277	4.2E-277	-276.38
Pb(NO2)2 (aq)	2.22E-16	2.27E-16	-15.643
Pb(NO3)2 (aq)	7.33E-15	7.5E-15	-14.125
Pb(OH)2 (aq)	1.14E-22	1.17E-22	-21.933
Pb(OH)3-	6.59E-32	5.18E-32	-31.286
Pb(SO4)2-2	2.19E-09	8.37E-10	-9.077
Pb+2	1.95E-08	7.46E-09	-8.127
Pb2OH+3	8.58E-21	9.84E-22	-21.007
Pb3(OH)4+2	1.04E-42	3.98E-43	-42.4
Pb4(OH)4+4	2.16E-46	4.59E-48	-47.339
PbCl+	4E-09	3.14E-09	-8.502
PbCl2 (aq)	8.42E-11	8.61E-11	-10.065
PbCl3-	1.14E-12	8.97E-13	-12.047
PbCl4-2	1.13E-14	4.3E-15	-14.367
PbCO3 (aq)	6.85E-19	7.01E-19	-18.155
PbF+	9.44E-15	7.42E-15	-14.13
PbF2 (aq)	6.29E-22	6.43E-22	-21.192
PbH2PO4+	1.13E-13	8.86E-14	-13.053
PbHCO3+	1.01E-13	7.91E-14	-13.102

Species	Concentration	Activity	Log activity
PbHPO4 (aq)	9.7E-18	9.92E-18	-17.003
PbNO2+	1.49E-11	1.17E-11	-10.93
PbNO3+	2.76E-11	2.17E-11	-10.664
PbOH+	7.58E-15	5.96E-15	-14.225
PbSO4 (aq)	2.2E-08	2.25E-08	-7.647
PO4-3	1.69E-22	1.98E-23	-22.704
S-2	2.6E-111	1E-111	-110.994
SO4-2	0.017285	0.006165	-2.21
Zn DOM1	5.63E-09	4.82E-09	-8.317
Zn(CO3)2-2	2.36E-31	9.02E-32	-31.045
Zn(N3)2 (aq)	1.07E-18	1.09E-18	-17.962
Zn(N3)3-	3.5E-25	2.75E-25	-24.56
Zn(NH3)2+2	2.78E-33	1.06E-33	-32.974
Zn(NH3)3+2	5.25E-47	2E-47	-46.698
Zn(NH3)4+2	4.85E-61	1.85E-61	-60.732
Zn(NO2)2 (aq)	2.16E-15	2.21E-15	-14.656
Zn(NO3)2 (aq)	1.05E-13	1.08E-13	-12.968
Zn(OH)2 (aq)	1.43E-19	1.46E-19	-18.836
Zn(OH)3-	2.6E-29	2.05E-29	-28.689
Zn(OH)4-2	3.77E-40	1.44E-40	-39.842
Zn(SO4)2-2	1.12E-06	4.26E-07	-6.37
Zn+2	1.44E-05	5.89E-06	-5.23
Zn2OH+3	5.5E-18	6.3E-19	-18.201
Zn2S3-2	2.7E-290	1E-290	-289.991
ZnCl+	2.67E-07	2.06E-07	-6.685
ZnCl2 (aq)	1.69E-09	1.73E-09	-8.761
ZnCl3-	3.05E-11	2.4E-11	-10.62
ZnCl4-2	3.8E-13	1.45E-13	-12.839
ZnCO3 (aq)	9.18E-18	9.39E-18	-17.027
ZnF+	9.02E-13	7.09E-13	-12.149
ZnHCO3+	3.15E-12	2.48E-12	-11.606
ZnHPO4 (aq)	1.26E-14	1.28E-14	-13.891
ZnN3+	4.75E-12	3.73E-12	-11.428
ZnNH3+2	1.87E-19	7.14E-20	-19.146
ZnNO2+	2.2E-10	1.73E-10	-9.763
ZnNO3+	3.83E-09	3.01E-09	-8.521
ZnOH+	1.52E-13	1.2E-13	-12.922
ZnS (aq)	1.1E-100	1.1E-100	-99.954
ZnSO4 (aq)	7.12E-06	7.28E-06	-5.138

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Species	Concentration	Activity	Log activity
Al DOM1	3.14E-06	3.11E-06	-5.508
Al(OH)2+	1.69E-12	1.34E-12	-11.874
Al(OH)3 (aq)	1.08E-17	1.11E-17	-16.956
Al(OH)4-	2.78E-22	2.17E-22	-21.663
Al(SO4)2-	0.000903	0.000705	-3.152
Al+3	0.000412	7.59E-05	-4.119
Al2(OH)2+4	3.73E-12	7.9E-14	-13.102
Al2(OH)2CO3+2	1.63E-17	6.23E-18	-17.206
Al2PO4+3	9.41E-12	1.08E-12	-11.968
Al3(OH)4+5	1.21E-18	2.95E-21	-20.53
AlCl+2	1.06E-06	4.06E-07	-6.392
AlF+2	1.3E-05	5.12E-06	-5.291
AlF2+	1.8E-08	1.42E-08	-7.847
AlF3 (aq)	1.14E-12	1.17E-12	-11.933
AlF4-	5.26E-18	4.11E-18	-17.386
AlHPO4+	4.37E-09	3.44E-09	-8.464
AlOH+2	4.35E-08	1.72E-08	-7.765
AlSO4+	0.003486	0.002724	-2.565
AsO4-3	1.95E-21	2.23E-22	-21.651
AsS(OH)HS-	1.4E-222	1.1E-222	-221.965
Ca DOM1	6.06E-07	5.19E-07	-6.285
Ca(NH3)2+2	2.73E-62	1.04E-62	-61.982
Ca(NO3)2	7.49E-15	7.66E-15	-14.116
Ca+2	0.005966	0.002533	-2.596
CaCl+	0.0001	7.89E-05	-4.103
CaCO3 (aq)	9.71E-17	9.93E-17	-16.003
CaCrO4 (aq)	6.48E-12	6.63E-12	-11.179
CaF+	2.56E-10	2.02E-10	-9.695
CaH2PO4+	2.91E-08	2.31E-08	-7.637
CaHCO3+	5.57E-10	4.45E-10	-9.351
CaHPO4 (aq)	1.24E-12	1.27E-12	-11.898
CaNH3+2	2.42E-32	9.24E-33	-32.034
CaNO3+	3.4E-06	2.67E-06	-5.573
CaOH+	1.14E-14	9.1E-15	-14.041
CaPO4-	1.5E-19	1.19E-19	-18.924
CaSO4 (aq)	0.003162	0.003233	-2.49
Cd DOM1	5.53E-13	4.74E-13	-12.324
Cd(CO3)2-2	3.09E-35	1.18E-35	-34.928
Cd(HS)2 (aq)	2.7E-212	2.7E-212	-211.562
Cd(NH3)2+2	1.54E-64	5.89E-65	-64.23
Cd(NH3)3+2	4.38E-93	1.67E-93	-92.777
Cd(NH3)4+2	3.7E-122	1.4E-122	-121.855
Cd(NO2)2 (aq)	2.52E-23	2.58E-23	-22.589
Cd(NO3)2 (aq)	1.37E-16	1.4E-16	-15.855

Species	Concentration	Activity	Log activity
Cd(OH)2 (aq)	8.81E-27	9.01E-27	-26.045
Cd(OH)3-	4.96E-38	3.9E-38	-37.409
Cd(OH)4-2	4.61E-50	1.76E-50	-49.755
Cd(SO4)2-2	2.89E-10	1.1E-10	-9.958
Cd+2	2.41E-09	9.21E-10	-9.036
Cd2OH+3	6.86E-26	7.85E-27	-26.105
CdCl+	1.43E-09	1.12E-09	-8.95
CdCl2 (aq)	5.78E-11	5.91E-11	-10.229
CdCO3 (aq)	5.8E-22	5.93E-22	-21.227
CdF+	1.22E-16	9.56E-17	-16.02
CdHCO3+	4.92E-16	3.87E-16	-15.413
CdHPO4 (aq)	4.79E-18	4.9E-18	-17.31
CdHS+	1.4E-110	1.1E-110	-109.944
CdNH3+2	1.13E-36	4.29E-37	-36.367
CdNO2+	2.97E-16	2.34E-16	-15.631
CdNO3+	1.54E-12	1.21E-12	-11.918
CdOH+	1.91E-18	1.5E-18	-17.824
CdSO4 (aq)	1.15E-09	1.18E-09	-8.93
Cl-1	0.017209	0.013108	-1.882
CO3-2	6.95E-17	2.75E-17	-16.561
Cr2O7-2	1.2E-11	4.56E-12	-11.341
CrO3Cl-	7.78E-10	6.11E-10	-9.214
CrO3H2PO4-	6.73E-12	5.29E-12	-11.276
CrO3HPO4-2	1.27E-12	4.86E-13	-12.314
CrO3SO4-2	3.64E-08	1.39E-08	-7.857
CrO4-2	1.24E-11	4.45E-12	-11.352
Cu DOM1	5.01E-10	4.29E-10	-9.368
Cu(CO3)2-2	6.56E-31	2.5E-31	-30.601
Cu(N3)2 (aq)	1.34E-18	1.37E-18	-17.864
Cu(N3)3-	3.83E-24	3.01E-24	-23.522
Cu(N3)4-2	9.1E-31	3.47E-31	-30.459
Cu(NH3)2+2	3E-60	1.15E-60	-59.941
Cu(NH3)3+2	2.79E-87	1.06E-87	-86.973
Cu(NH3)4+2	5.4E-115	2E-115	-114.689
Cu(NO2)2 (aq)	1.4E-22	1.43E-22	-21.846
Cu(NO3)2 (aq)	7.8E-16	7.97E-16	-15.098
Cu(OH)2 (aq)	6.3E-22	6.45E-22	-21.191
Cu(OH)3-	5.15E-30	4.05E-30	-29.392
Cu(OH)4-2	3.11E-42	1.19E-42	-41.926
Cu+2	5.12E-08	2.09E-08	-7.679
Cu2(OH)2+2	2.54E-23	9.68E-24	-23.014
Cu2OH+3	2.24E-20	2.57E-21	-20.59
Cu3(OH)4+2	3.28E-38	1.25E-38	-37.902
CuCl+	6.29E-10	4.87E-10	-9.312
CuCl2 (aq)	1.04E-12	1.07E-12	-11.973
CuCl3-	1.4E-16	1.08E-16	-15.965

Species	Concentration	Activity	Log activity
CuCl4-2 1	2.61E-20	1.01E-20	-19.997
CuCO3 (aq)	3.31E-18	3.39E-18	-17.47
CuF+	7.82E-15	6.14E-15	-14.212
CuHCO3+	2.23E-14	1.75E-14	-13.757
CuHPO4 (aq)	2.86E-16	2.93E-16	-15.533
CuHSO4+	8.11E-10	6.37E-10	-9.196
CuN3+	8.47E-13	6.66E-13	-12.177
CuNH3+2	8.45E-34	3.22E-34	-33.492
CuNO2+	7.03E-15	5.53E-15	-14.257
CuNO3+	2.76E-11	2.17E-11	-10.664
CuOH+	2.29E-14	1.77E-14	-13.752
CuS(aq)	1.7E-118	1.8E-118	-117.752
CuSO4 (aq)	2.56E-08	2.61E-08	-7.583
DOC (Gaussian DOM)	0.001399	0.00143	-2.845
DOM1	2.07E-05	3.14E-06	-5.504
F-1	9.16E-09	7.02E-09	-8.153
Fe DOM1	1.61E-06	1.59E-06	-5.798
Fe(N3)2+	1.15E-13	9.01E-14	-13.045
Fe(N3)3 (aq)	8.29E-19	8.48E-19	-18.072
Fe(NH3)2+2	3.03E-67	1.16E-67	-66.937
Fe(NH3)3+2	1.01E-96	3.87E-97	-96.412
Fe(NH3)4+2	1.4E-126	5.5E-127	-126.258
Fe(NO2)2+	5.23E-20	4.11E-20	-19.386
Fe(NO2)3 (aq)	1.16E-26	1.19E-26	-25.924
Fe(OH)2 (aq)	4.94E-28	5.05E-28	-27.296
Fe(OH)2+	3.14E-10	2.49E-10	-9.604
Fe(OH)3-	8.14E-37	6.42E-37	-36.193
Fe(OH)3 (aq)	3.55E-18	3.63E-18	-17.44
Fe(OH)4-	1.32E-24	1.04E-24	-23.982
Fe(SO4)2-	1.09E-06	8.56E-07	-6.068
Fe+2	1.07E-09	4.37E-10	-9.36
Fe+3	6.68E-07	1.23E-07	-6.909
Fe2(OH)2+4	7.99E-13	1.69E-14	-13.771
Fe3(OH)4+5	5.9E-19	1.43E-21	-20.844
FeCl+	4.6E-12	3.61E-12	-11.442
FeCl+2	9.18E-08	3.54E-08	-7.452
FeCrO4+	2.56E-11	2.01E-11	-10.696
FeF+	6.33E-17	4.98E-17	-16.303
FeF+2	2.14E-09	8.25E-10	-9.083
FeF2+	2.78E-13	2.19E-13	-12.659
FeF3 (aq)	1.4E-18	1.43E-18	-17.846
FeH2PO4+	1.03E-13	8.19E-14	-13.087
FeH2PO4+2	2.21E-09	8.73E-10	-9.059
FeHCO3+	9.11E-17	7.29E-17	-16.137
FeHPO4 (aq)	1.78E-18	1.82E-18	-17.739

Species	Concentration	Activity	Log activity
FeHPO4+	2.03E-09	1.61E-09	-8.793
FeHS+	2.8E-113	2.2E-113	-112.658
FeN3+2	2.21E-09	8.44E-10	-9.074
FeNH3+2	3.57E-38	1.36E-38	-37.866
FeNO2+2	1.29E-12	4.93E-13	-12.308
FeOH+	4.46E-18	3.52E-18	-17.454
FeOH+2	9.43E-08	3.63E-08	-7.44
FeSO4 (aq)	5.77E-10	5.9E-10	-9.229
FeSO4+	1.21E-05	9.5E-06	-5.022
H DOM1	9.44E-05	4.33E-05	-4.364
H+1	0.027288	0.022615	-1.646
H2AsO3-	7.65E-29	6.02E-29	-28.221
H2AsO4-	1.21E-06	9.48E-07	-6.023
H2CO3* (aq)	0.000967	0.000989	-3.005
H2CrO4 (aq)	2.63E-09	2.69E-09	-8.57
H2PO4-	6.07E-07	4.81E-07	-6.318
H2S (aq)	3.9E-104	4E-104	-103.401
H3AsO3	2.9E-21	2.96E-21	-20.528
H3AsO4	3.74E-06	3.83E-06	-5.417
H3PO4	1.35E-06	1.38E-06	-5.861
HAsO3-2	3.55E-41	1.35E-41	-40.868
HAsO4-2	1.08E-11	4.11E-12	-11.386
HCO3-	2.1E-08	1.67E-08	-7.778
HCrO4-	4.02E-07	3.16E-07	-6.5
HF (aq)	1.95E-07	2E-07	-6.7
HF2-	6.87E-15	5.27E-15	-14.278
Hg(CO3)2-2	2.44E-38	9.32E-39	-38.031
Hg(HS)2 (aq)	1.2E-200	1.2E-200	-199.905
Hg(N3)2 (aq)	1.21E-16	1.23E-16	-15.908
Hg(NH3)2+2	4.78E-62	1.82E-62	-61.739
Hg(NH3)4+2	2.7E-120	1E-120	-119.981
Hg(NO2)2 (aq)	1.64E-28	1.68E-28	-27.775
Hg(NO2)3-	1.87E-35	1.47E-35	-34.833
Hg(NO2)4-2	2.49E-43	9.52E-44	-43.022
Hg(NO3)2 (aq)	5.04E-29	5.15E-29	-28.288
Hg(OH)2	4.23E-24	4.33E-24	-23.364
Hg(SO4)2-2	9.73E-22	3.71E-22	-21.43
Hg+2	1.5E-20	5.72E-21	-20.243
Hg2OH+3	5.19E-42	5.94E-43	-42.226
Hg3(OH)3+3	1.06E-62	1.21E-63	-62.918
HgCl+	2.71E-15	2.13E-15	-14.672
HgCl2 (aq)	2.09E-10	2.14E-10	-9.669
HgCl3-1	3.55E-11	2.79E-11	-10.554
HgCl4-2	4.29E-12	1.64E-12	-11.786
HgClOH (aq)	6.39E-17	6.53E-17	-16.185
HgCO3 (aq)	1.18E-25	1.2E-25	-24.92

Species	Concentration	Activity	Log activity
HgF+	1.9E-27	1.5E-27	-26.825
HgHCO3+	5.75E-23	4.52E-23	-22.345
HgHS2-	2.3E-205	1.8E-205	-204.749
HgN3+	1.14E-13	8.98E-14	-13.047
HgNO2+	9.08E-24	7.13E-24	-23.147
HgNO3+	5.1E-25	4.01E-25	-24.397
HgOH+	9.55E-23	7.51E-23	-22.124
HgOHCO3-	7.89E-31	6.2E-31	-30.207
HgS2-2	4E-212	1.5E-212	-211.813
HgSO4 (aq)	5.77E-21	5.9E-21	-20.229
HN3 (aq)	4.99E-05	5.11E-05	-4.292
HNO2 (aq)	7.88E-08	8.06E-08	-7.094
HPO4-2	3.36E-12	1.29E-12	-11.888
HS-1	1.6E-109	1.2E-109	-108.918
HSO4-	0.013248	0.010352	-1.985
K+1	0.00032	0.000243	-3.614
K2HPO4 (aq)	8.11E-19	8.29E-19	-18.082
K2PO4-	2.68E-28	2.11E-28	-27.676
KCl (aq)	1.65E-06	1.69E-06	-5.772
KCr2O7-	1.22E-14	9.59E-15	-14.018
KCrO4-	5.12E-15	4.02E-15	-14.396
KF (aq)	7.65E-13	7.82E-13	-12.107
KH2PO4 (aq)	1.78E-10	1.82E-10	-9.741
KHPO4-	2.44E-15	1.94E-15	-14.713
KNO3 (aq)	5.62E-08	5.75E-08	-7.24
KOH (aq)	8.37E-17	8.56E-17	-16.068
KPO4-2	2.72E-25	1.04E-25	-24.984
KSO4-	1.12E-05	8.85E-06	-5.053
Mg DOM1	5.29E-08	4.53E-08	-7.343
Mg(NH3)2+2	1.19E-62	4.54E-63	-62.343
Mg+2	0.005032	0.002213	-2.655
Mg2CO3+2	1.37E-18	5.23E-19	-18.281
MgCl+	0.000139	0.000109	-3.962
MgCO3 (aq)	4.24E-17	4.34E-17	-16.363
MgF+	1.32E-09	1.03E-09	-8.987
MgHCO3+	4.62E-10	3.58E-10	-9.446
MgHPO4 (aq)	1.49E-12	1.53E-12	-11.816
MgOH+	1.88E-13	1.51E-13	-12.821
MgPO4-	2.05E-21	1.63E-21	-20.789
MgSO4 (aq)	0.002235	0.002285	-2.641
Mn+3	4.55E-05	8.39E-06	-5.076
N3-1	5.59E-08	4.39E-08	-7.357
Na+1	0.012143	0.009562	-2.019
Na2HPO4 (aq)	8.26E-16	8.45E-16	-15.073
Na2PO4-	8.85E-25	6.96E-25	-24.158
NaCl (aq)	6.87E-05	7.03E-05	-4.153

Species	Concentration	Activity	Log activity
NaCO3-	8.2E-18	6.5E-18	-17.187
NaCrO4-	2.69E-13	2.11E-13	-12.675
NaF (aq)	5.81E-11	5.95E-11	-10.226
NaH2PO4 (aq)	6.98E-09	7.14E-09	-8.146
NaHCO3 (aq)	9.23E-11	9.44E-11	-10.025
NaHPO4-	1.49E-13	1.18E-13	-12.929
NaNO3 (aq)	8.15E-07	8.33E-07	-6.079
NaOH (aq)	2.25E-15	2.3E-15	-14.638
NaPO4-2	1.18E-23	4.5E-24	-23.347
NaSO4-	0.000402	0.000319	-3.496
NH3 (aq)	1.07E-30	1.1E-30	-29.96
NH4+1	1.2E-22	9.04E-23	-22.044
NH4Cr2O7-	5.27E-33	4.14E-33	-32.383
NH4SO4-	7.59E-24	5.96E-24	-23.224
Ni DOM1	2.36E-09	2.03E-09	-8.693
Ni(N3)2 (aq)	7.33E-19	7.5E-19	-18.125
Ni(NH3)2+2	1.44E-60	5.48E-61	-60.261
Ni(NH3)3+2	9.13E-89	3.48E-89	-88.458
Ni(NH3)4+2	1.7E-117	6.6E-118	-117.183
Ni(NH3)5+2	1E-146	4E-147	-146.398
Ni(NH3)6+2	1.4E-176	5.2E-177	-176.285
Ni(NO2)2 (aq)	1.51E-21	1.54E-21	-20.812
Ni(OH)2 (aq)	7.51E-22	7.68E-22	-21.115
Ni(OH)3-	4.32E-31	3.39E-31	-30.469
Ni(SO4)2-2	2.58E-09	9.85E-10	-9.007
Ni+2	1.03E-05	3.94E-06	-5.405
NiCl+	2.37E-08	1.86E-08	-7.73
NiCl2 (aq)	8.52E-12	8.71E-12	-11.06
NiCO3 (aq)	3.93E-18	4.02E-18	-17.396
NiF+	6.35E-13	4.99E-13	-12.302
NiH2PO4+	1.58E-11	1.24E-11	-10.905
NiHCO3+	8.18E-12	6.43E-12	-11.192
NiHPO4 (aq)	3.64E-15	3.72E-15	-14.429
NiHS+	1.9E-109	1.5E-109	-108.833
NiN3+	4.14E-12	3.25E-12	-11.488
NiNH3+2	7.42E-33	2.83E-33	-32.548
NiNO2+	3.03E-13	2.38E-13	-12.623
NiNO3+	3.89E-09	3.06E-09	-8.515
NiOH+	1.35E-14	1.06E-14	-13.975
NiSO4 (aq)	4.36E-06	4.45E-06	-5.351
NO2-1	3.21E-09	2.52E-09	-8.598
NO3-1	0.000407	0.000309	-3.51
OH-	2.64E-13	2.02E-13	-12.694
Pb DOM1	3.56E-10	3.05E-10	-9.515
Pb(CO3)2-2	1.29E-31	4.91E-32	-31.309
Pb(HS)2 (aq)	2E-211	2E-211	-210.693

Species	Concentration	Activity	Log activity
Pb(NO2)2 (aq)	5.98E-23	6.12E-23	-22.213
Pb(NO3)2 (aq)	1.92E-14	1.97E-14	-13.706
Pb(OH)2 (aq)	1.13E-22	1.16E-22	-21.936
Pb(OH)3-	6.51E-32	5.12E-32	-31.291
Pb(SO4)2-2	2.19E-09	8.35E-10	-9.078
Pb+2	1.96E-08	7.47E-09	-8.127
Pb2OH+3	8.57E-21	9.81E-22	-21.008
Pb3(OH)4+2	1.03E-42	3.92E-43	-42.406
Pb4(OH)4+4	2.13E-46	4.52E-48	-47.344
PbCl+	4E-09	3.15E-09	-8.502
PbCl2 (aq)	8.43E-11	8.62E-11	-10.065
PbCl3-	1.14E-12	8.97E-13	-12.047
PbCl4-2	1.13E-14	4.3E-15	-14.367
PbCO3 (aq)	6.8E-19	6.95E-19	-18.158
PbF+	9.43E-15	7.41E-15	-14.13
PbF2 (aq)	6.26E-22	6.4E-22	-21.194
PbH2PO4+	1.12E-13	8.84E-14	-13.054
PbHCO3+	1E-13	7.88E-14	-13.103
PbHPO4 (aq)	9.64E-18	9.86E-18	-17.006
PbNO2+	7.75E-15	6.09E-15	-14.215
PbNO3+	4.47E-11	3.51E-11	-10.454
PbOH+	7.56E-15	5.94E-15	-14.226
PbSO4 (aq)	2.2E-08	2.25E-08	-7.648
PO4-3	1.67E-22	1.96E-23	-22.709
S-2	2.8E-125	1.1E-125	-124.973
SO4-2	0.017262	0.006154	-2.211
Zn DOM1	5.61E-09	4.81E-09	-8.318
Zn(CO3)2-2	2.32E-31	8.87E-32	-31.052
Zn(N3)2 (aq)	1.06E-18	1.08E-18	-17.965
Zn(N3)3-	3.46E-25	2.72E-25	-24.565
Zn(NH3)2+2	8.13E-61	3.1E-61	-60.508
Zn(NH3)3+2	2.63E-88	1E-88	-87.999
Zn(NH3)4+2	4.2E-116	1.6E-116	-115.8
Zn(NO2)2 (aq)	5.81E-22	5.94E-22	-21.226
Zn(NO3)2 (aq)	2.76E-13	2.82E-13	-12.549
Zn(OH)2 (aq)	1.42E-19	1.45E-19	-18.839
Zn(OH)3-	2.57E-29	2.02E-29	-28.694
Zn(OH)4-2	3.71E-40	1.42E-40	-39.849
Zn(SO4)2-2	1.11E-06	4.25E-07	-6.372
Zn+2	1.44E-05	5.89E-06	-5.23
Zn2OH+3	5.48E-18	6.27E-19	-18.202
ZnCl+	2.67E-07	2.06E-07	-6.685
ZnCl2 (aq)	1.7E-09	1.73E-09	-8.761
ZnCl3-	3.05E-11	2.4E-11	-10.62
ZnCl4-2	3.8E-13	1.45E-13	-12.839
ZnCO3 (aq)	9.11E-18	9.31E-18	-17.031

Species	Concentration	Activity	Log activity
ZnF+	9.01E-13	7.08E-13	-12.15
ZnHCO3+	3.14E-12	2.47E-12	-11.608
ZnHPO4 (aq)	1.25E-14	1.28E-14	-13.894
ZnN3+	4.73E-12	3.72E-12	-11.429
ZnNH3+2	3.2E-33	1.22E-33	-32.913
ZnNO2+	1.14E-13	8.95E-14	-13.048
ZnNO3+	6.21E-09	4.88E-09	-8.312
ZnOH+	1.52E-13	1.19E-13	-12.924
ZnS (aq)	1.1E-114	1.2E-114	-113.932
ZnSO4 (aq)	7.11E-06	7.27E-06	-5.138

B2: Species distribution

B2.1: Eh 100

Component	% of total concentration	Species name
CrO4-2	0.234	CrO4-2
	99.494	HCrO4-
	0.105	CaCrO4 (aq)
	0.143	CrO3SO4-2
NH4+1	93.633	NH4+1
	6.367	NH4SO4-
Cl-1	97.939	Cl-1
	0.529	CaCl+
	0.412	FeCl+
	0.735	MgCl+
	0.372	NaCl (aq)
Fe+2	64.226	Fe+2
	0.381	FeCl+
	35.388	FeSO4 (aq)
Zn+2	61.376	Zn+2
	0.471	Zn DOM1
	1.573	ZnCl+
	0.014	ZnCl2 (aq)
	30.909	ZnSO4 (aq)
	5.654	Zn(SO4)2-2
F-1	0.183	F-1
	0.053	HF (aq)
	99.041	AlF+2
	0.672	AlF2+
	0.025	MgF+
	0.02	FeF+
Pb+2	34.136	Pb+2
	12.253	Pb DOM1
	9.615	PbCl+
	0.286	PbCl2 (aq)

Component	% of total concentration	Species name
	39.149	PbSO4 (aq)
	4.542	Pb(SO4)2-2
	0.012	PbHCO3+
Ni+2	69.501	Ni+2
	0.314	Ni DOM1
	0.22	NiCl+
	29.939	NiSO4 (aq)
	0.021	Ni(SO4)2-2
N3-1	7.553	N3-1
	92.446	HN3 (aq)
PO4-3	0.01	HPO4-2
	25.034	H2PO4-
	0.76	H3PO4
	67.69	FeH2PO4+
	0.082	FeHPO4 (aq)
	1.121	CaH2PO4+
	4.712	AlHPO4+
	0.301	Al2PO4+3
	0.275	NaH2PO4 (aq)
AsO4-3	4.072	H3AsO4
	0.064	HAsO4-2
	95.864	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	45.417	DOM1
	23.937	H DOM1
	19.799	Al DOM1
	9.851	Ca DOM1
	0.863	Mg DOM1
	0.038	Ni DOM1
	0.09	Zn DOM1
Ca+2	63.672	Ca+2
	0.129	Ca DOM1
	1.487	CaCl+
	34.711	CaSO4 (aq)
Mg+2	66.747	Mg+2
	0.014	Mg DOM1
	2.574	MgCl+
	30.664	MgSO4 (aq)
K+1	95.681	K+1
	0.694	KCl (aq)
	3.625	KSO4-
Na+1	95.772	Na+1
	0.765	NaCl (aq)
	3.463	NaSO4-
CO3-2	0.159	HCO3-

Component	% of total concentration	Species name
	99.822	H2CO3* (aq)
	0.011	FeHCO3+
SO4-2	52.788	SO4-2
	0.53	HSO4-
	3.653	AlSO4+
	2.065	Al(SO4)2-
	0.018	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	25.61	FeSO4 (aq)
	5.846	MgSO4 (aq)
	8.249	CaSO4 (aq)
	1.124	NaSO4-
	0.031	KSO4-
	0.067	NH4SO4-
Mn+3	100	Mn+3
Cd+2	40.107	Cd+2
	0.181	Cd DOM1
	32.635	CdCl+
	1.867	CdCl2 (aq)
	19.491	CdSO4 (aq)
	5.719	Cd(SO4)2-2
Fe+3	1.265	Fe+3
	57.409	Fe DOM1
	12.501	FeOH+2
	2.833	Fe(OH)2+
	0.01	FeF+2
	0.244	FeCl+2
	22.995	FeSO4+
	2.259	Fe(SO4)2-
	0.269	FeN3+2
	0.206	FeHPO4+
NO2-1	74.833	NO2-1
	25.158	HNO2 (aq)
NO3-1	99.031	NO3-1
	0.765	CaNO3+
	0.013	KNO3 (aq)
	0.188	NaNO3 (aq)
HS-1	0.016	HS-1
	54.469	H2S (aq)
	0.018	NiHS+
	45.495	FeHS+
H3AsO3	100	H3AsO3
Hg(OH)2	99.998	HgN3+
Cu+2	58.122	Cu+2
	11.212	Cu DOM1
	0.99	CuCl+

Component	% of total concentration	Species name
	29.596	CuSO4 (aq)
	0.013	CuHSO4+
	0.061	CuN3+
Al+3	8.208	Al+3
	1.178	Al DOM1
	0.06	AlOH+2
	0.646	AlF+2
	0.029	AlCl+2
	70.07	AlSO4+
	19.8	Al(SO4)2-

B2.2: Eh 200

Component	% of total concentration	Species name
Hg(OH)2	99.989	HgN3+
NH4+1	93.733	NH4+1
	6.267	NH4SO4-
Cl-1	97.934	Cl-1
	0.531	CaCl+
	0.413	FeCl+
	0.736	MgCl+
	0.371	NaCl (aq)
Fe+2	64.706	Fe+2
	0.382	FeCl+
	34.908	FeSO4 (aq)
Zn+2	62.008	Zn+2
	0.287	Zn DOM1
	1.581	ZnCl+
	0.014	ZnCl2 (aq)
	30.576	ZnSO4 (aq)
	5.532	Zn(SO4)2-2
F-1	0.09	F-1
	0.052	HF (aq)
	99.501	AlF+2
	0.332	AlF2+
	0.012	MgF+
SO4-2	49.75	SO4-2
	0.992	HSO4-
	6.945	AlSO4+
	3.863	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	24.035	FeSO4 (aq)
	5.486	MgSO4 (aq)
	7.749	CaSO4 (aq)
	1.053	NaSO4-

Component	% of total concentration	Species name
	0.029	KSO4-
	0.063	NH4SO4-
Ni+2	70.026	Ni+2
	0.191	Ni DOM1
	0.221	NiCl+
	29.539	NiSO4 (aq)
	0.02	Ni(SO4)2-2
N3-1	3.94	N3-1
	96.059	HN3 (aq)
PO4-3	24.791	H2PO4-
	1.499	H3PO4
	67.216	FeH2PO4+
	0.041	FeHPO4 (aq)
	1.114	CaH2PO4+
	4.741	AlHPO4+
	0.31	Al2PO4+3
	0.272	NaH2PO4 (aq)
AsO4-3	7.799	H3AsO4
	0.031	HAsO4-2
	92.17	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	40.054	DOM1
	29.032	H DOM1
	24.311	Al DOM1
	5.992	Ca DOM1
	0.524	Mg DOM1
	0.023	Ni DOM1
	0.055	Zn DOM1
Ca+2	64.158	Ca+2
	0.078	Ca DOM1
	1.492	CaCl+
	34.271	CaSO4 (aq)
Mg+2	67.163	Mg+2
	2.58	MgCl+
	30.248	MgSO4 (aq)
K+1	95.74	K+1
	0.692	KCl (aq)
	3.568	KSO4-
Na+1	95.827	Na+1
	0.763	NaCl (aq)
	3.41	NaSO4-
CO3-2	0.08	HCO3-
	99.911	H2CO3* (aq)
Pb+2	36.266	Pb+2
	7.854	Pb DOM1

Component	% of total concentration	Species name
	10.161	PbCl+
	0.301	PbCl2 (aq)
	40.73	PbSO4 (aq)
	4.674	Pb(SO4)2-2
Mn+3	100	Mn+3
Cd+2	40.448	Cd+2
	0.11	Cd DOM1
	32.74	CdCl+
	1.867	CdCl2 (aq)
	19.249	CdSO4 (aq)
	5.586	Cd(SO4)2-2
CrO4-2	0.118	CrO4-2
	99.513	HCrO4-
	0.018	H2CrO4 (aq)
	0.053	CaCrO4 (aq)
	0.282	CrO3SO4-2
Cu+2	61.239	Cu+2
	7.126	Cu DOM1
	1.037	CuCl+
	30.532	CuSO4 (aq)
	0.028	CuHSO4+
	0.033	CuN3+
Fe+3	1.863	Fe+3
	50.828	Fe DOM1
	9.209	FeOH+2
	1.042	Fe(OH)2+
	0.358	FeCl+2
	33.128	FeSO4+
	3.203	Fe(SO4)2-
	0.206	FeN3+2
	0.149	FeHPO4+
NO2-1	59.886	NO2-1
	40.106	HNO2 (aq)
NO3-1	99.03	NO3-1
	0.767	CaNO3+
	0.013	KNO3 (aq)
	0.188	NaNO3 (aq)
HS-1	0.011	HS-1
	70.385	H2S (aq)
	0.012	NiHS+
	29.592	FeHS+
H3AsO3	100	H3AsO3
Al+3	8.469	Al+3
	0.731	Al DOM1
	0.031	AlOH+2
	0.328	AlF+2

Component	% of total concentration	Species name
	0.03	AlCl+2
	70.736	AlSO4+
	19.672	Al(SO4)2-

B2.3: Eh 300

Component	% of total concentration	Species name
Hg(OH)2	0.194	HgCl2 (aq)
	0.045	HgCl3-1
	99.747	HgN3+
NH4+1	93.344	NH4+1
	6.656	NH4SO4-
Cl-1	98.029	Cl-1
	0.527	CaCl+
	0.321	FeCl+
	0.732	MgCl+
	0.375	NaCl (aq)
Pb+2	35.859	Pb+2
	5.473	Pb DOM1
	9.532	PbCl+
	0.266	PbCl2 (aq)
	43.639	PbSO4 (aq)
	5.223	Pb(SO4)2-2
Zn+2	60.13	Zn+2
	0.196	Zn DOM1
	1.453	ZnCl+
	0.012	ZnCl2 (aq)
	32.143	ZnSO4 (aq)
	6.065	Zn(SO4)2-2
F-1	0.081	F-1
	0.095	HF (aq)
	99.501	AlF+2
	0.303	AlF2+
	0.011	MgF+
SO4-2	50.597	SO4-2
	2.091	HSO4-
	8.166	AlSO4+
	4.828	Al(SO4)2-
	0.018	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	19.412	FeSO4 (aq)
	5.678	MgSO4 (aq)
	8	CaSO4 (aq)
	1.096	NaSO4-
	0.03	KSO4-
	0.066	NH4SO4-

Component	% of total concentration	Species name
Ni+2	68.383	Ni+2
	0.131	Ni DOM1
	0.204	NiCl+
	31.258	NiSO4 (aq)
	0.022	Ni(SO4)2-2
N3-1	1.966	N3-1
	98.033	HN3 (aq)
PO4-3	29.515	H2PO4-
	3.651	H3PO4
	61.9	FeH2PO4+
	0.019	FeHPO4 (aq)
	1.311	CaH2PO4+
	3.151	AlHPO4+
	0.111	Al2PO4+3
	0.327	NaH2PO4 (aq)
AsO4-3	14.75	H3AsO4
	0.014	HAsO4-2
	85.236	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	35.914	DOM1
	40.413	H DOM1
	19.147	Al DOM1
	4.103	Ca DOM1
	0.36	Mg DOM1
	0.016	Ni DOM1
	0.037	Zn DOM1
Ca+2	62.487	Ca+2
	0.054	Ca DOM1
	1.375	CaCl+
	36.083	CaSO4 (aq)
Mg+2	65.686	Mg+2
	2.384	MgCl+
	31.924	MgSO4 (aq)
K+1	95.555	K+1
	0.652	KCl (aq)
	3.793	KSO4-
Na+1	95.664	Na+1
	0.717	NaCl (aq)
	3.618	NaSO4-
CO3-2	0.039	HCO3-
	99.957	H2CO3* (aq)
Al+3	7.772	Al+3
	0.479	Al DOM1
	0.014	AlOH+2
	0.273	AlF+2

Component	% of total concentration	Species name
	0.026	AlCl+2
	70.571	AlSO4+
	20.863	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	40.277	Cd+2
	0.077	Cd DOM1
	30.928	CdCl+
	1.661	CdCl2 (aq)
	20.77	CdSO4 (aq)
	6.286	Cd(SO4)2-2
CrO4-2	0.057	CrO4-2
	99.255	HCrO4-
	0.036	H2CrO4 (aq)
	0.026	CaCrO4 (aq)
	0.015	CrO3Cl-
	0.603	CrO3SO4-2
Cu+2	60.979	Cu+2
	5.003	Cu DOM1
	0.979	CuCl+
	32.959	CuSO4 (aq)
	0.06	CuHSO4+
	0.017	CuN3+
Fe+2	62.871	Fe+2
	0.352	FeCl+
	36.771	FeSO4 (aq)
NO2-1	42.197	NO2-1
	57.798	HNO2 (aq)
NO3-1	99.034	NO3-1
	0.761	CaNO3+
	0.013	KNO3 (aq)
	0.19	NaNO3 (aq)
HS-1	86.269	H2S (aq)
	13.717	FeHS+
H3AsO3	100	H3AsO3
Fe+3	2.238	Fe+3
	43.607	Fe DOM1
	5.453	FeOH+2
	0.307	Fe(OH)2+
	0.406	FeCl+2
	43.288	FeSO4+
	4.452	Fe(SO4)2-
	0.125	FeN3+2
	0.108	FeHPO4+

B2.4: Eh 400

Component	% of total concentration	Species name
Hg(OH)2	56.958	HgCl2 (aq)
	12.53	HgCl3-1
	1.998	HgCl4-2
	28.506	HgN3+
NH4+1	93.5	NH4+1
	6.5	NH4SO4-
Cl-1	98.065	Cl-1
	0.536	CaCl+
	0.261	FeCl+
	0.744	MgCl+
	0.379	NaCl (aq)
Pb+2	37.664	Pb+2
	2.242	Pb DOM1
	9.569	PbCl+
	0.254	PbCl2 (aq)
	45.067	PbSO4 (aq)
	5.197	Pb(SO4)2-2
Zn+2	60.761	Zn+2
	0.077	Zn DOM1
	1.402	ZnCl+
	0.011	ZnCl2 (aq)
	31.94	ZnSO4 (aq)
	5.807	Zn(SO4)2-2
F-1	0.078	F-1
	0.379	HF (aq)
	99.229	AlF+2
	0.295	AlF2+
	0.011	MgF+
SO4-2	48.621	SO4-2
	8.309	HSO4-
	8.226	AlSO4+
	4.734	Al(SO4)2-
	0.018	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	15.386	FeSO4 (aq)
	5.611	MgSO4 (aq)
	7.915	CaSO4 (aq)
	1.068	NaSO4-
	0.03	KSO4-
	0.064	NH4SO4-
Ni+2	68.806	Ni+2
	0.052	Ni DOM1
	0.196	NiCl+
	30.924	NiSO4 (aq)

Component	% of total concentration	Species name
	0.021	Ni(SO4)2-2
N3-1	0.486	N3-1
	99.514	HN3 (aq)
PO4-3	30.313	H2PO4-
	15.403	H3PO4
	51.725	FeH2PO4+
	1.368	CaH2PO4+
	0.821	AlHPO4+
	0.338	NaH2PO4 (aq)
AsO4-3	41.543	H3AsO4
	58.455	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	26.909	DOM1
	63.544	H DOM1
	7.691	Al DOM1
	1.61	Ca DOM1
	0.081	Fe DOM1
	0.141	Mg DOM1
	0.015	Zn DOM1
Ca+2	62.957	Ca+2
	0.021	Ca DOM1
	1.323	CaCl+
	35.699	CaSO4 (aq)
Mg+2	66.161	Mg+2
	2.29	MgCl+
	31.547	MgSO4 (aq)
K+1	95.678	K+1
	0.622	KCl (aq)
	3.7	KSO4-
Na+1	95.79	Na+1
	0.684	NaCl (aq)
	3.526	NaSO4-
CO3-2	99.99	H2CO3* (aq)
Al+3	7.95	Al+3
	0.192	Al DOM1
	0.272	AlF+2
	0.026	AlCl+2
	71.097	AlSO4+
	20.458	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	41.2	Cd+2
	0.031	Cd DOM1
	30.24	CdCl+
	1.547	CdCl2 (aq)
	20.89	CdSO4 (aq)

Component	% of total concentration	Species name
	6.092	Cd(SO4)2-2
CrO4-2	0.013	CrO4-2
	97.427	HCrO4-
	0.146	H2CrO4 (aq)
	0.056	CrO3Cl-
	2.344	CrO3SO4-2
Cu+2	63.174	Cu+2
	2.022	Cu DOM1
	0.969	CuCl+
	33.578	CuSO4 (aq)
	0.251	CuHSO4+
Fe+2	63.268	Fe+2
	0.338	FeCl+
	36.388	FeSO4 (aq)
NO2-1	15.094	NO2-1
	84.904	HNO2 (aq)
NO3-1	99.02	NO3-1
	0.774	CaNO3+
	0.013	KNO3 (aq)
	0.191	NaNO3 (aq)
HS-1	96.942	H2S (aq)
	3.054	FeHS+
H3AsO3	100	H3AsO3
Fe+3	3.287	Fe+3
	25.148	Fe DOM1
	1.964	FeOH+2
	0.027	Fe(OH)2+
	0.011	FeF+2
	0.568	FeCl+2
	62.626	FeSO4+
	6.272	Fe(SO4)2-
	0.046	FeN3+2
	0.011	FeH2PO4+2
	0.04	FeHPO4+

B2.5: Eh 500

Component	% of total concentration	Species name
Hg(OH)2	82.267	HgCl2 (aq)
	15.438	HgCl3-1
	2.078	HgCl4-2
	0.215	HgN3+
NH4+1	93.856	NH4+1
	6.144	NH4SO4-
Cl-1	98.165	Cl-1
	0.559	CaCl+
	0.098	FeCl+
	0.774	MgCl+
	0.387	NaCl (aq)
Pb+2	39.567	Pb+2
	0.966	Pb DOM1
	8.817	PbCl+
	0.203	PbCl2 (aq)
	45.642	PbSO4 (aq)
	4.8	Pb(SO4)2-2
Zn+2	62.05	Zn+2
	0.032	Zn DOM1
	1.254	ZnCl+
	31.443	ZnSO4 (aq)
	5.213	Zn(SO4)2-2
F-1	0.073	F-1
	1.082	HF (aq)
	98.543	AlF+2
	0.281	AlF2+
	0.01	MgF+
SO4-2	44.036	SO4-2
	23.437	HSO4-
	8.321	AlSO4+
	4.49	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	5.386	FeSO4 (aq)
	0.011	FeSO4+
	5.464	MgSO4 (aq)
	7.725	CaSO4 (aq)
	1.004	NaSO4-
	0.028	KSO4-
	0.061	NH4SO4-
Ni+2	69.62	Ni+2
	0.021	Ni DOM1
	0.174	NiCl+
	30.165	NiSO4 (aq)

Component	% of total concentration	Species name
	0.019	Ni(SO4)2-2
N3-1	0.159	N3-1
	99.838	HN3 (aq)
PO4-3	30.656	H2PO4-
	47.665	H3PO4
	19.487	FeH2PO4+
	0.042	FeH2PO4+2
	0.055	FeHPO4+
	1.437	CaH2PO4+
	0.298	AlHPO4+
	0.349	NaH2PO4 (aq)
AsO4-3	68.489	H3AsO4
	31.511	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	19.425	DOM1
	75.797	H DOM1
	3.358	Al DOM1
	0.669	Ca DOM1
	0.683	Fe DOM1
	0.058	Mg DOM1
Ca+2	63.975	Ca+2
	1.174	CaCl+
	34.841	CaSO4 (aq)
Mg+2	67.247	Mg+2
	2.029	MgCl+
	30.723	MgSO4 (aq)
K+1	95.968	K+1
	0.543	KCl (aq)
	3.489	KSO4-
Na+1	96.088	Na+1
	0.596	NaCl (aq)
	3.316	NaSO4-
CO3-2	99.997	H2CO3* (aq)
Al+3	8.304	Al+3
	0.084	Al DOM1
	0.27	AlF+2
	0.023	AlCl+2
	71.915	AlSO4+
	19.402	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	43.641	Cd+2
	0.013	Cd DOM1
	28.095	CdCl+
	1.247	CdCl2 (aq)
	21.332	CdSO4 (aq)

Component	% of total concentration	Species name
	5.672	Cd(SO4)2-2
CrO4-2	93.166	HCrO4-
	0.427	H2CrO4 (aq)
	0.14	CrO3Cl-
	6.251	CrO3SO4-2
Cu+2	64.496	Cu+2
	0.847	Cu DOM1
	0.866	CuCl+
	33.046	CuSO4 (aq)
	0.742	CuHSO4+
Fe+2	64.135	Fe+2
	0.301	FeCl+
	35.558	FeSO4 (aq)
NO2-1	5.493	NO2-1
	94.505	HNO2 (aq)
NO3-1	98.983	NO3-1
	0.806	CaNO3+
	0.013	KNO3 (aq)
	0.196	NaNO3 (aq)
HS-1	99.616	H2S (aq)
	0.382	FeHS+
H3AsO3	100	H3AsO3
Fe+3	4.039	Fe+3
	12.916	Fe DOM1
	0.805	FeOH+2
	0.013	FeF+2
	0.607	FeCl+2
	74.56	FeSO4+
	7.007	Fe(SO4)2-
	0.019	FeN3+2
	0.013	FeH2PO4+2
	0.017	FeHPO4+

B2.6: Eh 600

Component	% of total concentration	Species name
Hg(OH)2	83.915	HgCl2 (aq)
	14.294	HgCl3-1
	1.736	HgCl4-2
	0.054	HgN3+
NH4+1	94.022	NH4+1
	5.978	NH4SO4-
Cl-1	98.225	Cl-1
	0.571	CaCl+
	0.791	MgCl+
	0.392	NaCl (aq)
Pb+2	40.347	Pb+2
	0.759	Pb DOM1
	8.292	PbCl+
	0.175	PbCl2 (aq)
	45.828	PbSO4 (aq)
	4.596	Pb(SO4)2-2
Zn+2	62.625	Zn+2
	0.025	Zn DOM1
	1.165	ZnCl+
	31.238	ZnSO4 (aq)
	4.939	Zn(SO4)2-2
F-1	0.07	F-1
	1.444	HF (aq)
	98.184	AlF+2
	0.275	AlF2+
	0.015	FeF+2
	0.01	MgF+
SO4-2	41.852	SO4-2
	31.015	HSO4-
	8.364	AlSO4+
	4.374	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	0.225	FeSO4 (aq)
	0.027	FeSO4+
	5.402	MgSO4 (aq)
	7.643	CaSO4 (aq)
	0.975	NaSO4-
	0.027	KSO4-
	0.059	NH4SO4-
Ni+2	69.958	Ni+2
	0.017	Ni DOM1
	0.162	NiCl+
	29.846	NiSO4 (aq)

Component	% of total concentration	Species name
	0.018	Ni(SO4)2-2
N3-1	0.116	N3-1
	99.88	HN3 (aq)
PO4-3	30.823	H2PO4-
	66.07	H3PO4
	0.842	FeH2PO4+
	0.102	FeH2PO4+2
	0.097	FeHPO4+
	1.473	CaH2PO4+
	0.227	AlHPO4+
	0.354	NaH2PO4 (aq)
AsO4-3	74.974	H3AsO4
	25.026	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	17.398	DOM1
	78.119	H DOM1
	2.66	Al DOM1
	0.518	Ca DOM1
	1.253	Fe DOM1
	0.045	Mg DOM1
Ca+2	64.431	Ca+2
	1.088	CaCl+
	34.474	CaSO4 (aq)
Mg+2	67.75	Mg+2
	1.879	MgCl+
	30.371	MgSO4 (aq)
K+1	96.11	K+1
	0.5	KCl (aq)
	3.391	KSO4-
Na+1	96.235	Na+1
	0.547	NaCl (aq)
	3.218	NaSO4-
CO3-2	99.998	H2CO3* (aq)
Al+3	8.455	Al+3
	0.067	Al DOM1
	0.269	AlF+2
	0.022	AlCl+2
	72.287	AlSO4+
	18.899	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.014	Cd+2
	0.011	Cd DOM1
	26.727	CdCl+
	1.088	CdCl2 (aq)
	21.666	CdSO4 (aq)

Component	% of total concentration	Species name
	5.495	Cd(SO4)2-2
CrO4-2	91.193	HCrO4-
	0.575	H2CrO4 (aq)
	0.171	CrO3Cl-
	8.043	CrO3SO4-2
Cu+2	64.837	Cu+2
	0.655	Cu DOM1
	0.801	CuCl+
	32.701	CuSO4 (aq)
	1.002	CuHSO4+
Fe+2	64.509	Fe+2
	0.279	FeCl+
	35.206	FeSO4 (aq)
NO2-1	4.047	NO2-1
	95.951	HNO2 (aq)
NO3-1	98.963	NO3-1
	0.823	CaNO3+
	0.014	KNO3 (aq)
	0.198	NaNO3 (aq)
HS-1	99.987	H2S (aq)
	0.012	FeHS+
H3AsO3	100	H3AsO3
Fe+3	4.223	Fe+3
	10.508	Fe DOM1
	0.617	FeOH+2
	0.014	FeF+2
	0.583	FeCl+2
	76.995	FeSO4+
	7.016	Fe(SO4)2-
	0.014	FeN3+2
	0.014	FeH2PO4+2
	0.014	FeHPO4+

B2.7: Eh700

Component	% of total concentration	Species name
Hg(OH)2	83.983	HgCl2 (aq)
	14.243	HgCl3-1
	1.721	HgCl4-2
	0.051	HgN3+
NH4+1	94.028	NH4+1
	5.972	NH4SO4-
Cl-1	98.227	Cl-1
	0.571	CaCl+
	0.791	MgCl+
	0.392	NaCl (aq)
Pb+2	40.379	Pb+2
	0.752	Pb DOM1
	8.268	PbCl+
	0.174	PbCl2 (aq)
	45.836	PbSO4 (aq)
	4.588	Pb(SO4)2-2
Zn+2	62.648	Zn+2
	0.025	Zn DOM1
	1.161	ZnCl+
	31.23	ZnSO4 (aq)
	4.928	Zn(SO4)2-2
F-1	0.07	F-1
	1.459	HF (aq)
	98.168	AlF+2
	0.275	AlF2+
	0.015	FeF+2
	0.01	MgF+
SO4-2	41.761	SO4-2
	31.336	HSO4-
	8.366	AlSO4+
	4.369	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.011	NiSO4 (aq)
	0.027	FeSO4+
	5.399	MgSO4 (aq)
	7.64	CaSO4 (aq)
	0.974	NaSO4-
	0.027	KSO4-
	0.059	NH4SO4-
Ni+2	69.971	Ni+2
	0.016	Ni DOM1
	0.161	NiCl+
	29.834	NiSO4 (aq)
	0.018	Ni(SO4)2-2

Component	% of total concentration	Species name
N3-1	0.114	N3-1
	99.881	HN3 (aq)
PO4-3	30.83	H2PO4-
	66.884	H3PO4
	0.016	FeH2PO4+
	0.105	FeH2PO4+2
	0.099	FeHPO4+
	1.475	CaH2PO4+
	0.225	AlHPO4+
	0.355	NaH2PO4 (aq)
AsO4-3	75.198	H3AsO4
	24.802	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	17.323	DOM1
	78.193	H DOM1
	2.637	Al DOM1
	0.513	Ca DOM1
	1.282	Fe DOM1
	0.045	Mg DOM1
Ca+2	64.449	Ca+2
	1.085	CaCl+
	34.459	CaSO4 (aq)
Mg+2	67.771	Mg+2
	1.872	MgCl+
	30.357	MgSO4 (aq)
K+1	96.116	K+1
	0.498	KCl (aq)
	3.386	KSO4-
Na+1	96.241	Na+1
	0.545	NaCl (aq)
	3.214	NaSO4-
CO3-2	99.998	H2CO3* (aq)
Al+3	8.461	Al+3
	0.066	Al DOM1
	0.269	AlF+2
	0.022	AlCl+2
	72.302	AlSO4+
	18.879	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.075	Cd+2
	0.011	Cd DOM1
	26.665	CdCl+
	1.081	CdCl2 (aq)
	21.682	CdSO4 (aq)
	5.488	Cd(SO4)2-2

Component	% of total concentration	Species name
CrO4-2	91.112	HCrO4-
	0.582	H2CrO4 (aq)
	0.172	CrO3Cl-
	8.117	CrO3SO4-2
Cu+2	64.849	Cu+2
	0.649	Cu DOM1
	0.799	CuCl+
	32.687	CuSO4 (aq)
	1.013	CuHSO4+
Fe+2	64.523	Fe+2
	0.278	FeCl+
	35.192	FeSO4 (aq)
NO2-1	4	NO2-1
	95.998	HNO2 (aq)
NO3-1	98.962	NO3-1
	0.824	CaNO3+
	0.014	KNO3 (aq)
	0.198	NaNO3 (aq)
HS-1	99.999	H2S (aq)
H3AsO3	100	H3AsO3
Fe+3	4.23	Fe+3
	10.427	Fe DOM1
	0.611	FeOH+2
	0.014	FeF+2
	0.581	FeCl+2
	77.079	FeSO4+
	7.014	Fe(SO4)2-
	0.014	FeN3+2
	0.014	FeH2PO4+2
	0.013	FeHPO4+

B2.8: Eh 800

Component	% of total concentration	Species name
Hg(OH)2	83.989	HgCl2 (aq)
	14.242	HgCl3-1
	1.721	HgCl4-2
	0.047	HgN3+
NH4+1	94.065	NH4+1
	5.935	NH4SO4-
Cl-1	98.225	Cl-1
	0.572	CaCl+
	0.793	MgCl+
	0.392	NaCl (aq)
Pb+2	40.499	Pb+2
	0.741	Pb DOM1
	8.289	PbCl+
	0.175	PbCl2 (aq)
	45.663	PbSO4 (aq)
	4.543	Pb(SO4)2-2
	0.031	PbNO2+
	0.057	PbNO3+
Zn+2	62.809	Zn+2
	0.025	Zn DOM1
	1.164	ZnCl+
	31.1	ZnSO4 (aq)
	4.878	Zn(SO4)2-2
	0.017	ZnNO3+
F-1	0.07	F-1
	1.476	HF (aq)
	98.153	AlF+2
	0.273	AlF2+
	0.016	FeF+2
SO4-2	41.51	SO4-2
	31.735	HSO4-
	8.371	AlSO4+
	4.344	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.01	NiSO4 (aq)
	0.029	FeSO4+
	5.374	MgSO4 (aq)
	7.605	CaSO4 (aq)
	0.968	NaSO4-
	0.027	KSO4-
Ni+2	70.098	Ni+2
	0.016	Ni DOM1
	0.161	NiCl+
	29.687	NiSO4 (aq)

Component	% of total concentration	Species name
	0.018	Ni(SO4)2-2
	0.016	NiNO3+
N3-1	0.112	N3-1
	99.883	HN3 (aq)
PO4-3	30.444	H2PO4-
	67.305	H3PO4
	0.109	FeH2PO4+2
	0.101	FeHPO4+
	1.459	CaH2PO4+
	0.22	AlHPO4+
	0.35	NaH2PO4 (aq)
AsO4-3	75.549	H3AsO4
	24.451	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	17.213	DOM1
	78.297	H DOM1
	2.608	Al DOM1
	0.504	Ca DOM1
	1.326	Fe DOM1
	0.044	Mg DOM1
Ca+2	64.584	Ca+2
	1.086	CaCl+
	34.3	CaSO4 (aq)
	0.023	CaNO3+
Mg+2	67.908	Mg+2
	1.875	MgCl+
	30.216	MgSO4 (aq)
K+1	96.127	K+1
	0.498	KCl (aq)
	3.365	KSO4-
	0.01	KNO3 (aq)
Na+1	96.257	Na+1
	0.545	NaCl (aq)
	3.194	NaSO4-
CO3-2	99.998	H2CO3* (aq)
Al+3	8.524	Al+3
	0.065	Al DOM1
	0.269	AlF+2
	0.022	AlCl+2
	72.349	AlSO4+
	18.77	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.165	Cd+2
	0.01	Cd DOM1
	26.706	CdCl+

Component	% of total concentration	Species name
	1.082	CdCl2 (aq)
	21.579	CdSO4 (aq)
	5.428	Cd(SO4)2-2
	0.011	CdNO2+
	0.018	CdNO3+
CrO4-2	91.004	HCrO4-
	0.592	H2CrO4 (aq)
	0.175	CrO3Cl-
	8.212	CrO3SO4-2
Cu+2	64.967	Cu+2
	0.639	Cu DOM1
	0.8	CuCl+
	32.526	CuSO4 (aq)
	1.028	CuHSO4+
	0.017	CuNO2+
	0.022	CuNO3+
Fe+2	64.677	Fe+2
	0.279	FeCl+
	35.038	FeSO4 (aq)
NO2-1	3.928	NO2-1
	96.07	HNO2 (aq)
NO3-1	98.96	NO3-1
	0.825	CaNO3+
	0.014	KNO3 (aq)
	0.198	NaNO3 (aq)
HS-1	99.999	H2S (aq)
H3AsO3	100	H3AsO3
Fe+3	4.264	Fe+3
	10.32	Fe DOM1
	0.605	FeOH+2
	0.014	FeF+2
	0.586	FeCl+2
	77.175	FeSO4+
	6.978	Fe(SO4)2-
	0.016	FeNO2+2
	0.014	FeN3+2
	0.014	FeH2PO4+2
	0.013	FeHPO4+

B2.9: Eh 900

Component	% of total concentration	Species name
Hg(OH)2	83.989	HgCl2 (aq)
	14.242	HgCl3-1
	1.722	HgCl4-2
	0.046	HgN3+
NH4+1	94.075	NH4+1
	5.925	NH4SO4-
Cl-1	98.225	Cl-1
	0.573	CaCl+
	0.793	MgCl+
	0.392	NaCl (aq)
Pb+2	40.547	Pb+2
	0.738	Pb DOM1
	8.296	PbCl+
	0.175	PbCl2 (aq)
	45.617	PbSO4 (aq)
	4.532	Pb(SO4)2-2
	0.093	PbNO3+
Zn+2	62.856	Zn+2
	0.024	Zn DOM1
	1.164	ZnCl+
	31.056	ZnSO4 (aq)
	4.864	Zn(SO4)2-2
	0.027	ZnNO3+
F-1	0.069	F-1
	1.479	HF (aq)
	98.151	AlF+2
	0.272	AlF2+
	0.016	FeF+2
SO4-2	41.456	SO4-2
	31.816	HSO4-
	8.372	AlSO4+
	4.336	Al(SO4)2-
	0.017	ZnSO4 (aq)
	0.01	NiSO4 (aq)
	0.029	FeSO4+
	5.366	MgSO4 (aq)
	7.593	CaSO4 (aq)
	0.966	NaSO4-
	0.027	KSO4-
Ni+2	70.139	Ni+2
	0.016	Ni DOM1
	0.161	NiCl+
	29.64	NiSO4 (aq)
	0.018	Ni(SO4)2-2

Component	% of total concentration	Species name
	0.026	NiNO3+
N3-1	0.112	N3-1
	99.884	HN3 (aq)
PO4-3	30.359	H2PO4-
	67.395	H3PO4
	0.11	FeH2PO4+2
	0.102	FeHPO4+
	1.455	CaH2PO4+
	0.219	AlHPO4+
	0.349	NaH2PO4 (aq)
AsO4-3	75.625	H3AsO4
	24.375	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	17.191	DOM1
	78.318	H DOM1
	2.602	Al DOM1
	0.502	Ca DOM1
	1.335	Fe DOM1
	0.044	Mg DOM1
Ca+2	64.622	Ca+2
	1.087	CaCl+
	34.248	CaSO4 (aq)
	0.037	CaNO3+
Mg+2	67.952	Mg+2
	1.876	MgCl+
	30.172	MgSO4 (aq)
K+1	96.126	K+1
	0.498	KCl (aq)
	3.359	KSO4-
	0.017	KNO3 (aq)
Na+1	96.26	Na+1
	0.545	NaCl (aq)
	3.188	NaSO4-
CO3-2	99.998	H2CO3* (aq)
Al+3	8.544	Al+3
	0.065	Al DOM1
	0.269	AlF+2
	0.022	AlCl+2
	72.359	AlSO4+
	18.739	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.2	Cd+2
	0.01	Cd DOM1
	26.716	CdCl+
	1.082	CdCl2 (aq)

Component	% of total concentration	Species name
	21.549	CdSO4 (aq)
	5.413	Cd(SO4)2-2
	0.029	CdNO3+
CrO4-2	90.98	HCrO4-
	0.595	H2CrO4 (aq)
	0.176	CrO3Cl-
	8.232	CrO3SO4-2
Cu+2	65.016	Cu+2
	0.636	Cu DOM1
	0.8	CuCl+
	32.48	CuSO4 (aq)
	1.031	CuHSO4+
	0.035	CuNO3+
Fe+2	64.726	Fe+2
	0.279	FeCl+
	34.989	FeSO4 (aq)
NO2-1	3.913	NO2-1
	96.085	HNO2 (aq)
NO3-1	98.96	NO3-1
	0.826	CaNO3+
	0.014	KNO3 (aq)
	0.198	NaNO3 (aq)
HS-1	99.999	H2S (aq)
H3AsO3	100	H3AsO3
Fe+3	4.276	Fe+3
	10.298	Fe DOM1
	0.604	FeOH+2
	0.014	FeF+2
	0.587	FeCl+2
	77.21	FeSO4+
	6.969	Fe(SO4)2-
	0.014	FeN3+2
	0.014	FeH2PO4+2
	0.013	FeHPO4+

B3 Saturation indicies

B3.1: Eh 100

Mineral	log IAP	Sat. index
Al(OH)3 (am)	5.941	-5.534
Al(OH)3 (Soil)	5.941	-2.987
Al2O3(s)	11.885	-9.34
Al4(OH)10SO4(s)	14.593	-8.107
AlAsO4:2H2O(s)	-29.685	-13.885
AlOHF2(s)	-16.542	-16.949
AlOHSO4(s)	-3.23	0
Alunite	-0.646	-0.523
Anglesite	-10.402	-2.539
Anhydrite	-4.799	-0.483
Antlerite	-29.401	-38.189
Aragonite	-15.477	-7.198
Arsenolite	-10.584	-9.021
Artinite	-11.223	-21.554
As2O5(s)	-71.252	-36.543
As2S3(am)	-61.99	-15.605
Atacamite	-18.709	-26.668
Azurite	-59.928	-42.774
Bianchite	-7.446	-5.685
Birnessite	10.628	-7.463
Bixbyite	10.76	10.647
Boehmite	5.942	-3.352
Brochantite	-36.145	-52.6
Brucite	4.315	-13.479
Ca3(AsO4)2:4H2O(s)	-58.137	-39.237
Ca3(PO4)2 (am1)	-46.06	-21.132
Ca3(PO4)2 (am2)	-46.06	-18.339
Ca3(PO4)2 (beta)	-46.06	-16.812
Ca4H(PO4)3:3H2O(s)	-71.28	-23.969
CaCO3xH2O(s)	-15.478	-8.391
CaCrO4(s)	-12.092	-9.99
CaHPO4(s)	-25.217	-5.754
CaHPO4:2H2O(s)	-25.219	-6.084
Calcite	-15.477	-7.046
CaS(s)	-12.762	-23.942
Cd metal (alpha)	-12.613	-26.586
Cd metal (gamma)	-12.613	-26.693
Cd(OH)2(s)	-2.117	-16.336
Cd3(OH)4SO4(s)	-15.522	-38.082
Cd3(PO4)2(s)	-65.527	-32.927
Cd3OH2(SO4)2(s)	-24.693	-31.403
Cd4(OH)6SO4(s)	-17.639	-46.039

Mineral	log IAP	Sat. index
CdCl2(s)	-12.561	-12.016
CdCl2:1H2O(s)	-12.562	-10.915
CdCl2:2.5H2O(s)	-12.564	-10.607
CdF2(s)	-24.6	-23.668
CdOHCl(s)	-7.339	-11.065
CdSO4(s)	-11.288	-11.432
CdSO4:1H2O(s)	-11.289	-9.755
CdSO4:2.67H2O(s)	-11.291	-9.527
Cerrusite	-21.079	-7.729
Chalcanthite	-15.919	-13.243
Chalcopyrite	-36.173	0
Chloropyromorphite(c)	-100.14	-15.71
Chloropyromorphite(soil)	-100.14	-19.74
Cinnabar	-46.424	0.399
Claudetite	-10.584	-9.071
Cotunnite	-11.675	-6.736
Covellite	-23.878	-1.068
Cr(VI)-Ettringite	-11.303	-74.704
Cr(VI)-Jarosite	-42.666	-24.15
CrO3(s)	-16.465	-13.286
Cryolite	-57.097	-23.026
Cu azide	-24.81	-16.969
Cu(OH)2(s)	-6.743	-16.356
Cu2(OH)3NO3(s)	-95.394	-105.086
Cu3(AsO4)2:2H2O(s)	-91.481	-56.381
Cu3(PO4)2(s)	-79.406	-42.556
Cu3(PO4)2:3H2O(s)	-79.409	-44.289
CuCO3(s)	-26.592	-15.092
CuCrO4(s)	-23.207	-17.767
CuF2(s)	-29.226	-30.748
CuF2:2H2O(s)	-29.228	-24.771
CuOCuSO4(s)	-22.657	-33.798
Cupric Ferrite	-13.148	-20.414
CuSO4(s)	-15.914	-19.298
Diaspore	5.942	-1.558
Dolomite (disordered)	-31.011	-14.753
Dolomite (ordered)	-31.011	-14.161
Epsomite	-4.863	-2.667
Ettringite	10.575	-48.613
FCO3-Apatite	-151.84	-36.438
Fe(OH)2 (am)	4.839	-9.208
Fe(OH)2 (c)	4.839	-8.051
Fe(OH)2.7Cl.3(s)	-4.771	-1.731
Fe2(SO4)3(s)	-33.921	-31.658
Fe3(OH)8(s)	-1.569	-21.791
FeAsO4:2H2O(s)	-38.83	-18.63

Mineral	log IAP	Sat. index
Ferrihydrite	-3.204	-7.014
Ferrihydrite (aged)	-3.204	-6.504
FeS (ppt)	-12.295	-9.412
Fluorite	-18.111	-7.538
Galena	-18.365	-2.959
Gibbsite (C)	5.941	-2.437
Goethite	-3.203	-4.062
Goslarite	-7.447	-5.35
Greenockite	-19.251	-4.897
Greigite	-70.106	-25.071
Gypsum	-4.801	-0.185
Halite	-3.752	-5.28
Hematite	-6.405	-5.771
Hercynite	16.725	-8.076
Hg(OH)2(s)	-29.29	-25.794
Hg3O2CO3(s)	-107.717	-78.137
HgCl2(s)	-39.735	-17.817
HgSO4(s)	-38.461	-28.953
Hinsdalite	-22.167	-19.667
H-Jarosite	-27.956	-23.923
Huntite	-62.079	-32.766
Hydrocerrusite	-43.389	-24.629
Hydromagnesite	-57.826	-50.388
Hydroxyapatite	-66.904	-22.571
Hydroxylpyromorphite	-94.917	-32.127
Hydrozincite	-31.044	-41.182
K2Cr2O7(s)	-33.182	-15.448
K2CrO4(s)	-16.717	-16.093
K-Alum	-12.54	-7.186
KCl(s)	-5.349	-6.249
K-Jarosite	-28.081	-17.7
Langite	-36.146	-54.641
Larnakite	-11.631	-11.33
Laurionite	-6.453	-7.076
Lepidocrocite	-3.203	-4.574
Lime	4.373	-29.505
Litharge	-1.23	-14.318
Mackinawite	-12.295	-8.695
Maghemite	-6.405	-12.791
Magnesioferrite	-2.09	-20.645
Magnesite	-15.534	-7.953
Magnetite	-1.565	-6.235
Malachite	-33.335	-28.135
Massicot	-1.23	-14.526
Matlockite	-17.694	-8.519
Melanothallite	-17.188	-23.831

Mineral	log IAP	Sat. index
Melanterite	-4.338	-2.005
Metacinnabar	-46.424	0
Mg(OH)2 (active)	4.315	-14.479
Mg2(OH)3Cl:4H2O(s)	3.403	-22.597
Mg3(PO4)2(s)	-46.233	-22.953
MgCO3:5H2O(s)	-15.539	-10.999
MgCrO4(s)	-12.149	-18.07
MgF2(s)	-18.168	-10.107
MgHPO4:3H2O(s)	-25.278	-7.103
MgS(s)	-12.82	-30.5
Minium	6.808	-69.278
Mirabilite	-6.241	-4.644
Mn2(SO4)3(s)	-16.756	-12.039
Montroydite	-29.289	-25.572
Morenosite	-7.616	-5.397
Na2Cr2O7(s)	-29.988	-19.958
Na2CrO4(s)	-13.523	-16.573
NaF(s)	-9.771	-9.276
Na-Jarosite	-26.484	-21.989
Natron	-16.918	-15.207
Nesquehonite	-15.537	-11.014
Ni(OH)2 (am)	1.562	-11.912
Ni(OH)2 (c)	1.562	-9.228
Ni3(AsO4)2:8H2O(s)	-66.571	-41.071
Ni3(PO4)2(s)	-54.491	-23.191
Ni4(OH)6SO4(s)	-2.924	-34.924
NiCO3(s)	-18.287	-7.34
NiS (alpha)	-15.572	-10.052
NiS (beta)	-15.572	-4.552
NiS (gamma)	-15.572	-2.852
Nsutite	10.628	-6.876
Orpiment	-61.99	-14.09
Otavite	-21.966	-9.914
Pb azide (alpha)	-19.297	-10.323
Pb metal	-11.727	-15.967
Pb(OH)2(s)	-1.231	-9.737
Pb10(OH)6O(CO3)6(s)	-131.397	-122.637
Pb2(OH)3Cl(s)	-7.684	-16.477
Pb2O(OH)2(s)	-2.46	-28.65
Pb2O3(s)	8.038	-53.002
Pb2OCO3(s)	-22.309	-21.999
Pb3(AsO4)2(s)	-74.941	-39.441
Pb3(PO4)2(s)	-62.868	-19.338
Pb3O2CO3(s)	-23.539	-35.231
Pb3O2SO4(s)	-12.861	-24.028
Pb4(OH)6SO4(s)	-14.093	-35.193

Mineral	log IAP	Sat. index
Pb4O3SO4(s)	-14.091	-36.797
PbCrO4(s)	-17.694	-4.826
PbF2(s)	-23.713	-16.152
PbHPO4(s)	-30.82	-7.015
PbO:0.3H2O(s)	-1.23	-14.21
Periclase	4.316	-18.188
Phosgenite	-32.755	-12.945
Plattnerite	9.268	-42.134
Plumbgummite	-42.585	-9.795
Portlandite	4.372	-19.114
Pyrite	-18.933	-0.122
Realgar	-27.676	-6.946
Retgersite	-7.615	-5.547
Siderite	-15.009	-4.464
Smithsonite	-18.118	-7.241
Spharelite	-15.404	-4.401
Spinel	16.2	-23.006
Strengite	-32.794	-6.451
Struvite	-25.324	-12.064
Sulfur	-6.638	-4.592
Tenorite(am)	-6.742	-15.627
Tenorite(c)	-6.742	-14.777
Thenardite	-6.231	-6.608
Thermonatrite	-16.909	-17.61
Tsumebite	-38.796	-29.006
Vaterite	-15.477	-7.64
Vivianite	-44.666	-6.875
Wurtzite	-15.404	-6.655
Zincite	1.732	-10.043
Zincosite	-7.44	-11.872
Zn metal	-8.766	-35.487
Zn(NO3)2:6H2O(s)	-162.089	-165.255
Zn(OH)2 (am)	1.731	-11.264
Zn(OH)2 (beta)	1.731	-10.529
Zn(OH)2 (delta)	1.731	-10.113
Zn(OH)2 (epsilon)	1.731	-10.281
Zn(OH)2 (gamma)	1.731	-10.501
Zn2(OH)2SO4(s)	-5.71	-13.21
Zn2(OH)3Cl(s)	-1.761	-16.952
Zn3(PO4)2:4H2O(s)	-53.988	-18.568
Zn3AsO42:2.5H2O(s)	-66.059	-38.559
Zn3O(SO4)2(s)	-13.149	-33.632
Zn4(OH)6SO4(s)	-2.248	-30.648
Zn5(OH)8Cl2(s)	-1.791	-40.291
Zn-Al LDH(s)	-0.522	-20.352
ZnCl2(s)	-8.714	-16.205

Mineral	log IAP	Sat. index
ZnCO3(s)	-18.118	-7.318
ZnCO3:1H2O(s)	-18.119	-7.859
ZnF2(s)	-20.752	-20.581
ZnSO4:1H2O(s)	-7.441	-7.071

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Mineral	log IAP	Sat. index
Al(OH)3 (am)	5.348	-6.127
Al(OH)3 (Soil)	5.348	-3.58
Al2O3(s)	10.699	-10.526
Al4(OH)10SO4(s)	12.814	-9.886
AlAsO4:2H2O(s)	-27.38	-11.58
AlOHF2(s)	-17.149	-17.556
AlOHSO4(s)	-3.23	0
Alunite	-1.539	-1.416
Anglesite	-10.384	-2.521
Anhydrite	-4.804	-0.488
Antlerite	-12.587	-21.375
Aragonite	-16.075	-7.796
Arsenolite	-10.584	-9.021
Artinite	-12.42	-22.751
As2O5(s)	-65.455	-30.746
As2S3(am)	-94.989	-48.604
Atacamite	-7.596	-15.555
Azurite	-43.705	-26.552
Bianchite	-7.451	-5.69
Birnessite	11.174	-6.917
Bixbyite	8.953	8.841
Boehmite	5.349	-3.945
Brochantite	-13.923	-30.378
Brucite	3.716	-14.077
Ca3(AsO4)2:4H2O(s)	-54.135	-35.235
Ca3(PO4)2 (am1)	-47.265	-22.337
Ca3(PO4)2 (am2)	-47.265	-19.544
Ca3(PO4)2 (beta)	-47.265	-18.017
Ca4H(PO4)3:3H2O(s)	-72.788	-25.477
CaCO3xH2O(s)	-16.076	-8.989
CaCrO4(s)	-12.391	-10.289
CaHPO4(s)	-25.52	-6.057
CaHPO4:2H2O(s)	-25.522	-6.387
Calcite	-16.075	-7.644
CaS(s)	-24.361	-35.541
Cd metal (alpha)	-16.11	-30.082
Cd metal (gamma)	-16.11	-30.189

Mineral	log IAP	Sat. index
Cd(OH)2(s)	-2.715	-16.934
Cd3(OH)4SO4(s)	-16.723	-39.283
Cd3(PO4)2(s)	-66.731	-34.131
Cd3OH2(SO4)2(s)	-25.301	-32.011
Cd4(OH)6SO4(s)	-19.439	-47.839
CdCl2(s)	-12.561	-12.016
CdCl2:1H2O(s)	-12.562	-10.915
CdCl2:2.5H2O(s)	-12.564	-10.607
CdF2(s)	-25.212	-24.281
CdOHCl(s)	-7.638	-11.364
CdSO4(s)	-11.293	-11.437
CdSO4:1H2O(s)	-11.294	-9.76
CdSO4:2.67H2O(s)	-11.296	-9.532
Cerrusite	-21.654	-8.304
Chalcanthite	-9.919	-7.243
Chalcopyrite	-53.364	-17.191
Chloropyromorphite(c)	-101.833	-17.403
Chloropyromorphite(soil)	-101.833	-21.433
Cinnabar	-52.816	-5.993
Claudetite	-10.584	-9.071
Cotunnite	-11.652	-6.713
Covellite	-29.47	-6.661
Cr(VI)-Ettringite	-15.181	-78.582
Cr(VI)-Jarosite	-39.817	-21.3
CrO3(s)	-16.165	-12.986
Cryolite	-58.633	-24.562
Cu azide	-19.369	-11.528
Cu(OH)2(s)	-1.336	-10.949
Cu2(OH)3NO3(s)	-73.287	-82.979
Cu3(AsO4)2:2H2O(s)	-69.463	-34.363
Cu3(PO4)2(s)	-62.595	-25.745
Cu3(PO4)2:3H2O(s)	-62.598	-27.478
CuCO3(s)	-21.184	-9.684
CuCrO4(s)	-17.5	-12.06
CuF2(s)	-23.833	-25.355
CuF2:2H2O(s)	-23.835	-19.378
CuOCuSO4(s)	-11.25	-22.39
Cupric Ferrite	-6.04	-13.306
CuSO4(s)	-9.914	-13.298
Diaspore	5.349	-2.151
Dolomite (disordered)	-32.207	-15.949
Dolomite (ordered)	-32.207	-15.357
Epsomite	-4.869	-2.672
Ettringite	7.578	-51.611
FCO3-Apatite	-156.209	-40.807
Fe(OH)2 (am)	4.241	-9.806

Mineral	log IAP	Sat. index
Fe(OH)2 (c)	4.241	-8.649
Fe(OH)2.7Cl.3(s)	-3.831	-0.791
Fe2(SO4)3(s)	-30.441	-28.178
Fe3(OH)8(s)	-0.467	-20.689
FeAsO4:2H2O(s)	-35.082	-14.882
Ferrihydrite	-2.354	-6.164
Ferrihydrite (aged)	-2.354	-5.654
FeS (ppt)	-23.893	-21.01
Fluorite	-18.723	-8.15
Galena	-29.94	-14.534
Gibbsite (C)	5.348	-3.03
Goethite	-2.353	-3.212
Goslarite	-7.452	-5.354
Greenockite	-30.849	-16.495
Greigite	-113.003	-67.968
Gypsum	-4.806	-0.19
Halite	-3.753	-5.281
Hematite	-4.704	-4.071
Hercynite	14.94	-9.861
Hg(OH)2(s)	-24.682	-21.185
Hg3O2CO3(s)	-93.891	-64.311
HgCl2(s)	-34.528	-12.61
HgSO4(s)	-33.259	-23.751
Hinsdalite	-23.633	-21.133
H-Jarosite	-24.219	-20.186
Huntite	-64.472	-35.159
Hydrocerrusite	-45.115	-26.355
Hydromagnesite	-60.818	-53.38
Hydroxyapatite	-69.011	-24.678
Hydroxylpyromorphite	-96.91	-34.12
Hydrozincite	-34.031	-44.169
K2Cr2O7(s)	-33.184	-15.45
K2CrO4(s)	-17.019	-16.394
K-Alum	-12.247	-6.893
KCl(s)	-5.35	-6.25
K-Jarosite	-24.644	-14.263
Langite	-13.924	-32.419
Larnakite	-12.19	-11.888
Laurionite	-6.729	-7.352
Lepidocrocite	-2.353	-3.724
Lime	3.775	-30.104
Litharge	-1.805	-14.894
Mackinawite	-23.893	-20.293
Maghemite	-4.704	-11.09
Magnesioferrite	-0.988	-19.543
Magnesite	-16.132	-8.551

Mineral	log IAP	Sat. index
Magnetite	-0.463	-5.133
Malachite	-22.521	-17.32
Massicot	-1.805	-15.102
Matlockite	-17.978	-8.803
Melanothallite	-11.182	-17.825
Melanterite	-4.344	-2.011
Metacinnabar	-52.816	-6.391
Mg(OH)2 (active)	3.716	-15.078
Mg2(OH)3Cl:4H2O(s)	2.504	-23.496
Mg3(PO4)2(s)	-47.439	-24.159
MgCO3:5H2O(s)	-16.137	-11.597
MgCrO4(s)	-12.448	-18.369
MgF2(s)	-18.781	-10.72
MgHPO4:3H2O(s)	-25.581	-7.406
MgS(s)	-24.418	-42.098
Minium	7.979	-68.107
Mirabilite	-6.248	-4.651
Mn2(SO4)3(s)	-16.784	-12.066
Montroydite	-24.681	-20.964
Morenosite	-7.622	-5.403
Na2Cr2O7(s)	-29.989	-19.959
Na2CrO4(s)	-13.824	-16.874
NaF(s)	-10.079	-9.584
Na-Jarosite	-23.047	-18.552
Natron	-17.518	-15.807
Nesquehonite	-16.135	-11.613
Ni(OH)2 (am)	0.963	-12.51
Ni(OH)2 (c)	0.963	-9.827
Ni3(AsO4)2:8H2O(s)	-62.571	-37.071
Ni3(PO4)2(s)	-55.696	-24.396
Ni4(OH)6SO4(s)	-4.725	-36.725
NiCO3(s)	-18.885	-7.938
NiS (alpha)	-27.171	-21.651
NiS (beta)	-27.171	-16.151
NiS (gamma)	-27.171	-14.451
Nsutite	11.174	-6.33
Orpiment	-94.989	-47.089
Otavite	-22.563	-10.512
Pb azide (alpha)	-19.839	-10.865
Pb metal	-15.201	-19.441
Pb(OH)2(s)	-1.806	-10.312
Pb10(OH)6O(CO3)6(s)	-137.151	-128.391
Pb2(OH)3Cl(s)	-8.536	-17.329
Pb2O(OH)2(s)	-3.612	-29.802
Pb2O3(s)	9.785	-51.255
Pb2OCO3(s)	-23.46	-23.15

Mineral	log IAP	Sat. index
Pb3(AsO4)2(s)	-70.871	-35.371
Pb3(PO4)2(s)	-64.005	-20.475
Pb3O2CO3(s)	-25.265	-36.957
Pb3O2SO4(s)	-13.995	-25.162
Pb4(OH)6SO4(s)	-15.803	-36.903
Pb4O3SO4(s)	-15.8	-38.507
PbCrO4(s)	-17.97	-5.102
PbF2(s)	-24.303	-16.742
PbHPO4(s)	-31.1	-7.295
PbO:0.3H2O(s)	-1.806	-14.786
Periclase	3.717	-18.787
Phosgenite	-33.307	-13.497
Plattnerite	11.59	-39.811
Plumbgummite	-44.349	-11.559
Portlandite	3.774	-19.712
Pyrite	-38.633	-19.822
Realgar	-40.125	-19.395
Retgersite	-7.621	-5.553
Siderite	-15.607	-5.062
Smithsonite	-18.715	-7.838
Spharelite	-27.001	-15.999
Spinel	14.415	-24.791
Strengite	-31.649	-5.306
Struvite	-25.929	-12.669
Sulfur	-14.74	-12.694
Tenorite(am)	-1.335	-10.22
Tenorite(c)	-1.335	-9.37
Thenardite	-6.238	-6.615
Thermonatrite	-17.509	-18.21
Tsumebite	-34.245	-24.455
Vaterite	-16.075	-8.238
Vivianite	-45.872	-8.081
Wurtzite	-27.001	-18.252
Zincite	1.134	-10.641
Zincosite	-7.445	-11.877
Zn metal	-12.261	-38.983
Zn(NO3)2:6H2O(s)	-140.102	-143.268
Zn(OH)2 (am)	1.133	-11.861
Zn(OH)2 (beta)	1.133	-11.126
Zn(OH)2 (delta)	1.133	-10.711
Zn(OH)2 (epsilon)	1.133	-10.879
Zn(OH)2 (gamma)	1.133	-11.098
Zn2(OH)2SO4(s)	-6.312	-13.812
Zn2(OH)3Cl(s)	-2.657	-17.848
Zn3(PO4)2:4H2O(s)	-55.191	-19.771
Zn3AsO42:2.5H2O(s)	-62.055	-34.555

Mineral	log IAP	Sat. index
Zn3O(SO4)2(s)	-13.756	-34.238
Zn4(OH)6SO4(s)	-4.046	-32.446
Zn5(OH)8Cl2(s)	-4.181	-42.681
Zn-Al LDH(s)	-2.31	-22.14
ZnCl2(s)	-8.713	-16.204
ZnCO3(s)	-18.715	-7.915
ZnCO3:1H2O(s)	-18.716	-8.456
ZnF2(s)	-21.364	-21.192
ZnSO4:1H2O(s)	-7.446	-7.076

B3.3: Eh 300

Mineral	log IAP	Sat. index
Al(OH)3 (am)	4.471	-7.004
Al(OH)3 (Soil)	4.471	-4.457
Al2O3(s)	8.952	-12.272
Al4(OH)10SO4(s)	9.954	-12.746
AlAsO4:2H2O(s)	-25.377	-9.577
AlOHF2(s)	-17.497	-17.904
AlOHSO4(s)	-3.459	-0.229
Alunite	-3.183	-3.06
Anglesite	-10.355	-2.492
Anhydrite	-4.783	-0.466
Antlerite	-13.784	-22.572
Aragonite	-16.696	-8.417
Arsenolite	-10.58	-9.018
Artinite	-13.672	-24.003
As2O5(s)	-59.693	-24.983
As2S3(am)	-127.606	-81.221
Atacamite	-8.544	-16.503
Azurite	-45.542	-28.389
Bianchite	-7.444	-5.683
Birnessite	11.698	-6.393
Bixbyite	7.122	7.009
Boehmite	4.475	-4.819
Brochantite	-15.736	-32.191
Brucite	3.091	-14.702
Ca3(AsO4)2:4H2O(s)	-50.253	-31.353
Ca3(PO4)2 (am1)	-48.357	-23.428
Ca3(PO4)2 (am2)	-48.357	-20.635
Ca3(PO4)2 (beta)	-48.357	-19.108
Ca4H(PO4)3:3H2O(s)	-74.122	-26.811
CaCO3xH2O(s)	-16.7	-9.613
CaCrO4(s)	-12.703	-10.601
CaHPO4(s)	-25.755	-6.292
CaHPO4:2H2O(s)	-25.762	-6.627

Mineral	log IAP	Sat. index
Calcite	-16.696	-8.266
CaS(s)	-35.857	-47.037
Cd metal (alpha)	-19.602	-33.575
Cd metal (gamma)	-19.602	-33.682
Cd(OH)2(s)	-3.33	-17.55
Cd3(OH)4SO4(s)	-17.922	-40.482
Cd3(PO4)2(s)	-67.791	-35.191
Cd3OH2(SO4)2(s)	-25.852	-32.562
Cd4(OH)6SO4(s)	-21.252	-49.652
CdCl2(s)	-12.613	-12.067
CdCl2:1H2O(s)	-12.616	-10.968
CdCl2:2.5H2O(s)	-12.621	-10.664
CdF2(s)	-25.299	-24.368
CdOHCl(s)	-7.972	-11.697
CdSO4(s)	-11.261	-11.405
CdSO4:1H2O(s)	-11.264	-9.73
CdSO4:2.67H2O(s)	-11.27	-9.506
Cerrusite	-22.268	-8.918
Chalcanthite	-9.899	-7.222
Chalcopyrite	-76.453	-40.281
Chloropyromorphite(c)	-103.464	-19.034
Chloropyromorphite(soil)	-103.464	-23.064
Cinnabar	-62.77	-15.947
Claudetite	-10.58	-9.067
Cotunnite	-11.707	-6.768
Covellite	-40.956	-18.147
Cr(VI)-Ettringite	-19.811	-83.212
Cr(VI)-Jarosite	-37.379	-18.863
CrO3(s)	-15.854	-12.675
Cryolite	-58.852	-24.781
Cu azide	-19.963	-12.122
Cu(OH)2(s)	-1.951	-11.564
Cu2(OH)3NO3(s)	-63.3	-72.993
Cu3(AsO4)2:2H2O(s)	-65.543	-30.443
Cu3(PO4)2(s)	-63.654	-26.804
Cu3(PO4)2:3H2O(s)	-63.664	-28.544
CuCO3(s)	-21.795	-10.295
CuCrO4(s)	-17.802	-12.362
CuF2(s)	-23.92	-25.442
CuF2:2H2O(s)	-23.927	-19.469
CuOCuSO4(s)	-11.83	-22.971
Cupric Ferrite	-5.233	-12.499
CuSO4(s)	-9.882	-13.265
Diaspore	4.475	-3.025
Dolomite (disordered)	-33.449	-17.191
Dolomite (ordered)	-33.449	-16.599

Mineral	log IAP	Sat. index
Epsomite	-4.863	-2.666
Ettringite	3.949	-55.239
FCO3-Apatite	-159.694	-44.292
Fe(OH)2 (am)	3.508	-10.539
Fe(OH)2 (c)	3.508	-9.382
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-27.086	-24.824
Fe3(OH)8(s)	0.213	-20.009
FeAsO4:2H2O(s)	-31.496	-11.296
Ferrihydrite	-1.648	-5.458
Ferrihydrite (aged)	-1.648	-4.948
FeS (ppt)	-35.497	-32.614
Fluorite	-18.821	-8.248
Galena	-41.43	-26.023
Gibbsite (C)	4.471	-3.907
Goethite	-1.644	-2.504
Goslarite	-7.448	-5.35
Greenockite	-42.335	-27.981
Greigite	-155.807	-110.772
Gypsum	-4.789	-0.173
Halite	-3.78	-5.308
Hematite	-3.285	-2.651
Hercynite	12.464	-12.338
Hg(OH)2(s)	-23.765	-20.268
Hg3O2CO3(s)	-91.131	-61.551
HgCl2(s)	-33.047	-11.129
HgSO4(s)	-31.695	-22.187
Hinsdalite	-25.841	-23.341
H-Jarosite	-20.81	-16.778
Huntite	-66.955	-37.643
Hydrocerrusite	-46.962	-28.202
Hydromagnesite	-63.935	-56.497
Hydroxyapatite	-70.961	-26.628
Hydroxylpyromorphite	-98.822	-36.032
Hydrozincite	-37.155	-47.293
K2Cr2O7(s)	-33.176	-15.442
K2CrO4(s)	-17.322	-16.697
K-Alum	-12.166	-6.812
KCl(s)	-5.377	-6.277
K-Jarosite	-21.539	-11.158
Langite	-15.739	-34.234
Larnakite	-12.776	-12.475
Laurionite	-7.066	-7.689
Lepidocrocite	-1.644	-3.015
Lime	3.151	-30.727
Litharge	-2.421	-15.509

Mineral	log IAP	Sat. index
Mackinawite	-35.497	-31.897
Maghemite	-3.285	-9.671
Magnesioferrite	-0.191	-18.746
Magnesite	-16.753	-9.171
Magnetite	0.226	-4.444
Malachite	-23.747	-18.546
Massicot	-2.421	-15.718
Matlockite	-18.05	-8.875
Melanothallite	-11.234	-17.876
Melanterite	-4.446	-2.112
Metacinnabar	-62.77	-16.345
Mg(OH)2 (active)	3.091	-15.703
Mg2(OH)3Cl:4H2O(s)	1.527	-24.473
Mg3(PO4)2(s)	-48.527	-25.247
MgCO3:5H2O(s)	-16.77	-12.23
MgCrO4(s)	-12.76	-18.681
MgF2(s)	-18.878	-10.816
MgHPO4:3H2O(s)	-25.822	-7.647
MgS(s)	-35.914	-53.594
Minium	9.011	-67.076
Mirabilite	-6.243	-4.646
Mn2(SO4)3(s)	-16.68	-11.962
Montroydite	-23.761	-20.044
Morenosite	-7.615	-5.396
Na2Cr2O7(s)	-29.983	-19.953
Na2CrO4(s)	-14.129	-17.179
NaF(s)	-10.124	-9.629
Na-Jarosite	-19.943	-15.448
Natron	-18.156	-16.445
Nesquehonite	-16.763	-12.24
Ni(OH)2 (am)	0.339	-13.134
Ni(OH)2 (c)	0.339	-10.451
Ni3(AsO4)2:8H2O(s)	-58.691	-33.191
Ni3(PO4)2(s)	-56.781	-25.481
Ni4(OH)6SO4(s)	-6.573	-38.573
NiCO3(s)	-19.504	-8.557
NiS (alpha)	-38.666	-33.146
NiS (beta)	-38.666	-27.646
NiS (gamma)	-38.666	-25.946
Nsutite	11.698	-5.806
Orpiment	-127.606	-79.706
Otavite	-23.174	-11.123
Pb azide (alpha)	-20.437	-11.462
Pb metal	-18.696	-22.937
Pb(OH)2(s)	-2.425	-10.931
Pb10(OH)6O(CO3)6(s)	-143.306	-134.546

Mineral	log IAP	Sat. index
Pb2(OH)3Cl(s)	-9.49	-18.283
Pb2O(OH)2(s)	-4.846	-31.036
Pb2O3(s)	11.433	-49.607
Pb2OCO3(s)	-24.69	-24.38
Pb3(AsO4)2(s)	-66.956	-31.456
Pb3(PO4)2(s)	-65.073	-21.543
Pb3O2CO3(s)	-27.111	-38.803
Pb3O2SO4(s)	-15.198	-26.365
Pb4(OH)6SO4(s)	-17.629	-38.729
Pb4O3SO4(s)	-17.619	-40.326
PbCrO4(s)	-18.275	-5.406
PbF2(s)	-24.393	-16.831
PbHPO4(s)	-31.328	-7.523
PbO:0.3H2O(s)	-2.422	-15.402
Periclase	3.094	-19.409
Phosgenite	-33.975	-14.165
Plattnerite	13.854	-37.548
Plumbgummite	-46.814	-14.024
Portlandite	3.148	-20.338
Pyrite	-58.23	-39.419
Realgar	-52.436	-31.706
Retgersite	-7.611	-5.543
Siderite	-16.336	-5.79
Smithsonite	-19.337	-8.46
Spharelite	-38.499	-27.496
Spinel	12.047	-27.16
Strengite	-30.554	-4.211
Struvite	-26.469	-13.209
Sulfur	-22.733	-20.688
Tenorite(am)	-1.948	-10.832
Tenorite(c)	-1.948	-9.983
Thenardite	-6.209	-6.586
Thermonatrite	-18.126	-18.827
Tsumebite	-35.711	-25.921
Vaterite	-16.696	-8.86
Vivianite	-47.302	-9.511
Wurtzite	-38.499	-29.75
Zincite	0.51	-11.265
Zincosite	-7.424	-11.856
Zn metal	-15.765	-42.486
Zn(NO3)2:6H2O(s)	-118.309	-121.475
Zn(OH)2 (am)	0.506	-12.488
Zn(OH)2 (beta)	0.506	-11.753
Zn(OH)2 (delta)	0.506	-11.338
Zn(OH)2 (epsilon)	0.506	-11.506
Zn(OH)2 (gamma)	0.506	-11.725

Mineral	log IAP	Sat. index
Zn2(OH)2SO4(s)	-6.917	-14.417
Zn2(OH)3Cl(s)	-3.628	-18.819
Zn3(PO4)2:4H2O(s)	-56.294	-20.874
Zn3AsO42:2.5H2O(s)	-58.171	-30.671
Zn3O(SO4)2(s)	-14.338	-34.82
Zn4(OH)6SO4(s)	-5.904	-34.304
Zn5(OH)8Cl2(s)	-6.75	-45.25
Zn-Al LDH(s)	-4.438	-24.268
ZnCl2(s)	-8.776	-16.267
ZnCO3(s)	-19.337	-8.537
ZnCO3:1H2O(s)	-19.341	-9.081
ZnF2(s)	-21.462	-21.291
ZnSO4:1H2O(s)	-7.427	-7.057

B3.4: Eh 400

Mineral	log IAP	Sat. index
Al(OH)3 (am)	2.651	-8.824
Al(OH)3 (Soil)	2.651	-6.277
Al2O3(s)	5.312	-15.912
Al4(OH)10SO4(s)	3.886	-18.814
AlAsO4:2H2O(s)	-24.996	-9.196
AlOHF2(s)	-18.119	-18.526
AlOHSO4(s)	-4.067	-0.837
Alunite	-6.828	-6.705
Anglesite	-10.341	-2.478
Anhydrite	-4.788	-0.472
Antlerite	-16.186	-24.974
Aragonite	-17.914	-9.635
Arsenolite	-10.727	-9.164
Artinite	-16.109	-26.44
As2O5(s)	-55.291	-20.582
As2S3(am)	-151.402	-105.018
Atacamite	-10.364	-18.323
Azurite	-49.157	-32.004
Bianchite	-7.447	-5.686
Birnessite	11.005	-7.086
Bixbyite	3.462	3.349
Boehmite	2.654	-6.639
Brochantite	-19.343	-35.798
Brucite	1.873	-15.92
Ca3(AsO4)2:4H2O(s)	-49.504	-30.604
Ca3(PO4)2 (am1)	-50.76	-25.831
Ca3(PO4)2 (am2)	-50.76	-23.038
Ca3(PO4)2 (beta)	-50.76	-21.511
Ca4H(PO4)3:3H2O(s)	-77.118	-29.806

Mineral	log IAP	Sat. index
CaCO3xH2O(s)	-17.917	-10.83
CaCrO4(s)	-13.315	-11.213
CaHPO4(s)	-26.348	-6.885
CaHPO4:2H2O(s)	-26.355	-7.22
Calcite	-17.914	-9.484
CaS(s)	-44.958	-56.138
Cd metal (alpha)	-23.087	-37.059
Cd metal (gamma)	-23.087	-37.166
Cd(OH)2(s)	-4.541	-18.76
Cd3(OH)4SO4(s)	-20.34	-42.9
Cd3(PO4)2(s)	-70.172	-37.572
Cd3OH2(SO4)2(s)	-27.058	-33.768
Cd4(OH)6SO4(s)	-24.881	-53.281
CdCl2(s)	-12.644	-12.098
CdCl2:1H2O(s)	-12.648	-11
CdCl2:2.5H2O(s)	-12.653	-10.695
CdF2(s)	-25.311	-24.38
CdOHCl(s)	-8.592	-12.318
CdSO4(s)	-11.259	-11.403
CdSO4:1H2O(s)	-11.262	-9.728
CdSO4:2.67H2O(s)	-11.268	-9.504
Cerrusite	-23.468	-10.117
Chalcanthite	-9.891	-7.214
Chalcopyrite	-94.739	-58.566
Chloropyromorphite(c)	-106.994	-22.564
Chloropyromorphite(soil)	-106.994	-26.594
Cinnabar	-69.366	-22.543
Claudetite	-10.727	-9.214
Cotunnite	-11.727	-6.788
Covellite	-50.045	-27.235
Cr(VI)-Ettringite	-28.942	-92.343
Cr(VI)-Jarosite	-37.31	-18.794
CrO3(s)	-15.249	-12.07
Cryolite	-58.909	-24.838
Cu azide	-21.156	-13.315
Cu(OH)2(s)	-3.156	-12.769
Cu2(OH)3NO3(s)	-57.224	-66.916
Cu3(AsO4)2:2H2O(s)	-64.756	-29.656
Cu3(PO4)2(s)	-66.018	-29.168
Cu3(PO4)2:3H2O(s)	-66.029	-30.909
CuCO3(s)	-23	-11.5
CuCrO4(s)	-18.402	-12.962
CuF2(s)	-23.926	-25.448
CuF2:2H2O(s)	-23.933	-19.476
CuOCuSO4(s)	-13.027	-24.168
Cupric Ferrite	-6.792	-14.058

Mineral	log IAP	Sat. index
CuSO4(s)	-9.874	-13.258
Diaspore	2.654	-4.845
Dolomite (disordered)	-35.885	-19.627
Dolomite (ordered)	-35.885	-19.035
Epsomite	-4.869	-2.672
Ettringite	-3.359	-62.547
FCO3-Apatite	-166.947	-51.545
Fe(OH)2 (am)	2.194	-11.853
Fe(OH)2 (c)	2.194	-10.696
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-23.803	-21.54
Fe3(OH)8(s)	-1.455	-21.677
FeAsO4:2H2O(s)	-29.472	-9.272
Ferrihydrite	-1.825	-5.635
Ferrihydrite (aged)	-1.825	-5.125
FeS (ppt)	-44.694	-41.811
Fluorite	-18.84	-8.267
Galena	-50.512	-35.106
Gibbsite (C)	2.651	-5.727
Goethite	-1.821	-2.68
Goslarite	-7.451	-5.353
Greenockite	-51.429	-37.075
Greigite	-189.008	-143.973
Gypsum	-4.795	-0.178
Halite	-3.801	-5.329
Hematite	-3.639	-3.005
Hercynite	7.51	-17.292
Hg(OH)2(s)	-22.477	-18.981
Hg3O2CO3(s)	-87.269	-57.689
HgCl2(s)	-30.581	-8.663
HgSO4(s)	-29.195	-19.687
Hinsdalite	-30.663	-28.163
H-Jarosite	-18.916	-14.883
Huntite	-71.828	-42.515
Hydrocerrusite	-50.559	-31.799
Hydromagnesite	-70.026	-62.588
Hydroxyapatite	-75.174	-30.841
Hydroxylpyromorphite	-102.942	-40.152
Hydrozincite	-43.234	-53.372
K2Cr2O7(s)	-33.185	-15.452
K2CrO4(s)	-17.937	-17.312
K-Alum	-12.171	-6.817
KCl(s)	-5.397	-6.297
K-Jarosite	-20.255	-9.874
Langite	-19.346	-37.841
Larnakite	-13.962	-13.66

Mineral	log IAP	Sat. index
Laurionite	-7.675	-8.298
Lepidocrocite	-1.821	-3.192
Lime	1.933	-31.945
Litharge	-3.62	-16.708
Mackinawite	-44.694	-41.094
Maghemite	-3.639	-10.025
Magnesioferrite	-1.763	-20.318
Magnesite	-17.971	-10.39
Magnetite	-1.441	-6.112
Malachite	-26.156	-20.956
Massicot	-3.62	-16.917
Matlockite	-18.06	-8.885
Melanothallite	-11.259	-17.902
Melanterite	-4.547	-2.214
Metacinnabar	-69.366	-22.941
Mg(OH)2 (active)	1.873	-16.921
Mg2(OH)3Cl:4H2O(s)	-0.32	-26.32
Mg3(PO4)2(s)	-50.931	-27.651
MgCO3:5H2O(s)	-17.988	-13.448
MgCrO4(s)	-13.373	-19.294
MgF2(s)	-18.897	-10.836
MgHPO4:3H2O(s)	-26.416	-8.241
MgS(s)	-45.016	-62.696
Minium	7.689	-68.398
Mirabilite	-6.251	-4.654
Mn2(SO4)3(s)	-16.702	-11.985
Montroydite	-22.474	-18.757
Morenosite	-7.62	-5.401
Na2Cr2O7(s)	-29.994	-19.964
Na2CrO4(s)	-14.745	-17.795
NaF(s)	-10.135	-9.64
Na-Jarosite	-18.659	-14.164
Natron	-19.378	-17.666
Nesquehonite	-17.981	-13.459
Ni(OH)2 (am)	-0.878	-14.352
Ni(OH)2 (c)	-0.878	-11.668
Ni3(AsO4)2:8H2O(s)	-57.943	-32.443
Ni3(PO4)2(s)	-59.184	-27.884
Ni4(OH)6SO4(s)	-10.23	-42.23
NiCO3(s)	-20.722	-9.775
NiS (alpha)	-47.767	-42.247
NiS (beta)	-47.767	-36.747
NiS (gamma)	-47.767	-35.047
Nsutite	11.005	-6.499
Orpiment	-151.402	-103.503
Otavite	-24.385	-12.334

Mineral	log IAP	Sat. index
Pb azide (alpha)	-21.623	-12.649
Pb metal	-22.169	-26.41
Pb(OH)2(s)	-3.624	-12.129
Pb10(OH)6O(CO3)6(s)	-155.296	-146.536
Pb2(OH)3Cl(s)	-11.299	-20.092
Pb2O(OH)2(s)	-7.244	-33.434
Pb2O3(s)	11.309	-49.731
Pb2OCO3(s)	-27.088	-26.778
Pb3(AsO4)2(s)	-66.152	-30.652
Pb3(PO4)2(s)	-67.42	-23.89
Pb3O2CO3(s)	-30.708	-42.4
Pb3O2SO4(s)	-17.582	-28.749
Pb4(OH)6SO4(s)	-21.212	-42.312
Pb4O3SO4(s)	-21.202	-43.909
PbCrO4(s)	-18.869	-6
PbF2(s)	-24.394	-16.832
PbHPO4(s)	-31.902	-8.097
PbO:0.3H2O(s)	-3.621	-16.601
Periclase	1.876	-20.627
Phosgenite	-35.194	-15.384
Plattnerite	14.929	-36.472
Plumbgummite	-52.224	-19.434
Portlandite	1.93	-21.556
Pyrite	-73.037	-54.226
Realgar	-61.53	-40.8
Retgersite	-7.616	-5.548
Siderite	-17.65	-7.104
Smithsonite	-20.553	-9.676
Spharelite	-47.598	-36.595
Spinel	7.188	-32.018
Strengite	-30.106	-3.763
Struvite	-27.672	-14.412
Sulfur	-28.343	-26.297
Tenorite(am)	-3.153	-12.037
Tenorite(c)	-3.153	-11.187
Thenardite	-6.218	-6.595
Thermonatrite	-19.347	-20.048
Tsumebite	-38.688	-28.898
Vaterite	-17.914	-10.078
Vivianite	-49.994	-12.203
Wurtzite	-47.598	-38.849
Zincite	-0.706	-12.481
Zincosite	-7.427	-11.859
Zn metal	-19.255	-45.976
Zn(NO3)2:6H2O(s)	-102.553	-105.718
Zn(OH)2 (am)	-0.709	-13.704

Mineral	log IAP	Sat. index
Zn(OH)2 (beta)	-0.709	-12.969
Zn(OH)2 (delta)	-0.709	-12.553
Zn(OH)2 (epsilon)	-0.709	-12.721
Zn(OH)2 (gamma)	-0.709	-12.94
Zn2(OH)2SO4(s)	-8.136	-15.636
Zn2(OH)3Cl(s)	-5.47	-20.661
Zn3(PO4)2:4H2O(s)	-58.691	-23.271
Zn3AsO42:2.5H2O(s)	-57.417	-29.917
Zn3O(SO4)2(s)	-15.56	-36.042
Zn4(OH)6SO4(s)	-9.554	-37.954
Zn5(OH)8Cl2(s)	-11.649	-50.149
Zn-Al LDH(s)	-8.689	-28.519
ZnCl2(s)	-8.812	-16.303
ZnCO3(s)	-20.553	-9.753
ZnCO3:1H2O(s)	-20.557	-10.297
ZnF2(s)	-21.479	-21.308
ZnSO4:1H2O(s)	-7.43	-7.06

B3.5: Eh 500

Mineral	log IAP	Sat. index
Al(OH)3 (am)	1.242	-10.233
Al(OH)3 (Soil)	1.242	-7.686
Al2O3(s)	2.494	-18.73
Al4(OH)10SO4(s)	-0.814	-23.514
AlAsO4:2H2O(s)	-25.396	-9.596
AlOHF2(s)	-18.619	-19.026
AlOHSO4(s)	-4.54	-1.31
Alunite	-9.66	-9.537
Anglesite	-10.337	-2.474
Anhydrite	-4.799	-0.483
Antlerite	-18.081	-26.869
Aragonite	-18.862	-10.583
Arsenolite	-13.778	-12.215
Artinite	-18.006	-28.337
As2O5(s)	-53.273	-18.563
As2S3(am)	-182.064	-135.679
Atacamite	-11.834	-19.793
Azurite	-51.989	-34.836
Bianchite	-7.455	-5.694
Birnessite	10.845	-7.246
Bixbyite	0.606	0.494
Boehmite	1.245	-8.048
Brochantite	-22.181	-38.636
Brucite	0.925	-16.868

Mineral	log IAP	Sat. index
Ca3(AsO4)2:4H2O(s)	-50.327	-31.427
Ca3(PO4)2 (am1)	-52.621	-27.693
Ca3(PO4)2 (am2)	-52.621	-24.9
Ca3(PO4)2 (beta)	-52.621	-23.373
Ca4H(PO4)3:3H2O(s)	-79.437	-32.126
CaCO3xH2O(s)	-18.865	-11.778
CaCrO4(s)	-13.797	-11.695
CaHPO4(s)	-26.806	-7.342
CaHPO4:2H2O(s)	-26.812	-7.678
Calcite	-18.862	-10.432
CaS(s)	-55.109	-66.289
Cd metal (alpha)	-26.549	-40.521
Cd metal (gamma)	-26.549	-40.628
Cd(OH)2(s)	-5.468	-19.687
Cd3(OH)4SO4(s)	-22.187	-44.747
Cd3(PO4)2(s)	-71.975	-39.375
Cd3OH2(SO4)2(s)	-27.969	-34.679
Cd4(OH)6SO4(s)	-27.655	-56.055
CdCl2(s)	-12.739	-12.193
CdCl2:1H2O(s)	-12.742	-11.094
CdCl2:2.5H2O(s)	-12.747	-10.79
CdF2(s)	-25.33	-24.398
CdOHCl(s)	-9.103	-12.829
CdSO4(s)	-11.251	-11.394
CdSO4:1H2O(s)	-11.254	-9.72
CdSO4:2.67H2O(s)	-11.26	-9.496
Cerrusite	-24.4	-11.049
Chalcanthite	-9.899	-7.222
Chalcopyrite	-115.481	-79.309
Chloropyromorphite(c)	-109.764	-25.334
Chloropyromorphite(soil)	-109.764	-29.364
Cinnabar	-79.243	-32.42
Claudetite	-13.778	-12.265
Cotunnite	-11.825	-6.886
Covellite	-60.191	-37.382
Cr(VI)-Ettringite	-36.046	-99.447
Cr(VI)-Jarosite	-37.231	-18.715
CrO3(s)	-14.784	-11.605
Cryolite	-59.024	-24.953
Cu azide	-22.098	-14.257
Cu(OH)2(s)	-4.1	-13.713
Cu2(OH)3NO3(s)	-49.447	-59.14
Cu3(AsO4)2:2H2O(s)	-65.568	-30.468
Cu3(PO4)2(s)	-67.869	-31.019
Cu3(PO4)2:3H2O(s)	-67.88	-32.76
CuCO3(s)	-23.945	-12.445

Mineral	log IAP	Sat. index
CuCrO4(s)	-18.88	-13.44
CuF2(s)	-23.961	-25.483
CuF2:2H2O(s)	-23.968	-19.511
CuOCuSO4(s)	-13.978	-25.119
Cupric Ferrite	-7.985	-15.251
CuSO4(s)	-9.882	-13.266
Diaspore	1.245	-6.254
Dolomite (disordered)	-37.782	-21.524
Dolomite (ordered)	-37.782	-20.932
Epsomite	-4.881	-2.684
Ettringite	-9.052	-68.241
FCO3-Apatite	-172.602	-57.2
Fe(OH)2 (am)	0.802	-13.245
Fe(OH)2 (c)	0.802	-12.088
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-21.246	-18.983
Fe3(OH)8(s)	-3.097	-23.319
FeAsO4:2H2O(s)	-28.587	-8.387
Ferrihydrite	-1.949	-5.76
Ferrihydrite (aged)	-1.949	-5.25
FeS (ppt)	-55.29	-52.407
Fluorite	-18.878	-8.305
Galena	-60.646	-45.24
Gibbsite (C)	1.242	-7.136
Goethite	-1.946	-2.805
Goslarite	-7.458	-5.361
Greenockite	-61.56	-47.206
Greigite	-227.464	-182.429
Gypsum	-4.806	-0.19
Halite	-3.862	-5.39
Hematite	-3.889	-3.255
Hercynite	3.3	-21.502
Hg(OH)2(s)	-23.151	-19.655
Hg3O2CO3(s)	-89.293	-59.713
HgCl2(s)	-30.422	-8.504
HgSO4(s)	-28.934	-19.426
Hinsdalite	-34.396	-31.896
H-Jarosite	-17.42	-13.387
Huntite	-75.623	-46.31
Hydrocerrusite	-53.354	-34.594
Hydromagnesite	-74.769	-67.332
Hydroxyapatite	-78.441	-34.108
Hydroxylpyromorphite	-106.128	-43.338
Hydrozincite	-47.952	-58.09
K2Cr2O7(s)	-33.208	-15.475
K2CrO4(s)	-18.424	-17.8

Mineral	log IAP	Sat. index
K-Alum	-12.185	-6.832
KCl(s)	-5.457	-6.357
K-Jarosite	-19.235	-8.854
Langite	-22.184	-40.679
Larnakite	-14.888	-14.586
Laurionite	-8.19	-8.813
Lepidocrocite	-1.946	-3.317
Lime	0.986	-32.892
Litharge	-4.551	-17.639
Mackinawite	-55.29	-51.69
Maghemite	-3.889	-10.275
Magnesioferrite	-2.961	-21.516
Magnesite	-18.92	-11.339
Magnetite	-3.083	-7.754
Malachite	-28.044	-22.844
Massicot	-4.551	-17.848
Matlockite	-18.12	-8.945
Melanothallite	-11.37	-18.013
Melanterite	-5.004	-2.67
Metacinnabar	-79.243	-32.819
Mg(OH)2 (active)	0.925	-17.869
Mg2(OH)3Cl:4H2O(s)	-1.799	-27.799
Mg3(PO4)2(s)	-52.796	-29.516
MgCO3:5H2O(s)	-18.937	-14.397
MgCrO4(s)	-13.855	-19.776
MgF2(s)	-18.937	-10.875
MgHPO4:3H2O(s)	-26.874	-8.699
MgS(s)	-55.167	-72.847
Minium	7.43	-68.656
Mirabilite	-6.271	-4.674
Mn2(SO4)3(s)	-16.751	-12.034
Montroydite	-23.148	-19.431
Morenosite	-7.631	-5.412
Na2Cr2O7(s)	-30.018	-19.988
Na2CrO4(s)	-15.235	-18.284
NaF(s)	-10.158	-9.663
Na-Jarosite	-17.64	-13.146
Natron	-20.333	-18.622
Nesquehonite	-18.93	-14.408
Ni(OH)2 (am)	-1.825	-15.299
Ni(OH)2 (c)	-1.825	-12.615
Ni3(AsO4)2:8H2O(s)	-58.766	-33.266
Ni3(PO4)2(s)	-61.047	-29.747
Ni4(OH)6SO4(s)	-13.084	-45.084
NiCO3(s)	-21.67	-10.723
NiS (alpha)	-57.917	-52.397

Mineral	log IAP	Sat. index
NiS (beta)	-57.917	-46.897
NiS (gamma)	-57.917	-45.197
Nsutite	10.845	-6.659
Orpiment	-182.064	-134.164
Otavite	-25.313	-13.262
Pb azide (alpha)	-22.553	-13.579
Pb metal	-25.635	-29.876
Pb(OH)2(s)	-4.554	-13.06
Pb10(OH)6O(CO3)6(s)	-164.612	-155.852
Pb2(OH)3Cl(s)	-12.744	-21.537
Pb2O(OH)2(s)	-9.106	-35.296
Pb2O3(s)	11.982	-49.058
Pb2OCO3(s)	-28.951	-28.641
Pb3(AsO4)2(s)	-66.926	-31.426
Pb3(PO4)2(s)	-69.234	-25.704
Pb3O2CO3(s)	-33.502	-45.194
Pb3O2SO4(s)	-19.439	-30.607
Pb4(OH)6SO4(s)	-24	-45.1
Pb4O3SO4(s)	-23.99	-46.697
PbCrO4(s)	-19.335	-6.466
PbF2(s)	-24.416	-16.854
PbHPO4(s)	-32.343	-8.538
PbO:0.3H2O(s)	-4.552	-17.532
Periclase	0.928	-21.575
Phosgenite	-36.224	-16.414
Plattnerite	16.533	-34.869
Plumbgummite	-56.402	-23.612
Portlandite	0.983	-22.503
Pyrite	-90.301	-71.49
Realgar	-73.526	-52.796
Retgersite	-7.628	-5.56
Siderite	-19.043	-8.497
Smithsonite	-21.497	-10.621
Spharelite	-57.744	-46.742
Spinel	3.423	-35.784
Strengite	-29.742	-3.398
Struvite	-28.606	-15.346
Sulfur	-35.011	-32.966
Tenorite(am)	-4.096	-12.981
Tenorite(c)	-4.096	-12.131
Thenardite	-6.237	-6.614
Thermonatrite	-20.303	-21.004
Tsumebite	-41.004	-31.214
Vaterite	-18.862	-11.026
Vivianite	-53.192	-15.401
Wurtzite	-57.744	-48.996

Mineral	log IAP	Sat. index
Zincite	-1.649	-13.424
Zincosite	-7.435	-11.867
Zn metal	-22.733	-49.454
Zn(NO3)2:6H2O(s)	-84.169	-87.335
Zn(OH)2 (am)	-1.652	-14.647
Zn(OH)2 (beta)	-1.652	-13.912
Zn(OH)2 (delta)	-1.652	-13.496
Zn(OH)2 (epsilon)	-1.652	-13.664
Zn(OH)2 (gamma)	-1.652	-13.884
Zn2(OH)2SO4(s)	-9.087	-16.587
Zn2(OH)3Cl(s)	-6.94	-22.131
Zn3(PO4)2:4H2O(s)	-60.541	-25.121
Zn3AsO42:2.5H2O(s)	-58.228	-30.728
Zn3O(SO4)2(s)	-16.519	-37.001
Zn4(OH)6SO4(s)	-12.392	-40.792
Zn5(OH)8Cl2(s)	-15.533	-54.033
Zn-Al LDH(s)	-11.985	-31.815
ZnCl2(s)	-8.923	-16.414
ZnCO3(s)	-21.497	-10.697
ZnCO3:1H2O(s)	-21.501	-11.241
ZnF2(s)	-21.514	-21.342
ZnSO4:1H2O(s)	-7.438	-7.068

B3.6: Eh 600

Mineral	log IAP	Sat. index
Al(OH)3 (am)	0.848	-10.627
Al(OH)3 (Soil)	0.848	-8.08
Al2O3(s)	1.707	-19.518
Al4(OH)10SO4(s)	-2.129	-24.829
AlAsO4:2H2O(s)	-25.74	-9.94
AlOHF2(s)	-18.764	-19.171
AlOHSO4(s)	-4.673	-1.443
Alunite	-10.455	-10.331
Anglesite	-10.336	-2.473
Anhydrite	-4.804	-0.488
Antlerite	-18.618	-27.406
Aragonite	-19.128	-10.849
Arsenolite	-20.126	-18.563
Artinite	-18.539	-28.87
As2O5(s)	-53.173	-18.464
As2S3(am)	-226.314	-179.929
Atacamite	-12.269	-20.228
Azurite	-52.788	-35.634
Bianchite	-7.458	-5.698

Mineral	log IAP	Sat. index
Birnessite	12.055	-6.036
Bixbyite	-0.197	-0.31
Boehmite	0.852	-8.442
Brochantite	-22.983	-39.439
Brucite	0.658	-17.135
Ca3(AsO4)2:4H2O(s)	-51.025	-32.125
Ca3(PO4)2 (am1)	-53.137	-28.208
Ca3(PO4)2 (am2)	-53.137	-25.416
Ca3(PO4)2 (beta)	-53.137	-23.888
Ca4H(PO4)3:3H2O(s)	-80.077	-32.766
CaCO3xH2O(s)	-19.132	-12.045
CaCrO4(s)	-13.934	-11.832
CaHPO4(s)	-26.93	-7.467
CaHPO4:2H2O(s)	-26.937	-7.802
Calcite	-19.128	-10.698
CaS(s)	-68.009	-79.189
Cd metal (alpha)	-30.027	-44
Cd metal (gamma)	-30.027	-44.107
Cd(OH)2(s)	-5.723	-19.942
Cd3(OH)4SO4(s)	-22.69	-45.25
Cd3(PO4)2(s)	-72.457	-39.857
Cd3OH2(SO4)2(s)	-28.211	-34.921
Cd4(OH)6SO4(s)	-28.413	-56.813
CdCl2(s)	-12.799	-12.253
CdCl2:1H2O(s)	-12.802	-11.154
CdCl2:2.5H2O(s)	-12.807	-10.85
CdF2(s)	-25.335	-24.404
CdOHCl(s)	-9.261	-12.986
CdSO4(s)	-11.244	-11.388
CdSO4:1H2O(s)	-11.248	-9.713
CdSO4:2.67H2O(s)	-11.253	-9.49
Cerrusite	-24.66	-11.309
Chalcanthite	-9.904	-7.227
Chalcopyrite	-142.657	-106.484
Chloropyromorphite(c)	-110.54	-26.11
Chloropyromorphite(soil)	-110.54	-30.14
Cinnabar	-92.064	-45.241
Claudetite	-20.126	-18.613
Cotunnite	-11.89	-6.951
Covellite	-73.092	-50.282
Cr(VI)-Ettringite	-38.041	-101.442
Cr(VI)-Jarosite	-37.194	-18.678
CrO3(s)	-14.654	-11.475
Cryolite	-59.075	-25.004
Cu azide	-22.365	-14.524
Cu(OH)2(s)	-4.365	-13.978

Mineral	log IAP	Sat. index
Cu2(OH)3NO3(s)	-37.218	-46.91
Cu3(AsO4)2:2H2O(s)	-66.266	-31.166
Cu3(PO4)2(s)	-68.385	-31.535
Cu3(PO4)2:3H2O(s)	-68.395	-33.275
CuCO3(s)	-24.211	-12.711
CuCrO4(s)	-19.016	-13.576
CuF2(s)	-23.978	-25.499
CuF2:2H2O(s)	-23.984	-19.527
CuOCuSO4(s)	-14.249	-25.39
Cupric Ferrite	-8.309	-15.575
CuSO4(s)	-9.887	-13.271
Diaspore	0.852	-6.648
Dolomite (disordered)	-38.316	-22.058
Dolomite (ordered)	-38.316	-21.466
Epsomite	-4.887	-2.69
Ettringite	-10.653	-69.842
FCO3-Apatite	-174.18	-58.778
Fe(OH)2 (am)	-0.839	-14.886
Fe(OH)2 (c)	-0.839	-13.729
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-20.522	-18.259
Fe3(OH)8(s)	-4.796	-25.018
FeAsO4:2H2O(s)	-28.567	-8.367
Ferrihydrite	-1.979	-5.789
Ferrihydrite (aged)	-1.979	-5.279
FeS (ppt)	-69.565	-66.682
Fluorite	-18.895	-8.322
Galena	-73.54	-58.134
Gibbsite (C)	0.848	-7.53
Goethite	-1.975	-2.835
Goslarite	-7.462	-5.364
Greenockite	-74.449	-60.095
Greigite	-279.701	-234.666
Gypsum	-4.811	-0.195
Halite	-3.9	-5.428
Hematite	-3.947	-3.313
Hercynite	0.871	-23.931
Hg(OH)2(s)	-23.338	-19.842
Hg3O2CO3(s)	-89.853	-60.273
HgCl2(s)	-30.414	-8.496
HgSO4(s)	-28.859	-19.351
Hinsdalite	-35.435	-32.935
H-Jarosite	-16.986	-12.953
Huntite	-76.69	-47.377
Hydrocerrusite	-54.133	-35.373
Hydromagnesite	-76.103	-68.666

Mineral	log IAP	Sat. index
Hydroxyapatite	-79.346	-35.013
Hydroxylpyromorphite	-107.003	-44.213
Hydrozincite	-49.274	-59.412
K2Cr2O7(s)	-33.217	-15.484
K2CrO4(s)	-18.563	-17.939
K-Alum	-12.192	-6.838
KCl(s)	-5.494	-6.394
K-Jarosite	-18.935	-8.554
Langite	-22.987	-41.482
Larnakite	-15.146	-14.845
Laurionite	-8.352	-8.975
Lepidocrocite	-1.975	-3.346
Lime	0.721	-33.158
Litharge	-4.811	-17.899
Mackinawite	-69.565	-65.965
Maghemite	-3.947	-10.333
Magnesioferrite	-3.285	-21.841
Magnesite	-19.187	-11.605
Magnetite	-4.783	-9.453
Malachite	-28.577	-23.376
Massicot	-4.811	-18.107
Matlockite	-18.158	-8.983
Melanothallite	-11.441	-18.084
Melanterite	-6.384	-4.051
Metacinnabar	-92.064	-45.64
Mg(OH)2 (active)	0.658	-18.136
Mg2(OH)3Cl:4H2O(s)	-2.234	-28.234
Mg3(PO4)2(s)	-53.313	-30.033
MgCO3:5H2O(s)	-19.204	-14.664
MgCrO4(s)	-13.992	-19.913
MgF2(s)	-18.954	-10.892
MgHPO4:3H2O(s)	-26.999	-8.824
MgS(s)	-68.068	-85.748
Minium	9.875	-66.211
Mirabilite	-6.28	-4.683
Mn2(SO4)3(s)	-16.772	-12.055
Montroydite	-23.335	-19.618
Morenosite	-7.637	-5.418
Na2Cr2O7(s)	-30.029	-19.999
Na2CrO4(s)	-15.375	-18.425
NaF(s)	-10.168	-9.673
Na-Jarosite	-17.341	-12.846
Natron	-20.604	-18.892
Nesquehonite	-19.197	-14.675
Ni(OH)2 (am)	-2.091	-15.565
Ni(OH)2 (c)	-2.091	-12.881

Mineral	log IAP	Sat. index
Ni3(AsO4)2:8H2O(s)	-59.464	-33.964
Ni3(PO4)2(s)	-61.562	-30.262
Ni4(OH)6SO4(s)	-13.887	-45.887
NiCO3(s)	-21.937	-10.99
NiS (alpha)	-70.817	-65.297
NiS (beta)	-70.817	-59.797
NiS (gamma)	-70.817	-58.097
Nsutite	12.055	-5.449
Orpiment	-226.314	-178.415
Otavite	-25.568	-13.517
Pb azide (alpha)	-22.814	-13.839
Pb metal	-29.118	-33.359
Pb(OH)2(s)	-4.814	-13.32
Pb10(OH)6O(CO3)6(s)	-167.211	-158.451
Pb2(OH)3Cl(s)	-13.166	-21.959
Pb2O(OH)2(s)	-9.625	-35.815
Pb2O3(s)	14.686	-46.354
Pb2OCO3(s)	-29.47	-29.161
Pb3(AsO4)2(s)	-67.605	-32.105
Pb3(PO4)2(s)	-69.73	-26.2
Pb3O2CO3(s)	-34.281	-45.973
Pb3O2SO4(s)	-19.957	-31.125
Pb4(OH)6SO4(s)	-24.778	-45.878
Pb4O3SO4(s)	-24.768	-47.474
PbCrO4(s)	-19.465	-6.596
PbF2(s)	-24.426	-16.865
PbHPO4(s)	-32.462	-8.657
PbO:0.3H2O(s)	-4.812	-17.792
Periclase	0.662	-21.842
Phosgenite	-36.55	-16.74
Plattnerite	19.497	-31.905
Plumbgummite	-57.561	-24.771
Portlandite	0.717	-22.769
Pyrite	-113.987	-95.176
Realgar	-90.946	-70.216
Retgersite	-7.633	-5.565
Siderite	-20.685	-10.139
Smithsonite	-21.762	-10.885
Spharelite	-70.643	-59.64
Spinel	2.368	-36.838
Strengite	-29.629	-3.286
Struvite	-28.865	-15.605
Sulfur	-44.422	-42.376
Tenorite(am)	-4.362	-13.246
Tenorite(c)	-4.362	-12.397
Thenardite	-6.246	-6.623

Mineral	log IAP	Sat. index
Thermonatrite	-20.573	-21.274
Tsumebite	-41.648	-31.858
Vaterite	-19.128	-11.292
Vivianite	-57.832	-20.042
Wurtzite	-70.643	-61.894
Zincite	-1.913	-13.688
Zincosite	-7.438	-11.87
Zn metal	-26.221	-52.942
Zn(NO3)2:6H2O(s)	-58.911	-62.077
Zn(OH)2 (am)	-1.917	-14.911
Zn(OH)2 (beta)	-1.917	-14.176
Zn(OH)2 (delta)	-1.917	-13.761
Zn(OH)2 (epsilon)	-1.917	-13.929
Zn(OH)2 (gamma)	-1.917	-14.148
Zn2(OH)2SO4(s)	-9.355	-16.855
Zn2(OH)3Cl(s)	-7.371	-22.562
Zn3(PO4)2:4H2O(s)	-61.051	-25.631
Zn3AsO42:2.5H2O(s)	-58.921	-31.421
Zn3O(SO4)2(s)	-16.789	-37.272
Zn4(OH)6SO4(s)	-13.188	-41.588
Zn5(OH)8Cl2(s)	-16.659	-55.159
Zn-Al LDH(s)	-12.908	-32.738
ZnCl2(s)	-8.992	-16.483
ZnCO3(s)	-21.762	-10.962
ZnCO3:1H2O(s)	-21.766	-11.506
ZnF2(s)	-21.529	-21.357
ZnSO4:1H2O(s)	-7.442	-7.071

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Mineral	log IAP	Sat. index
Al(OH)3 (am)	0.834	-10.641
Al(OH)3 (Soil)	0.834	-8.095
Al2O3(s)	1.677	-19.547
Al4(OH)10SO4(s)	-2.177	-24.877
AlAsO4:2H2O(s)	-25.753	-9.953
AlOHF2(s)	-18.769	-19.176
AlOHSO4(s)	-4.678	-1.448
Alunite	-10.484	-10.361
Anglesite	-10.336	-2.473
Anhydrite	-4.805	-0.488
Antlerite	-18.638	-27.426
Aragonite	-19.138	-10.859
Arsenolite	-27.099	-25.536
Artinite	-18.559	-28.89
As2O5(s)	-53.17	-18.461
As2S3(am)	-275.115	-228.73
Atacamite	-12.285	-20.244
Azurite	-52.817	-35.664
Bianchite	-7.459	-5.698
Birnessite	13.784	-4.307
Bixbyite	-0.227	-0.34
Boehmite	0.837	-8.457
Brochantite	-23.013	-39.469
Brucite	0.649	-17.145
Ca3(AsO4)2:4H2O(s)	-51.052	-32.152
Ca3(PO4)2 (am1)	-53.156	-28.227
Ca3(PO4)2 (am2)	-53.156	-25.435
Ca3(PO4)2 (beta)	-53.156	-23.907
Ca4H(PO4)3:3H2O(s)	-80.101	-32.789
CaCO3xH2O(s)	-19.142	-12.055
CaCrO4(s)	-13.939	-11.837
CaHPO4(s)	-26.935	-7.471
CaHPO4:2H2O(s)	-26.942	-7.807
Calcite	-19.138	-10.708
CaS(s)	-81.961	-93.141
Cd metal (alpha)	-33.524	-47.497
Cd metal (gamma)	-33.524	-47.604
Cd(OH)2(s)	-5.732	-19.951
Cd3(OH)4SO4(s)	-22.708	-45.268
Cd3(PO4)2(s)	-72.474	-39.874
Cd3OH2(SO4)2(s)	-28.22	-34.93
Cd4(OH)6SO4(s)	-28.441	-56.841
CdCl2(s)	-12.801	-12.256
CdCl2:1H2O(s)	-12.805	-11.157

Mineral	log IAP	Sat. index
CdCl2:2.5H2O(s)	-12.81	-10.853
CdF2(s)	-25.335	-24.404
CdOHCl(s)	-9.267	-12.992
CdSO4(s)	-11.244	-11.388
CdSO4:1H2O(s)	-11.247	-9.713
CdSO4:2.67H2O(s)	-11.253	-9.489
Cerrusite	-24.669	-11.319
Chalcanthite	-9.904	-7.228
Chalcopyrite	-172.296	-136.124
Chloropyromorphite(c)	-110.569	-26.139
Chloropyromorphite(soil)	-110.569	-30.169
Cinnabar	-106.013	-59.19
Claudetite	-27.099	-25.586
Cotunnite	-11.893	-6.954
Covellite	-87.044	-64.234
Cr(VI)-Ettringite	-38.115	-101.516
Cr(VI)-Jarosite	-37.192	-18.676
CrO3(s)	-14.649	-11.471
Cryolite	-59.077	-25.006
Cu azide	-22.375	-14.534
Cu(OH)2(s)	-4.375	-13.988
Cu2(OH)3NO3(s)	-23.291	-32.983
Cu3(AsO4)2:2H2O(s)	-66.293	-31.193
Cu3(PO4)2(s)	-68.403	-31.553
Cu3(PO4)2:3H2O(s)	-68.414	-33.294
CuCO3(s)	-24.221	-12.721
CuCrO4(s)	-19.021	-13.581
CuF2(s)	-23.978	-25.5
CuF2:2H2O(s)	-23.985	-19.528
CuOCuSO4(s)	-14.259	-25.4
Cupric Ferrite	-8.321	-15.587
CuSO4(s)	-9.887	-13.271
Diaspore	0.837	-6.663
Dolomite (disordered)	-38.335	-22.077
Dolomite (ordered)	-38.335	-21.485
Epsomite	-4.887	-2.69
Ettringite	-10.713	-69.901
FCO3-Apatite	-174.238	-58.836
Fe(OH)2 (am)	-2.584	-16.631
Fe(OH)2 (c)	-2.584	-15.474
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-20.495	-18.232
Fe3(OH)8(s)	-6.543	-26.765
FeAsO4:2H2O(s)	-28.567	-8.367
Ferrihydrite	-1.98	-5.79
Ferrihydrite (aged)	-1.98	-5.28

Mineral	log IAP	Sat. index
FeS (ppt)	-85.253	-82.369
Fluorite	-18.896	-8.323
Galena	-87.492	-72.086
Gibbsite (C)	0.834	-7.545
Goethite	-1.976	-2.836
Goslarite	-7.462	-5.364
Greenockite	-88.401	-74.046
Greigite	-337.217	-292.182
Gypsum	-4.811	-0.195
Halite	-3.902	-5.429
Hematite	-3.949	-3.315
Hercynite	-0.903	-25.705
Hg(OH)2(s)	-23.344	-19.848
Hg3O2CO3(s)	-89.871	-60.291
HgCl2(s)	-30.413	-8.496
HgSO4(s)	-28.856	-19.348
Hinsdalite	-35.473	-32.973
H-Jarosite	-16.969	-12.937
Huntite	-76.729	-47.417
Hydrocerrusite	-54.162	-35.402
Hydromagnesite	-76.153	-68.715
Hydroxyapatite	-79.38	-35.047
Hydroxylpyromorphite	-107.035	-44.245
Hydrozincite	-49.323	-59.461
K2Cr2O7(s)	-33.218	-15.484
K2CrO4(s)	-18.568	-17.944
K-Alum	-12.192	-6.838
KCl(s)	-5.496	-6.396
K-Jarosite	-18.924	-8.543
Langite	-23.017	-41.512
Larnakite	-15.156	-14.854
Laurionite	-8.358	-8.981
Lepidocrocite	-1.976	-3.347
Lime	0.711	-33.168
Litharge	-4.82	-17.909
Mackinawite	-85.253	-81.653
Maghemite	-3.949	-10.335
Magnesioferrite	-3.297	-21.853
Magnesite	-19.197	-11.615
Magnetite	-6.53	-11.2
Malachite	-28.596	-23.396
Massicot	-4.82	-18.117
Matlockite	-18.16	-8.985
Melanothallite	-11.445	-18.087
Melanterite	-8.12	-5.786
Metacinnabar	-106.013	-59.588

Mineral	log IAP	Sat. index
Mg(OH)2 (active)	0.649	-18.145
Mg2(OH)3Cl:4H2O(s)	-2.251	-28.251
Mg3(PO4)2(s)	-53.332	-30.052
MgCO3:5H2O(s)	-19.214	-14.674
MgCrO4(s)	-13.997	-19.918
MgF2(s)	-18.954	-10.893
MgHPO4:3H2O(s)	-27.004	-8.829
MgS(s)	-82.02	-99.7
Minium	13.335	-62.752
Mirabilite	-6.28	-4.683
Mn2(SO4)3(s)	-16.773	-12.056
Montroydite	-23.341	-19.624
Morenosite	-7.637	-5.418
Na2Cr2O7(s)	-30.03	-19.999
Na2CrO4(s)	-15.38	-18.43
NaF(s)	-10.169	-9.674
Na-Jarosite	-17.33	-12.835
Natron	-20.614	-18.902
Nesquehonite	-19.207	-14.684
Ni(OH)2 (am)	-2.101	-15.575
Ni(OH)2 (c)	-2.101	-12.891
Ni3(AsO4)2:8H2O(s)	-59.491	-33.991
Ni3(PO4)2(s)	-61.581	-30.281
Ni4(OH)6SO4(s)	-13.917	-45.917
NiCO3(s)	-21.947	-11
NiS (alpha)	-84.77	-79.25
NiS (beta)	-84.77	-73.75
NiS (gamma)	-84.77	-72.05
Nsutite	13.784	-3.72
Orpiment	-275.115	-227.215
Otavite	-25.578	-13.526
Pb azide (alpha)	-22.823	-13.849
Pb metal	-32.616	-36.856
Pb(OH)2(s)	-4.824	-13.33
Pb10(OH)6O(CO3)6(s)	-167.307	-158.547
Pb2(OH)3Cl(s)	-13.182	-21.975
Pb2O(OH)2(s)	-9.644	-35.834
Pb2O3(s)	18.155	-42.885
Pb2OCO3(s)	-29.49	-29.18
Pb3(AsO4)2(s)	-67.631	-32.131
Pb3(PO4)2(s)	-69.749	-26.219
Pb3O2CO3(s)	-34.31	-46.002
Pb3O2SO4(s)	-19.976	-31.144
Pb4(OH)6SO4(s)	-24.807	-45.907
Pb4O3SO4(s)	-24.796	-47.503
PbCrO4(s)	-19.47	-6.601

Mineral	log IAP	Sat. index
PbF2(s)	-24.427	-16.865
PbHPO4(s)	-32.466	-8.661
PbO:0.3H2O(s)	-4.821	-17.801
Periclase	0.652	-21.852
Phosgenite	-36.562	-16.752
Plattnerite	22.975	-28.426
Plumbgummite	-57.604	-24.814
Portlandite	0.707	-22.779
Pyrite	-140.129	-121.318
Realgar	-110.119	-89.389
Retgersite	-7.633	-5.565
Siderite	-22.43	-11.884
Smithsonite	-21.772	-10.895
Spharelite	-84.595	-73.592
Spinel	2.329	-36.877
Strengite	-29.625	-3.282
Struvite	-28.874	-15.614
Sulfur	-54.876	-52.83
Tenorite(am)	-4.372	-13.256
Tenorite(c)	-4.372	-12.407
Thenardite	-6.246	-6.623
Thermonatrite	-20.583	-21.284
Tsumebite	-41.672	-31.882
Vaterite	-19.138	-11.302
Vivianite	-63.057	-25.266
Wurtzite	-84.595	-75.846
Zincite	-1.923	-13.698
Zincosite	-7.438	-11.87
Zn metal	-29.719	-56.44
Zn(NO3)2:6H2O(s)	-31.026	-34.192
Zn(OH)2 (am)	-1.926	-14.921
Zn(OH)2 (beta)	-1.926	-14.186
Zn(OH)2 (delta)	-1.926	-13.77
Zn(OH)2 (epsilon)	-1.926	-13.938
Zn(OH)2 (gamma)	-1.926	-14.158
Zn2(OH)2SO4(s)	-9.365	-16.865
Zn2(OH)3Cl(s)	-7.387	-22.578
Zn3(PO4)2:4H2O(s)	-61.07	-25.65
Zn3AsO42:2.5H2O(s)	-58.948	-31.448
Zn3O(SO4)2(s)	-16.8	-37.282
Zn4(OH)6SO4(s)	-13.217	-41.617
Zn5(OH)8Cl2(s)	-16.701	-55.201
Zn-Al LDH(s)	-12.942	-32.772
ZnCl2(s)	-8.996	-16.486
ZnCO3(s)	-21.772	-10.972
ZnCO3:1H2O(s)	-21.775	-11.515

Mineral	log IAP	Sat. index
ZnF2(s)	-21.529	-21.358
ZnSO4:1H2O(s)	-7.442	-7.072

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Mineral	log IAP	Sat. index
Al(OH)3 (am)	0.812	-10.663
Al(OH)3 (Soil)	0.812	-8.117
Al2O3(s)	1.634	-19.591
Al4(OH)10SO4(s)	-2.251	-24.951
AlAsO4:2H2O(s)	-25.773	-9.973
AlOHF2(s)	-18.781	-19.188
AlOHSO4(s)	-4.686	-1.456
Alunite	-10.53	-10.407
Anglesite	-10.337	-2.474
Anhydrite	-4.807	-0.49
Antlerite	-18.672	-27.46
Aragonite	-19.154	-10.875
Arsenolite	-34.058	-32.496
Artinite	-18.59	-28.921
As2O5(s)	-53.166	-18.457
As2S3(am)	-323.813	-277.429
Atacamite	-12.309	-20.268
Azurite	-52.865	-35.711
Bianchite	-7.46	-5.699
Birnessite	15.5	-2.591
Bixbyite	-0.277	-0.389
Boehmite	0.815	-8.478
Brochantite	-23.063	-39.518
Brucite	0.633	-17.16
Ca3(AsO4)2:4H2O(s)	-51.095	-32.195
Ca3(PO4)2 (am1)	-53.197	-28.269
Ca3(PO4)2 (am2)	-53.197	-25.476
Ca3(PO4)2 (beta)	-53.197	-23.949
Ca4H(PO4)3:3H2O(s)	-80.155	-32.844
CaCO3xH2O(s)	-19.157	-12.07
CaCrO4(s)	-13.947	-11.845
CaHPO4(s)	-26.948	-7.484
CaHPO4:2H2O(s)	-26.955	-7.82
Calcite	-19.154	-10.724
CaS(s)	-95.89	-107.07
Cd metal (alpha)	-37.022	-50.995
Cd metal (gamma)	-37.022	-51.101
Cd(OH)2(s)	-5.748	-19.967
Cd3(OH)4SO4(s)	-22.742	-45.302

Mineral	log IAP	Sat. index
Cd3(PO4)2(s)	-72.516	-39.916
Cd3OH2(SO4)2(s)	-28.24	-34.95
Cd4(OH)6SO4(s)	-28.49	-56.89
CdCl2(s)	-12.801	-12.255
CdCl2:1H2O(s)	-12.804	-11.156
CdCl2:2.5H2O(s)	-12.809	-10.852
CdF2(s)	-25.341	-24.409
CdOHCl(s)	-9.274	-13
CdSO4(s)	-11.246	-11.39
CdSO4:1H2O(s)	-11.249	-9.715
CdSO4:2.67H2O(s)	-11.255	-9.492
Cerrusite	-24.685	-11.334
Chalcanthite	-9.906	-7.23
Chalcopyrite	-201.882	-165.709
Chloropyromorphite(c)	-110.629	-26.199
Chloropyromorphite(soil)	-110.629	-30.229
Cinnabar	-119.942	-73.119
Claudetite	-34.058	-32.546
Cotunnite	-11.892	-6.953
Covellite	-100.973	-78.163
Cr(VI)-Ettringite	-38.23	-101.631
Cr(VI)-Jarosite	-37.192	-18.676
CrO3(s)	-14.642	-11.463
Cryolite	-59.093	-25.022
Cu azide	-22.391	-14.549
Cu(OH)2(s)	-4.391	-14.004
Cu2(OH)3NO3(s)	-14.145	-23.838
Cu3(AsO4)2:2H2O(s)	-66.336	-31.236
Cu3(PO4)2(s)	-68.446	-31.596
Cu3(PO4)2:3H2O(s)	-68.456	-33.336
CuCO3(s)	-24.237	-12.737
CuCrO4(s)	-19.029	-13.589
CuF2(s)	-23.984	-25.506
CuF2:2H2O(s)	-23.991	-19.534
CuOCuSO4(s)	-14.277	-25.418
Cupric Ferrite	-8.342	-15.608
CuSO4(s)	-9.889	-13.273
Diaspore	0.815	-6.684
Dolomite (disordered)	-38.367	-22.109
Dolomite (ordered)	-38.367	-21.517
Epsomite	-4.889	-2.692
Ettringite	-10.809	-69.998
FCO3-Apatite	-174.364	-58.962
Fe(OH)2 (am)	-4.327	-18.374
Fe(OH)2 (c)	-4.327	-17.217
Fe(OH)2.7Cl.3(s)	-3.04	0

Mineral	log IAP	Sat. index
Fe2(SO4)3(s)	-20.459	-18.196
Fe3(OH)8(s)	-8.292	-28.514
FeAsO4:2H2O(s)	-28.567	-8.367
Ferrihydrite	-1.982	-5.792
Ferrihydrite (aged)	-1.982	-5.282
FeS (ppt)	-100.909	-98.026
Fluorite	-18.901	-8.328
Galena	-101.421	-86.014
Gibbsite (C)	0.812	-7.567
Goethite	-1.979	-2.838
Goslarite	-7.464	-5.366
Greenockite	-102.33	-87.975
Greigite	-394.618	-349.583
Gypsum	-4.813	-0.197
Halite	-3.902	-5.429
Hematite	-3.954	-3.32
Hercynite	-2.69	-27.492
Hg(OH)2(s)	-23.36	-19.864
Hg3O2CO3(s)	-89.92	-60.34
HgCl2(s)	-30.413	-8.496
HgSO4(s)	-28.859	-19.35
Hinsdalite	-35.538	-33.038
H-Jarosite	-16.949	-12.917
Huntite	-76.792	-47.479
Hydrocerrusite	-54.208	-35.448
Hydromagnesite	-76.231	-68.793
Hydroxyapatite	-79.45	-35.117
Hydroxylpyromorphite	-107.103	-44.313
Hydrozincite	-49.401	-59.538
K2Cr2O7(s)	-33.219	-15.485
K2CrO4(s)	-18.577	-17.953
K-Alum	-12.195	-6.841
KCl(s)	-5.496	-6.396
K-Jarosite	-18.912	-8.531
Langite	-23.066	-41.561
Larnakite	-15.173	-14.871
Laurionite	-8.365	-8.988
Lepidocrocite	-1.979	-3.35
Lime	0.695	-33.183
Litharge	-4.836	-17.924
Mackinawite	-100.909	-97.309
Maghemite	-3.954	-10.34
Magnesioferrite	-3.318	-21.873
Magnesite	-19.213	-11.631
Magnetite	-8.278	-12.949
Malachite	-28.628	-23.428

Mineral	log IAP	Sat. index
Massicot	-4.836	-18.132
Matlockite	-18.162	-8.987
Melanothallite	-11.444	-18.087
Melanterite	-9.849	-7.516
Metacinnabar	-119.942	-73.518
Mg(OH)2 (active)	0.633	-18.161
Mg2(OH)3Cl:4H2O(s)	-2.274	-28.274
Mg3(PO4)2(s)	-53.373	-30.093
MgCO3:5H2O(s)	-19.23	-14.69
MgCrO4(s)	-14.005	-19.926
MgF2(s)	-18.96	-10.899
MgHPO4:3H2O(s)	-27.017	-8.842
MgS(s)	-95.949	-113.629
Minium	16.77	-59.316
Mirabilite	-6.283	-4.686
Mn2(SO4)3(s)	-16.782	-12.064
Montroydite	-23.357	-19.64
Morenosite	-7.639	-5.42
Na2Cr2O7(s)	-30.031	-20
Na2CrO4(s)	-15.389	-18.439
NaF(s)	-10.172	-9.677
Na-Jarosite	-17.318	-12.823
Natron	-20.63	-18.919
Nesquehonite	-19.223	-14.7
Ni(OH)2 (am)	-2.117	-15.59
Ni(OH)2 (c)	-2.117	-12.907
Ni3(AsO4)2:8H2O(s)	-59.534	-34.034
Ni3(PO4)2(s)	-61.623	-30.323
Ni4(OH)6SO4(s)	-13.966	-45.966
NiCO3(s)	-21.963	-11.015
NiS (alpha)	-98.699	-93.179
NiS (beta)	-98.699	-87.679
NiS (gamma)	-98.699	-85.979
Nsutite	15.5	-2.004
Orpiment	-323.813	-275.914
Otavite	-25.593	-13.542
Pb azide (alpha)	-22.838	-13.864
Pb metal	-36.113	-40.354
Pb(OH)2(s)	-4.839	-13.345
Pb10(OH)6O(CO3)6(s)	-167.46	-158.7
Pb2(OH)3Cl(s)	-13.204	-21.997
Pb2O(OH)2(s)	-9.675	-35.865
Pb2O3(s)	21.606	-39.434
Pb2OCO3(s)	-29.52	-29.211
Pb3(AsO4)2(s)	-67.673	-32.173
Pb3(PO4)2(s)	-69.789	-26.259

Mineral	log IAP	Sat. index
Pb3O2CO3(s)	-34.356	-46.048
Pb3O2SO4(s)	-20.008	-31.176
Pb4(OH)6SO4(s)	-24.854	-45.954
Pb4O3SO4(s)	-24.844	-47.551
PbCrO4(s)	-19.477	-6.609
PbF2(s)	-24.432	-16.87
PbHPO4(s)	-32.478	-8.673
PbO:0.3H2O(s)	-4.837	-17.817
Periclase	0.636	-21.867
Phosgenite	-36.576	-16.766
Plattnerite	26.442	-24.96
Plumbgummite	-57.679	-24.889
Portlandite	0.692	-22.794
Pyrite	-166.217	-147.405
Realgar	-129.253	-108.523
Retgersite	-7.636	-5.568
Siderite	-24.173	-13.627
Smithsonite	-21.787	-10.911
Spharelite	-98.524	-87.521
Spinel	2.27	-36.936
Strengite	-29.625	-3.282
Struvite	-33.637	-20.377
Sulfur	-65.308	-63.262
Tenorite(am)	-4.388	-13.272
Tenorite(c)	-4.388	-12.422
Thenardite	-6.249	-6.626
Thermonatrite	-20.6	-21.3
Tsumebite	-41.715	-31.925
Vaterite	-19.154	-11.318
Vivianite	-68.281	-30.49
Wurtzite	-98.524	-89.775
Zincite	-1.939	-13.713
Zincosite	-7.44	-11.872
Zn metal	-33.216	-59.937
Zn(NO3)2:6H2O(s)	-12.688	-15.854
Zn(OH)2 (am)	-1.942	-14.936
Zn(OH)2 (beta)	-1.942	-14.201
Zn(OH)2 (delta)	-1.942	-13.786
Zn(OH)2 (epsilon)	-1.942	-13.954
Zn(OH)2 (gamma)	-1.942	-14.173
Zn2(OH)2SO4(s)	-9.382	-16.882
Zn2(OH)3Cl(s)	-7.41	-22.601
Zn3(PO4)2:4H2O(s)	-61.111	-25.691
Zn3AsO42:2.5H2O(s)	-58.99	-31.49
Zn3O(SO4)2(s)	-16.819	-37.301
Zn4(OH)6SO4(s)	-13.266	-41.666

Mineral	log IAP	Sat. index
Zn5(OH)8Cl2(s)	-16.762	-55.262
Zn-Al LDH(s)	-12.995	-32.825
ZnCl2(s)	-8.995	-16.486
ZnCO3(s)	-21.787	-10.987
ZnCO3:1H2O(s)	-21.791	-11.531
ZnF2(s)	-21.535	-21.363
ZnSO4:1H2O(s)	-7.443	-7.073

B3.9: Eh 900

Mineral	log IAP	Sat. index
Al(OH)3 (am)	0.807	-10.668
Al(OH)3 (Soil)	0.807	-8.121
Al2O3(s)	1.624	-19.6
Al4(OH)10SO4(s)	-2.267	-24.967
AlAsO4:2H2O(s)	-25.777	-9.977
AlOHF2(s)	-18.784	-19.191
AlOHSO4(s)	-4.688	-1.458
Alunite	-10.54	-10.417
Anglesite	-10.338	-2.475
Anhydrite	-4.807	-0.491
Antlerite	-18.679	-27.467
Aragonite	-19.158	-10.879
Arsenolite	-41.047	-39.484
Artinite	-18.597	-28.928
As2O5(s)	-53.165	-18.456
As2S3(am)	-372.727	-326.343
Atacamite	-12.314	-20.273
Azurite	-52.875	-35.722
Bianchite	-7.461	-5.7
Birnessite	17.242	-0.849
Bixbyite	-0.289	-0.401
Boehmite	0.811	-8.483
Brochantite	-23.074	-39.529
Brucite	0.629	-17.164
Ca3(AsO4)2:4H2O(s)	-51.105	-32.205
Ca3(PO4)2 (am1)	-53.207	-28.278
Ca3(PO4)2 (am2)	-53.207	-25.486
Ca3(PO4)2 (beta)	-53.207	-23.958
Ca4H(PO4)3:3H2O(s)	-80.168	-32.856
CaCO3xH2O(s)	-19.161	-12.074
CaCrO4(s)	-13.949	-11.847
CaHPO4(s)	-26.951	-7.487
CaHPO4:2H2O(s)	-26.958	-7.823
Calcite	-19.158	-10.727
CaS(s)	-109.869	-121.049

Mineral	log IAP	Sat. index
Cd metal (alpha)	-40.52	-54.493
Cd metal (gamma)	-40.52	-54.599
Cd(OH)2(s)	-5.751	-19.971
Cd3(OH)4SO4(s)	-22.75	-45.31
Cd3(PO4)2(s)	-72.525	-39.925
Cd3OH2(SO4)2(s)	-28.245	-34.955
Cd4(OH)6SO4(s)	-28.501	-56.901
CdCl2(s)	-12.801	-12.255
CdCl2:1H2O(s)	-12.804	-11.156
CdCl2:2.5H2O(s)	-12.809	-10.852
CdF2(s)	-25.343	-24.411
CdOHCl(s)	-9.276	-13.001
CdSO4(s)	-11.247	-11.391
CdSO4:1H2O(s)	-11.25	-9.716
CdSO4:2.67H2O(s)	-11.256	-9.492
Cerrusite	-24.688	-11.337
Chalcanthite	-9.907	-7.23
Chalcopyrite	-231.584	-195.411
Chloropyromorphite(c)	-110.643	-26.213
Chloropyromorphite(soil)	-110.643	-30.243
Cinnabar	-133.921	-87.098
Claudetite	-41.047	-39.534
Cotunnite	-11.892	-6.953
Covellite	-114.952	-92.142
Cr(VI)-Ettringite	-38.255	-101.656
Cr(VI)-Jarosite	-37.192	-18.676
CrO3(s)	-14.64	-11.461
Cryolite	-59.098	-25.027
Cu azide	-22.394	-14.553
Cu(OH)2(s)	-4.395	-14.008
Cu2(OH)3NO3(s)	-13.941	-23.634
Cu3(AsO4)2:2H2O(s)	-66.346	-31.246
Cu3(PO4)2(s)	-68.455	-31.605
Cu3(PO4)2:3H2O(s)	-68.465	-33.345
CuCO3(s)	-24.24	-12.74
CuCrO4(s)	-19.031	-13.591
CuF2(s)	-23.986	-25.508
CuF2:2H2O(s)	-23.993	-19.535
CuOCuSO4(s)	-14.281	-25.422
Cupric Ferrite	-8.346	-15.613
CuSO4(s)	-9.89	-13.274
Diaspore	0.811	-6.689
Dolomite (disordered)	-38.374	-22.116
Dolomite (ordered)	-38.374	-21.524
Epsomite	-4.89	-2.693
Ettringite	-10.831	-70.02

Mineral	log IAP	Sat. index
FCO3-Apatite	-174.393	-58.991
Fe(OH)2 (am)	-6.075	-20.122
Fe(OH)2 (c)	-6.075	-18.965
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-20.451	-18.188
Fe3(OH)8(s)	-10.04	-30.262
FeAsO4:2H2O(s)	-28.567	-8.367
Ferrihydrite	-1.983	-5.793
Ferrihydrite (aged)	-1.983	-5.283
FeS (ppt)	-116.632	-113.749
Fluorite	-18.903	-8.33
Galena	-115.399	-99.993
Gibbsite (C)	0.807	-7.571
Goethite	-1.979	-2.839
Goslarite	-7.464	-5.367
Greenockite	-116.308	-101.954
Greigite	-452.268	-407.233
Gypsum	-4.814	-0.198
Halite	-3.902	-5.429
Hematite	-3.955	-3.321
Hercynite	-4.447	-29.249
Hg(OH)2(s)	-23.364	-19.868
Hg3O2CO3(s)	-89.931	-60.351
HgCl2(s)	-30.413	-8.496
HgSO4(s)	-28.859	-19.351
Hinsdalite	-35.552	-33.052
H-Jarosite	-16.945	-12.912
Huntite	-76.806	-47.493
Hydrocerrusite	-54.218	-35.458
Hydromagnesite	-76.249	-68.811
Hydroxyapatite	-79.466	-35.133
Hydroxylpyromorphite	-107.118	-44.328
Hydrozincite	-49.418	-59.556
K2Cr2O7(s)	-33.219	-15.486
K2CrO4(s)	-18.579	-17.955
K-Alum	-12.195	-6.842
KCl(s)	-5.496	-6.396
K-Jarosite	-18.91	-8.529
Langite	-23.077	-41.573
Larnakite	-15.177	-14.875
Laurionite	-8.367	-8.99
Lepidocrocite	-1.979	-3.35
Lime	0.691	-33.187
Litharge	-4.839	-17.927
Mackinawite	-116.632	-113.032
Maghemite	-3.955	-10.341

Mineral	log IAP	Sat. index
Magnesioferrite	-3.322	-21.878
Magnesite	-19.216	-11.635
Magnetite	-10.027	-14.697
Malachite	-28.635	-23.435
Massicot	-4.839	-18.135
Matlockite	-18.163	-8.988
Melanothallite	-11.444	-18.087
Melanterite	-11.594	-9.261
Metacinnabar	-133.921	-87.497
Mg(OH)2 (active)	0.629	-18.165
Mg2(OH)3Cl:4H2O(s)	-2.279	-28.279
Mg3(PO4)2(s)	-53.383	-30.103
MgCO3:5H2O(s)	-19.233	-14.693
MgCrO4(s)	-14.007	-19.928
MgF2(s)	-18.962	-10.9
MgHPO4:3H2O(s)	-27.02	-8.845
MgS(s)	-109.928	-127.608
Minium	20.255	-55.832
Mirabilite	-6.284	-4.687
Mn2(SO4)3(s)	-16.785	-12.067
Montroydite	-23.361	-19.644
Morenosite	-7.64	-5.421
Na2Cr2O7(s)	-30.031	-20.001
Na2CrO4(s)	-15.391	-18.441
NaF(s)	-10.173	-9.678
Na-Jarosite	-17.316	-12.821
Natron	-20.634	-18.922
Nesquehonite	-19.226	-14.704
Ni(OH)2 (am)	-2.121	-15.594
Ni(OH)2 (c)	-2.121	-12.911
Ni3(AsO4)2:8H2O(s)	-59.544	-34.044
Ni3(PO4)2(s)	-61.633	-30.333
Ni4(OH)6SO4(s)	-13.978	-45.978
NiCO3(s)	-21.966	-11.019
NiS (alpha)	-112.678	-107.158
NiS (beta)	-112.678	-101.658
NiS (gamma)	-112.678	-99.958
Nsutite	17.242	-0.262
Orpiment	-372.727	-324.828
Otavite	-25.597	-13.546
Pb azide (alpha)	-22.842	-13.867
Pb metal	-39.611	-43.851
Pb(OH)2(s)	-4.842	-13.348
Pb10(OH)6O(CO3)6(s)	-167.493	-158.733
Pb2(OH)3Cl(s)	-13.209	-22.002
Pb2O(OH)2(s)	-9.681	-35.871

Mineral	log IAP	Sat. index
Pb2O3(s)	25.094	-35.946
Pb2OCO3(s)	-29.527	-29.217
Pb3(AsO4)2(s)	-67.682	-32.182
Pb3(PO4)2(s)	-69.798	-26.268
Pb3O2CO3(s)	-34.366	-46.058
Pb3O2SO4(s)	-20.016	-31.183
Pb4(OH)6SO4(s)	-24.865	-45.965
Pb4O3SO4(s)	-24.855	-47.561
PbCrO4(s)	-19.479	-6.61
PbF2(s)	-24.434	-16.872
PbHPO4(s)	-32.481	-8.676
PbO:0.3H2O(s)	-4.84	-17.82
Periclase	0.633	-21.871
Phosgenite	-36.58	-16.77
Plattnerite	29.933	-21.469
Plumbgummite	-57.695	-24.905
Portlandite	0.688	-22.798
Pyrite	-192.421	-173.609
Realgar	-148.469	-127.74
Retgersite	-7.636	-5.568
Siderite	-25.921	-15.375
Smithsonite	-21.791	-10.914
Spharelite	-112.502	-101.5
Spinel	2.257	-36.949
Strengite	-29.625	-3.282
Struvite	-47.407	-34.147
Sulfur	-75.788	-73.743
Tenorite(am)	-4.391	-13.276
Tenorite(c)	-4.391	-12.426
Thenardite	-6.25	-6.627
Thermonatrite	-20.603	-21.304
Tsumebite	-41.725	-31.935
Vaterite	-19.158	-11.321
Vivianite	-73.523	-35.733
Wurtzite	-112.502	-103.754
Zincite	-1.942	-13.717
Zincosite	-7.441	-11.872
Zn metal	-36.714	-63.435
Zn(NO3)2:6H2O(s)	-12.269	-15.435
Zn(OH)2 (am)	-1.945	-14.94
Zn(OH)2 (beta)	-1.945	-14.205
Zn(OH)2 (delta)	-1.945	-13.789
Zn(OH)2 (epsilon)	-1.945	-13.957
Zn(OH)2 (gamma)	-1.945	-14.177
Zn2(OH)2SO4(s)	-9.386	-16.886
Zn2(OH)3Cl(s)	-7.415	-22.606

Mineral	log IAP	Sat. index
Zn3(PO4)2:4H2O(s)	-61.121	-25.701
Zn3AsO42:2.5H2O(s)	-59	-31.5
Zn3O(SO4)2(s)	-16.823	-37.306
Zn4(OH)6SO4(s)	-13.277	-41.677
Zn5(OH)8Cl2(s)	-16.776	-55.276
Zn-Al LDH(s)	-13.006	-32.836
ZnCl2(s)	-8.995	-16.486
ZnCO3(s)	-21.791	-10.991
ZnCO3:1H2O(s)	-21.794	-11.534
ZnF2(s)	-21.537	-21.365
ZnSO4:1H2O(s)	-7.444	-7.074

B4 Mass distribution

B4.1: Eh 100

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.002025	42.035	0	0	0.002793	57.965
AsO4-3	8.34E-14	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.02595	100	0	0	0	0
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	8.12E-14	0	0	0	7.87E-08	100
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.028113	100	0	0	7.87E-08	0
Fe+3	9.41E-12	100	0	0	0	0
H+1	0.002603	100	0	0	0	0
H3AsO3	4.95E-06	100	0	0	0	0
Hg(OH)2	4.69E-14	0.019	0	0	2.49E-10	99.981
HS-1	1.9E-10	0.12	0	0	1.58E-07	99.88
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	1.04E-59	100	0	0	0	0
NO3-1	5.33E-79	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
SO4-2	0.038848	93.293	0	0	0.002793	6.707
Zn+2	2.29E-05	100	0	0	0	0

B3.2: Eh 200

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004009	83.203	0	0	0.000809	16.797
AsO4-3	3.45E-11	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.02595	100	0	0	0	0
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.028114	100	0	0	0	0
Fe+3	3.62E-10	100	0	0	0	0
H+1	0.003195	100	0	0	0	0
H3AsO3	4.95E-06	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	1.47E-21	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	1.61E-51	100	0	0	0	0
NO3-1	5.25E-68	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.040831	98.057	0	0	0.000809	1.943
Zn+2	2.29E-05	100	0	0	0	0

B4.3: Eh 300

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	1.38E-08	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.024111	92.913	0	0	0.001839	7.087
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.021983	100	0	0	0	0
Fe+3	1.27E-08	0	0	0	0.006131	100
H+1	0.004467	100	0	0	0	0
H3AsO3	4.93E-06	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	1.6E-32	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	2.42E-43	100	0	0	0	0
NO3-1	4.2E-57	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.4: Eh 400

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	7.77E-07	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.022798	87.854	0	0	0.003152	12.146
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.017607	100	0	0	0	0
Fe+3	3.9E-07	0.004	0	0	0.010506	99.996
H+1	0.011907	100	0	0	0	0
H3AsO3	4.17E-06	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	1.86E-40	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	2.69E-37	100	0	0	0	0
NO3-1	3.13E-49	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.5: Eh 500

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	4.82E-06	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.01941	74.798	0	0	0.00654	25.202
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.006308	100	0	0	0	0
Fe+3	6.37E-06	0.029	0	0	0.021799	99.971
H+1	0.031112	100	0	0	0	0
H3AsO3	1.25E-07	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	1.14E-49	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	3.25E-30	100	0	0	0	0
NO3-1	4.71E-40	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.6: Eh 600

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	4.95E-06	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.0176	67.822	0	0	0.00835	32.178
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.000266	100	0	0	0	0
Fe+3	1.44E-05	0.052	0	0	0.027833	99.948
H+1	0.041361	100	0	0	0	0
H3AsO3	8.36E-11	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	2.63E-62	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	5E-05	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	1.11E-20	100	0	0	0	0
NO3-1	1.97E-27	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	2E-06	100	0	0	0	0
SO4-2	0.04164	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.7: Eh 700

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	4.95E-06	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.017522	67.521	0	0	0.008428	32.479
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	4.89E-06	100	0	0	0	0
Fe+3	1.48E-05	0.053	0	0	0.028094	99.947
H+1	0.041804	100	0	0	0	0
H3AsO3	2.73E-14	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	3.01E-76	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	5E-05	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	0.000412	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	3.18E-10	100	0	0	0	0
NO3-1	1.72E-13	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	2E-06	100	0	0	0	0
SO4-2	0.04164	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.8: Eh 800

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	4.95E-06	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.01752	67.517	0	0	0.008429	32.483
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	9.15E-08	100	0	0	0	0
Fe+3	1.55E-05	0.055	0	0	0.028098	99.945
H+1	0.042635	100	0	0	0	0
H3AsO3	9.04E-18	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	3.67E-90	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	7.46E-09	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	0.000158	100	0	0	0	0
NO3-1	0.000254	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B4.9: Eh 900

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.004818	100	0	0	0	0
AsO4-3	4.95E-06	100	0	0	0	0
Ca+2	0.009232	100	0	0	0	0
Cd+2	5.34E-09	100	0	0	0	0
Cl-1	0.01752	67.517	0	0	0.008429	32.483
CO3-2	0.000967	100	0	0	0	0
CrO4-2	4.42E-07	100	0	0	0	0
Cu+2	7.87E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.001399	100	0	0	0	0
DOM1	0.000121	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	1.65E-09	100	0	0	0	0
Fe+3	1.56E-05	0.056	0	0	0.028098	99.944
H+1	0.042634	100	0	0	0	0
H3AsO3	2.9E-21	100	0	0	0	0
Hg(OH)2	2.49E-10	100	0	0	0	0
HS-1	3.9E-104	100	0	0	0	0
K+1	0.000333	100	0	0	0	0
Mg+2	0.007406	100	0	0	0	0
Mn+3	4.55E-05	100	0	0	0	0
N3-1	0.00005	100	0	0	0	0
Na+1	0.012614	100	0	0	0	0
NH4+1	1.28E-22	100	0	0	0	0
Ni+2	1.47E-05	100	0	0	0	0
NO2-1	8.2E-08	100	0	0	0	0
NO3-1	0.000412	100	0	0	0	0
Pb+2	4.83E-08	100	0	0	0	0
PO4-3	0.000002	100	0	0	0	0
SO4-2	0.041641	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

B5 Finite solids

B5.1: Eh 100

Solid	Equilibrium amount (mol/l)
Metacinnabar	2.49E-10
Chalcopyrite	7.87E-08
AlOHSO4(s)	2.79E-03

B5.2: Eh 200

Solid	Equilibrium amount (mol/l)
AlOHSO4(s)	8.09E-04

B5.3: Eh 300

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	6.13E-03

B5.4: Eh 400

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	1.05E-02

B5.5: Eh 500

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.18E-02

B5.6: Eh 600

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.78E-02

B5.7: Eh 700

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.81E-02

B5.8: Eh 800

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.81E-02

B5.9: Eh 900

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.81E-02

Appendix C - Lime dosing of water discharge from Big Swamp into Reach 3 of Boundary Creek

C1: Aqueous species

C1.1 pH 2

Species	Concentration	Activity	Log activity
Al DOM1	4.28E-06	4.24E-06	-5.372
Al(OH)2+	2.19E-11	1.83E-11	-10.739
Al(OH)3 (aq)	3.41E-16	3.45E-16	-15.463
Al(OH)4-	1.87E-20	1.54E-20	-19.812
Al(SO4)2-	0.000103	8.5E-05	-4.07
Al+3	0.000799	0.0002	-3.7
Al2(OH)2+4	6.05E-11	2.84E-12	-11.547
Al2(OH)2CO3+2	6.41E-15	2.98E-15	-14.525
Al2PO4+3	3.17E-10	5.67E-11	-10.246
Al3(OH)4+5	1.72E-16	1.45E-18	-17.84
AlCl+2	3.01E-06	1.4E-06	-5.854
AlF+2	1.31E-05	6.3E-06	-5.2
AlF2+	9.86E-09	8.21E-09	-8.086
AlF3 (aq)	3.12E-13	3.16E-13	-12.501
AlF4-	6.31E-19	5.21E-19	-18.283
AlHPO4+	3.69E-08	3.05E-08	-7.516
AlOH+2	2.14E-07	1.03E-07	-6.988
AlSO4+	0.001857	0.001533	-2.814
As3S4(HS)-	3.1E-130	2.5E-130	-129.598
AsO4-3	1.28E-26	2.29E-27	-26.641
AsS(OH)HS-	1.41E-48	1.17E-48	-47.933
Ca DOM1	2.18E-07	1.93E-07	-6.714
Ca(NH3)2+2	3.34E-24	1.55E-24	-23.809
Ca(NO3)2	3.5E-138	3.5E-138	-137.457
Ca+2	0.003614	0.001812	-2.742

Species	Concentration	Activity	Log activity
CaCl+	8.97E-05	7.41E-05	-4.13
CaCO3 (aq)	9.38E-16	9.48E-16	-15.023
CaCrO4 (aq)	1E-11	1.01E-11	-10.995
CaF+	8.15E-11	6.77E-11	-10.17
CaH2PO4+	2.95E-08	2.46E-08	-7.609
CaHCO3+	2.24E-09	1.88E-09	-8.726
CaHPO4 (aq)	3.02E-12	3.05E-12	-11.515
CaNH3+2	2.05E-13	9.54E-14	-13.02
CaNO3+	5.84E-68	4.82E-68	-67.317
CaOH+	1.77E-14	1.48E-14	-13.829
CaPO4-	7.8E-19	6.5E-19	-18.187
CaSO4 (aq)	0.00049	0.000495	-3.305
Cd DOM1	7.82E-13	6.92E-13	-12.16
Cd(CO3)2-2	1.27E-32	5.9E-33	-32.229
Cd(HS)2 (aq)	1.13E-51	1.14E-51	-50.944
Cd(HS)3-	1.28E-78	1.05E-78	-77.977
Cd(HS)4-2	5.3E-105	2.5E-105	-104.61
Cd(NH3)2+2	7.4E-26	3.45E-26	-25.463
Cd(NH3)3+2	3.03E-35	1.41E-35	-34.85
Cd(NH3)4+2	3.66E-45	1.7E-45	-44.769
Cd(NO2)2 (aq)	1.6E-105	1.6E-105	-104.783
Cd(NO3)2 (aq)	2.5E-139	2.5E-139	-138.603
Cd(OH)2 (aq)	1.3E-25	1.31E-25	-24.882
Cd(OH)3-	1.57E-36	1.29E-36	-35.888
Cd(OH)4-2	2.86E-48	1.33E-48	-47.876
Cd(SO4)2-2	3.05E-11	1.42E-11	-10.848
Cd+2	5.55E-09	2.58E-09	-8.588

Species	Concentration	Activity	Log activity
Cd2OH+3	7.88E-25	1.41E-25	-24.851
CdCl+	5E-09	4.13E-09	-8.384
CdCl2 (aq)	2.83E-10	2.86E-10	-9.544
CdCO3 (aq)	2.2E-20	2.22E-20	-19.654
CdF+	1.52E-16	1.26E-16	-15.901
CdHCO3+	7.75E-15	6.4E-15	-14.194
CdHPO4 (aq)	4.58E-17	4.63E-17	-16.334
CdHS+	4.7E-30	3.88E-30	-29.411
CdNH3+2	3.74E-17	1.74E-17	-16.759
CdNO2+	3.79E-57	3.13E-57	-56.504
CdNO3+	1.04E-73	8.56E-74	-73.068
CdOH+	1.16E-17	9.59E-18	-17.018
CdSO4 (aq)	6.99E-10	7.07E-10	-9.151
Cl-1	0.02117	0.017213	-1.764
CO3-2	7.62E-16	3.67E-16	-15.436
Cr2O7-2	8.65E-12	4.03E-12	-11.395
CrO3Cl-	4.02E-10	3.32E-10	-9.479
CrO3H2PO4-	3.95E-12	3.26E-12	-11.486
CrO3HPO4-2	1.46E-12	6.78E-13	-12.169
CrO3SO4-2	2.65E-09	1.23E-09	-8.91
CrO4-2	2.08E-11	9.48E-12	-11.023
Cu DOM1	3.23E-10	2.86E-10	-9.544
Cu(CO3)2-2	1.23E-28	5.71E-29	-28.243
Cu(N3)2 (aq)	2.82E-18	2.85E-18	-17.545
Cu(N3)3-	9.68E-24	8E-24	-23.097
Cu(N3)4-2	2.53E-30	1.18E-30	-29.929
Cu(NH3)2+2	6.57E-22	3.06E-22	-21.515
Cu(NH3)3+2	8.82E-30	4.1E-30	-29.387

Species	Concentration	Activity	Log activity
Cu(NH3)4+2	2.45E-38	1.14E-38	-37.944
Cu(NO2)2 (aq)	4.1E-105	4.2E-105	-104.38
Cu(NO3)2 (aq)	6.4E-139	6.5E-139	-138.187
Cu(OH)2 (aq)	4.24E-21	4.29E-21	-20.368
Cu(OH)3-	7.43E-29	6.14E-29	-28.212
Cu(OH)4-2	8.81E-41	4.1E-41	-40.387
Cu+2	5.44E-08	2.68E-08	-7.572
Cu2(OH)2+2	1.77E-22	8.24E-23	-22.084
Cu2OH+3	5.36E-20	9.59E-21	-20.018
Cu2S3-2	1.73E-98	8.1E-99	-98.093
Cu3(OH)4+2	1.52E-36	7.08E-37	-36.15
CuCl+	9.98E-10	8.19E-10	-9.087
CuCl2 (aq)	2.32E-12	2.35E-12	-11.629
CuCl3-	3.83E-16	3.14E-16	-15.503
CuCl4-2 1	8.09E-20	3.83E-20	-19.416
CuCO3 (aq)	5.72E-17	5.78E-17	-16.238
CuF+	4.46E-15	3.68E-15	-14.434
CuHCO3+	1.6E-13	1.32E-13	-12.879
CuHPO4 (aq)	1.25E-15	1.26E-15	-14.898
CuHSO4+	9.35E-11	7.73E-11	-10.112
CuN3+	1.32E-12	1.09E-12	-11.964
CuNH3+2	1.28E-14	5.96E-15	-14.225
CuNO2+	4.09E-56	3.38E-56	-55.471
CuNO3+	8.48E-73	7E-73	-72.155
CuOH+	6.29E-14	5.17E-14	-13.287
CuS(aq)	6.17E-38	6.24E-38	-37.205
CuSO4 (aq)	7.08E-09	7.16E-09	-8.145

Species	Concentration	Activity	Log activity
DOC (Gaussian DOM)	0.000333	0.000337	-3.473
DOM1	5.69E-06	1.27E-06	-5.896
F-1	4.03E-09	3.29E-09	-8.483
Fe DOM1	6.02E-11	5.97E-11	-10.224
Fe(N3)2+	1.28E-17	1.06E-17	-16.976
Fe(N3)3 (aq)	1.25E-22	1.27E-22	-21.897
Fe(NH3)2+2	1.17E-22	5.43E-23	-22.265
Fe(NH3)3+2	5.64E-33	2.62E-33	-32.581
Fe(NH3)4+2	1.16E-43	5.4E-44	-43.267
Fe(NO2)2+	8.2E-107	6.8E-107	-106.17
Fe(NO2)3 (aq)	9.3E-155	9.4E-155	-154.029
Fe(OH)2 (aq)	5.84E-21	5.91E-21	-20.229
Fe(OH)2+	1.12E-13	9.31E-14	-13.031
Fe(OH)3-	2.06E-29	1.71E-29	-28.767
Fe(OH)3 (aq)	3.06E-21	3.09E-21	-20.51
Fe(OH)4-	2.44E-27	2.03E-27	-26.693
Fe(SO4)2-	3.42E-12	2.83E-12	-11.549
Fe+2	0.001998	0.000983	-3.007
Fe+3	3.55E-11	8.88E-12	-11.052
Fe2(OH)2+4	9.74E-21	4.57E-22	-21.34
Fe3(OH)4+5	1.72E-30	1.45E-32	-31.84
FeCl+	1.29E-05	1.07E-05	-4.972
FeCl+2	7.05E-12	3.34E-12	-11.476
FeCrO4+	3.74E-15	3.09E-15	-14.51
FeF+	6.35E-11	5.25E-11	-10.28
FeF+2	5.88E-14	2.79E-14	-13.555
FeF2+	4.18E-18	3.47E-18	-17.46

Species	Concentration	Activity	Log activity
FeF3 (aq)	1.05E-23	1.06E-23	-22.976
FeH2PO4+	3.3E-07	2.75E-07	-6.561
FeH2PO4+2	1.95E-13	9.37E-14	-13.028
FeHCO3+	1.16E-09	9.68E-10	-9.014
FeHPO4 (aq)	1.37E-11	1.38E-11	-10.859
FeHPO4+	4.7E-13	3.91E-13	-12.407
FeHS+	7.29E-27	6.02E-27	-26.221
FeN3+2	1.67E-13	7.75E-14	-13.11
FeNH3+2	9.51E-13	4.43E-13	-12.354
FeNO2+2	3.64E-58	1.7E-58	-57.771
FeOH+	2.17E-11	1.8E-11	-10.744
FeOH+2	1.26E-11	5.97E-12	-11.224
FeSO4 (aq)	0.000281	0.000284	-3.546
FeSO4+	1.77E-10	1.47E-10	-9.834
H DOM1	1.85E-05	9.95E-06	-5.002
H+1	0.011666	0.01	-2
H2AsO3-	2.76E-14	2.28E-14	-13.642
H2AsO4-	2.3E-12	1.9E-12	-11.722
H2CO3* (aq)	0.002552	0.002581	-2.588
H2CrO4 (aq)	1.11E-09	1.12E-09	-8.95
H2PO4-	8.62E-07	7.18E-07	-6.144
H2S (aq)	2.11E-24	2.14E-24	-23.67
H3AsO3	4.91E-07	4.96E-07	-6.305
H3AsO4	3.35E-12	3.38E-12	-11.471
H3PO4	8.99E-07	9.09E-07	-6.042
HAsO3-2	2.49E-26	1.16E-26	-25.936
HAsO4-2	4E-17	1.86E-17	-16.73
HCO3-	1.18E-07	9.84E-08	-7.007

Species	Concentration	Activity	Log activity
HCrO4-	3.61E-07	2.98E-07	-6.525
HF (aq)	4.09E-08	4.14E-08	-7.383
HF2-	6.27E-16	5.12E-16	-15.291
Hg(CO3)2-2	3.9E-36	1.82E-36	-35.741
Hg(HS)2 (aq)	1.99E-40	2.02E-40	-39.696
Hg(N3)2 (aq)	1.13E-15	1.14E-15	-14.942
Hg(NH3)2+2	8.94E-24	4.16E-24	-23.381
Hg(NH3)4+2	1.07E-43	4.97E-44	-43.304
Hg(NO2)2 (aq)	4.1E-111	4.2E-111	-110.378
Hg(NO2)3-	2.1E-159	1.8E-159	-158.757
Hg(NO2)4-2	1.2E-208	5.4E-209	-208.266
Hg(NO3)2 (aq)	3.6E-152	3.6E-152	-151.445
Hg(OH)2	2.43E-23	2.46E-23	-22.609
Hg(SO4)2-2	4.01E-23	1.86E-23	-22.73
Hg+2	1.34E-20	6.25E-21	-20.204
Hg2OH+3	9.06E-42	1.62E-42	-41.79
Hg3(OH)3+3	1.05E-61	1.87E-62	-61.727
HgCl+	3.7E-15	3.06E-15	-14.515
HgCl2 (aq)	3.99E-10	4.04E-10	-9.394
HgCl3-1	8.37E-11	6.91E-11	-10.16
HgCl4-2	1.14E-11	5.33E-12	-11.273
HgClOH (aq)	2.12E-16	2.14E-16	-15.67
HgCO3 (aq)	1.74E-24	1.76E-24	-23.755
HgF+	9.29E-28	7.67E-28	-27.115
HgHCO3+	3.53E-22	2.92E-22	-21.535
HgHS2-	7.9E-45	6.52E-45	-44.186

Species	Concentration	Activity	Log activity
HgN3+	4.03E-12	3.33E-12	-11.477
HgNO2+	4.51E-65	3.73E-65	-64.429
HgNO3+	1.34E-86	1.11E-86	-85.956
HgOH+	2.27E-22	1.87E-22	-21.728
HgOHCO3-	2.5E-29	2.06E-29	-28.685
HgS2-2	2.73E-51	1.27E-51	-50.896
HgSO4 (aq)	1.37E-21	1.38E-21	-20.86
HN3 (aq)	2.85E-05	2.88E-05	-4.541
HNO2 (aq)	1.68E-49	1.7E-49	-48.769
HPO4-2	9.2E-12	4.36E-12	-11.36
HS-1	1.8E-29	1.47E-29	-28.833
HSO4-	0.001187	0.00098	-3.009
K+1	0.000149	0.000121	-3.918
K2HPO4 (aq)	6.82E-19	6.89E-19	-18.162
K2PO4-	4.8E-28	3.97E-28	-27.402
KCl (aq)	1.09E-06	1.1E-06	-5.957
KCr2O7-	5.09E-15	4.2E-15	-14.376
KCrO4-	5.16E-15	4.26E-15	-14.371
KF (aq)	1.8E-13	1.82E-13	-12.74
KH2PO4 (aq)	1.33E-10	1.35E-10	-9.871
KHPO4-	3.89E-15	3.24E-15	-14.489
KNO3 (aq)	7.13E-70	7.21E-70	-69.142
KOH (aq)	9.58E-17	9.68E-17	-16.014
KPO4-2	8.45E-25	3.93E-25	-24.405
KSO4-	1.13E-06	9.42E-07	-6.026
Mg DOM1	1.61E-08	1.42E-08	-7.847
Mg(NH3)2+2	1.23E-24	5.71E-25	-24.243
Mg+2	0.002607	0.001335	-2.875

Species	Concentration	Activity	Log activity
Mg2CO3+2	5.46E-18	2.54E-18	-17.595
MgCl+	0.000105	8.65E-05	-4.063
MgCO3 (aq)	3.45E-16	3.49E-16	-15.457
MgF+	3.52E-10	2.91E-10	-9.536
MgHCO3+	1.55E-09	1.27E-09	-8.895
MgHPO4 (aq)	3.07E-12	3.11E-12	-11.508
MgOH+	2.47E-13	2.08E-13	-12.683
MgPO4-	8.98E-21	7.48E-21	-20.126
MgSO4 (aq)	0.000292	0.000295	-3.53
Mn+3	5.1E-06	1.27E-06	-5.895
N3-1	6.78E-08	5.6E-08	-7.252
Na+1	0.006857	0.005678	-2.246
Na2HPO4 (aq)	9.93E-16	1E-15	-14.998
Na2PO4-	2.26E-24	1.87E-24	-23.728
NaCl (aq)	5.42E-05	5.48E-05	-4.261
NaCO3-	6.19E-17	5.15E-17	-16.288
NaCrO4-	3.24E-13	2.67E-13	-12.573
NaF (aq)	1.64E-11	1.65E-11	-10.781
NaH2PO4 (aq)	6.25E-09	6.32E-09	-8.199
NaHCO3 (aq)	3.27E-10	3.31E-10	-9.48
NaHPO4-	2.83E-13	2.36E-13	-12.627
NaNO3 (aq)	1.24E-68	1.25E-68	-67.903
NaOH (aq)	3.08E-15	3.12E-15	-14.506
NaPO4-2	4.38E-23	2.04E-23	-22.691
NaSO4-	4.87E-05	4.06E-05	-4.392
NH3 (aq)	1.57E-11	1.58E-11	-10.8
NH4+1	0.000716	0.000578	-3.238
NH4Cr2O7-	2.83E-14	2.33E-14	-13.632

Species	Concentration	Activity	Log activity
NH4SO4-	9.88E-06	8.16E-06	-5.089
Ni DOM1	4.73E-10	4.19E-10	-9.378
Ni(N3)2 (aq)	4.8E-19	4.85E-19	-18.314
Ni(NH3)2+2	9.77E-23	4.54E-23	-22.343
Ni(NH3)3+2	8.96E-32	4.17E-32	-31.38
Ni(NH3)4+2	2.44E-41	1.14E-41	-40.945
Ni(NH3)5+2	2.14E-51	9.97E-52	-51.001
Ni(NH3)6+2	4.01E-62	1.87E-62	-61.729
Ni(NO2)2 (aq)	1.4E-104	1.4E-104	-103.854
Ni(OH)2 (aq)	1.57E-21	1.59E-21	-20.8
Ni(OH)3-	1.93E-30	1.6E-30	-29.797
Ni(SO4)2-2	3.86E-11	1.79E-11	-10.746
Ni+2	3.36E-06	1.56E-06	-5.806
NiCl+	1.18E-08	9.73E-09	-8.012
NiCl2 (aq)	5.9E-12	5.97E-12	-11.224
NiCO3 (aq)	2.11E-17	2.13E-17	-16.672
NiF+	1.13E-13	9.3E-14	-13.032
NiH2PO4+	8.93E-12	7.37E-12	-11.132
NiHCO3+	1.83E-11	1.51E-11	-10.822
NiHPO4 (aq)	4.93E-15	4.99E-15	-14.302
NiHS+	8.59E-30	7.1E-30	-29.149
NiN3+	2E-12	1.65E-12	-11.783
NiNH3+2	3.49E-14	1.62E-14	-13.789
NiNO2+	5.47E-55	4.52E-55	-54.345
NiNO3+	3.71E-71	3.07E-71	-70.513
NiOH+	1.16E-14	9.6E-15	-14.018
NiSO4 (aq)	3.75E-07	3.79E-07	-6.421
NO2-1	1.46E-50	1.2E-50	-49.919

Species	Concentration	Activity	Log activity
NO3-1	9.62E-66	7.8E-66	-65.108
OH-	5.65E-13	4.61E-13	-12.336
Pb DOM1	3.96E-10	3.51E-10	-9.455
Pb(CO3)2-2	4.15E-29	1.93E-29	-28.714
Pb(HS)2 (aq)	6.55E-51	6.62E-51	-50.179
Pb(HS)3-	2.35E-78	1.94E-78	-77.712
Pb(NO2)2 (aq)	3E-105	3.1E-105	-104.511
Pb(NO3)2 (aq)	2.7E-137	2.8E-137	-136.558
Pb(OH)2 (aq)	1.31E-21	1.33E-21	-20.877
Pb(OH)3-	1.62E-30	1.34E-30	-29.874
Pb(SO4)2-2	1.82E-10	8.45E-11	-10.073
Pb+2	3.54E-08	1.65E-08	-7.783
Pb2OH+3	6.09E-20	1.09E-20	-19.963
Pb3(OH)4+2	2.45E-40	1.14E-40	-39.943
Pb4(OH)4+4	6.18E-44	2.9E-45	-44.538
PbCl+	1.1E-08	9.12E-09	-8.04
PbCl2 (aq)	3.24E-10	3.28E-10	-9.484
PbCl3-	5.43E-12	4.49E-12	-11.348
PbCl4-2	6.07E-14	2.82E-14	-13.549
PbCO3 (aq)	2.03E-17	2.05E-17	-16.689
PbF+	9.28E-15	7.67E-15	-14.115
PbF2 (aq)	3.07E-22	3.1E-22	-21.508
PbH2PO4+	3.52E-13	2.91E-13	-12.536
PbHCO3+	1.24E-12	1.03E-12	-11.989
PbHPO4 (aq)	7.26E-17	7.34E-17	-16.134
PbNO2+	7.78E-56	6.43E-56	-55.192
PbNO3+	2.37E-72	1.96E-72	-71.708

Species	Concentration	Activity	Log activity
PbOH+	3.62E-14	2.99E-14	-13.525
PbSO4 (aq)	1.05E-08	1.06E-08	-7.973
PO4-3	8E-22	1.49E-22	-21.826
S-2	6.18E-45	2.93E-45	-44.533
SO4-2	0.002911	0.001318	-2.88
Zn DOM1	4.67E-09	4.13E-09	-8.384
Zn(CO3)2-2	5.61E-29	2.61E-29	-28.583
Zn(N3)2 (aq)	2.88E-18	2.91E-18	-17.536
Zn(N3)3-	1.13E-24	9.33E-25	-24.03
Zn(NH3)2+2	2.3E-22	1.07E-22	-21.971
Zn(NH3)3+2	1.07E-30	4.98E-31	-30.302
Zn(NH3)4+2	2.45E-39	1.14E-39	-38.944
Zn(NO2)2 (aq)	2.2E-104	2.2E-104	-103.65
Zn(NO3)2 (aq)	2.9E-136	3E-136	-135.527
Zn(OH)2 (aq)	1.23E-18	1.24E-18	-17.906
Zn(OH)3-	4.79E-28	3.96E-28	-27.403
Zn(OH)4-2	1.36E-38	6.31E-39	-38.2
Zn(SO4)2-2	6.92E-08	3.22E-08	-7.492
Zn+2	1.98E-05	9.73E-06	-5.012
Zn2OH+3	2.18E-17	3.9E-18	-17.409
Zn2S3-2	1.44E-90	6.71E-91	-90.173
Zn4S6-4	1.6E-178	7.7E-180	-179.116
ZnCl+	5.45E-07	4.48E-07	-6.349
ZnCl2 (aq)	4.88E-09	4.94E-09	-8.307
ZnCl3-	1.09E-10	8.96E-11	-10.047
ZnCl4-2	1.53E-12	7.12E-13	-12.147
ZnCO3 (aq)	2.03E-16	2.05E-16	-15.688

Species	Concentration	Activity	Log activity
ZnF+	6.63E-13	5.48E-13	-12.261
ZnHCO3+	2.91E-11	2.41E-11	-10.619
ZnHPO4 (aq)	7.03E-14	7.11E-14	-13.148
ZnN3+	9.49E-12	7.84E-12	-11.106
ZnNH3+2	6.26E-14	2.91E-14	-13.536
ZnNO2+	8.55E-55	7.06E-55	-54.151
ZnNO3+	2.46E-70	2.03E-70	-69.692
ZnOH+	5.43E-13	4.49E-13	-12.348
ZnS (aq)	5.25E-34	5.31E-34	-33.275
ZnSO4 (aq)	2.54E-06	2.57E-06	-5.59

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Species	Concentration	Activity	Log activity
Al DOM1	1.3E-05	1.29E-05	-4.89
Al(OH)2+	1.85E-09	1.56E-09	-8.808
Al(OH)3 (aq)	2.91E-13	2.94E-13	-12.532
Al(OH)4-	1.57E-16	1.31E-16	-15.882
Al(SO4)2-	0.000136	0.000113	-3.945
Al+3	0.000647	0.000171	-3.768
Al2(OH)2+4	3.84E-09	2.07E-10	-9.685
Al2(OH)2CO3+2	4.51E-11	2.17E-11	-10.663
Al2PO4+3	2.83E-08	5.47E-09	-8.262
Al3(OH)4+5	8.64E-13	8.99E-15	-14.046
AlCl+2	2.51E-06	1.21E-06	-5.918
AlF+2	1.31E-05	6.53E-06	-5.185
AlF2+	1.23E-08	1.03E-08	-7.987
AlF3 (aq)	4.76E-13	4.81E-13	-12.318
AlF4-	1.15E-18	9.62E-19	-18.017
AlHPO4+	4.12E-07	3.43E-07	-6.464
AlOH+2	1.77E-06	8.79E-07	-6.056
AlSO4+	0.001965	0.001637	-2.786
As3S4(HS)-	1.2E-188	9.7E-189	-188.014
AsO4-3	1.17E-21	2.27E-22	-21.644
AsS(OH)HS-	2.19E-67	1.83E-67	-66.738
Ca DOM1	7.68E-07	6.83E-07	-6.166
Ca(NH3)2+2	3.26E-22	1.57E-22	-21.804
Ca(NO3)2	3.5E-118	3.5E-118	-117.455
Ca+2	0.003494	0.001803	-2.744
CaCl+	8.94E-05	7.45E-05	-4.128

Species	Concentration	Activity	Log activity
CaCO3 (aq)	9.33E-14	9.42E-14	-13.026
CaCrO4 (aq)	1.01E-10	1.02E-10	-9.989
CaF+	9.75E-11	8.16E-11	-10.088
CaH2PO4+	3.85E-08	3.23E-08	-7.491
CaHCO3+	2.21E-08	1.87E-08	-7.729
CaHPO4 (aq)	3.97E-11	4.01E-11	-10.397
CaNH3+2	1.99E-12	9.57E-13	-12.019
CaNO3+	5.79E-58	4.82E-58	-57.317
CaOH+	1.75E-13	1.47E-13	-12.831
CaPO4-	1.02E-16	8.53E-17	-16.069
CaSO4 (aq)	0.00061	0.000616	-3.211
Cd DOM1	2.76E-12	2.45E-12	-11.61
Cd(CO3)2-2	1.22E-28	5.87E-29	-28.232
Cd(HS)2 (aq)	1.77E-69	1.79E-69	-68.748
Cd(HS)3-	2.5E-105	2.1E-105	-104.683
Cd(HS)4-2	1.3E-140	6.1E-141	-140.218
Cd(NH3)2+2	7.25E-24	3.49E-24	-23.457
Cd(NH3)3+2	2.99E-32	1.44E-32	-31.841
Cd(NH3)4+2	3.64E-41	1.75E-41	-40.756
Cd(NO2)2 (aq)	1.65E-89	1.67E-89	-88.778
Cd(NO3)2 (aq)	2.5E-119	2.5E-119	-118.599
Cd(OH)2 (aq)	1.3E-23	1.31E-23	-22.883
Cd(OH)3-	1.55E-33	1.29E-33	-32.89
Cd(OH)4-2	2.75E-44	1.32E-44	-43.878
Cd(SO4)2-2	4.59E-11	2.21E-11	-10.655
Cd+2	5.35E-09	2.58E-09	-8.589
Cd2OH+3	7.26E-24	1.4E-24	-23.853

Species	Concentration	Activity	Log activity
CdCl+	5E-09	4.17E-09	-8.38
CdCl2 (aq)	2.88E-10	2.91E-10	-9.536
CdCO3 (aq)	2.19E-18	2.21E-18	-17.655
CdF+	1.83E-16	1.52E-16	-15.818
CdHCO3+	7.66E-14	6.38E-14	-13.195
CdHPO4 (aq)	6.04E-16	6.1E-16	-15.215
CdHS+	5.83E-39	4.86E-39	-38.313
CdNH3+2	3.63E-16	1.75E-16	-15.757
CdNO2+	3.78E-49	3.15E-49	-48.502
CdNO3+	1.03E-63	8.59E-64	-63.066
CdOH+	1.15E-16	9.57E-17	-16.019
CdSO4 (aq)	8.73E-10	8.82E-10	-9.055
Cl-1	0.02117	0.017395	-1.76
CO3-2	7.36E-14	3.66E-14	-13.436
Cr2O7-2	8.67E-12	4.18E-12	-11.379
CrO3Cl-	4.11E-11	3.42E-11	-10.466
CrO3H2PO4-	5.27E-13	4.39E-13	-12.358
CrO3HPO4-2	1.89E-12	9.11E-13	-12.041
CrO3SO4-2	3.26E-10	1.57E-10	-9.805
CrO4-2	2.04E-10	9.65E-11	-10.015
Cu DOM1	1.13E-09	1E-09	-8.999
Cu(CO3)2-2	1.17E-24	5.61E-25	-24.251
Cu(N3)2 (aq)	2.66E-16	2.69E-16	-15.571
Cu(N3)3-	8.86E-21	7.38E-21	-20.132
Cu(N3)4-2	2.21E-26	1.06E-26	-25.973
Cu(NH3)2+2	6.36E-20	3.07E-20	-19.514
Cu(NH3)3+2	8.6E-27	4.14E-27	-26.382
Cu(NH3)4+2	2.41E-34	1.16E-34	-33.936

Species	Concentration	Activity	Log activity
Cu(NO2)2 (aq)	4.12E-89	4.16E-89	-88.381
Cu(NO3)2 (aq)	6.4E-119	6.5E-119	-118.189
Cu(OH)2 (aq)	4.18E-19	4.22E-19	-18.375
Cu(OH)3-	7.25E-26	6.04E-26	-25.219
Cu(OH)4-2	8.37E-37	4.03E-37	-36.395
Cu+2	5.21E-08	2.64E-08	-7.578
Cu2(OH)2+2	1.66E-20	8.01E-21	-20.097
Cu2OH+3	4.82E-19	9.33E-20	-19.03
Cu2S3-2	3.2E-122	1.5E-122	-121.81
Cu3(OH)4+2	1.41E-32	6.78E-33	-32.169
CuCl+	9.85E-10	8.17E-10	-9.088
CuCl2 (aq)	2.34E-12	2.37E-12	-11.626
CuCl3-	3.86E-16	3.2E-16	-15.495
CuCl4-2 1	8.04E-20	3.94E-20	-19.404
CuCO3 (aq)	5.64E-15	5.7E-15	-14.244
CuF+	5.29E-15	4.41E-15	-14.356
CuHCO3+	1.56E-12	1.3E-12	-11.885
CuHPO4 (aq)	1.63E-14	1.64E-14	-13.784
CuHSO4+	1.14E-11	9.52E-12	-11.021
CuN3+	1.26E-11	1.05E-11	-10.979
CuNH3+2	1.23E-13	5.92E-14	-13.227
CuNO2+	4.03E-48	3.36E-48	-47.474
CuNO3+	8.34E-63	6.95E-63	-62.158
CuOH+	6.14E-13	5.09E-13	-12.293
CuS(aq)	7.64E-46	7.71E-46	-45.113
CuSO4 (aq)	8.74E-09	8.83E-09	-8.054
DOC (Gaussian DOM)	0.000333	0.000336	-3.473

Species	Concentration	Activity	Log activity
DOM1	8.46E-06	2.02E-06	-5.694
F-1	4.84E-09	3.99E-09	-8.399
Fe DOM1	2.13E-10	2.11E-10	-9.675
Fe(N3)2+	1.21E-15	1.01E-15	-14.997
Fe(N3)3 (aq)	1.17E-19	1.18E-19	-18.928
Fe(NH3)2+2	1.14E-20	5.49E-21	-20.26
Fe(NH3)3+2	5.55E-30	2.67E-30	-29.573
Fe(NH3)4+2	1.15E-39	5.56E-40	-39.255
Fe(NO2)2+	8.18E-91	6.82E-91	-90.166
Fe(NO2)3 (aq)	9.4E-131	9.5E-131	-130.023
Fe(OH)2 (aq)	5.81E-19	5.87E-19	-18.231
Fe(OH)2+	1.1E-11	9.26E-12	-11.033
Fe(OH)3-	2.03E-26	1.7E-26	-25.77
Fe(OH)3 (aq)	3.04E-18	3.07E-18	-17.512
Fe(OH)4-	2.4E-23	2.01E-23	-22.696
Fe(SO4)2-	5.28E-12	4.4E-12	-11.357
Fe+2	0.001928	0.000979	-3.009
Fe+3	3.35E-11	8.84E-12	-11.054
Fe2(OH)2+4	8.4E-19	4.52E-20	-19.345
Fe3(OH)4+5	1.37E-26	1.42E-28	-27.847
FeCl+	1.29E-05	1.07E-05	-4.969
FeCl+2	6.86E-12	3.37E-12	-11.473
FeCrO4+	3.76E-14	3.13E-14	-13.504
FeF+	7.6E-11	6.34E-11	-10.198
FeF+2	6.85E-14	3.36E-14	-13.473
FeF2+	6.06E-18	5.07E-18	-17.295
FeF3 (aq)	1.86E-23	1.88E-23	-22.727
FeH2PO4+	4.3E-07	3.61E-07	-6.442

Species	Concentration	Activity	Log activity
FeH2PO4+2	2.47E-13	1.23E-13	-12.91
FeHCO3+	1.14E-08	9.62E-09	-8.017
FeHPO4 (aq)	1.8E-10	1.82E-10	-9.74
FeHPO4+	6.12E-12	5.14E-12	-11.289
FeHS+	9.02E-36	7.51E-36	-35.124
FeN3+2	1.57E-12	7.55E-13	-12.122
FeNH3+2	9.22E-12	4.44E-12	-11.352
FeNO2+2	3.53E-50	1.7E-50	-49.77
FeOH+	2.14E-10	1.8E-10	-9.746
FeOH+2	1.21E-10	5.94E-11	-10.226
FeSO4 (aq)	0.00035	0.000354	-3.451
FeSO4+	2.18E-10	1.82E-10	-9.739
H DOM1	6.39E-06	3.54E-06	-5.451
H+1	0.00116	0.001	-3
H2AsO3-	2.72E-13	2.26E-13	-12.645
H2AsO4-	2.26E-09	1.88E-09	-8.725
H2CO3* (aq)	0.002551	0.002576	-2.589
H2CrO4 (aq)	1.13E-10	1.14E-10	-9.942
H2PO4-	1.13E-06	9.47E-07	-6.024
H2S (aq)	2.65E-34	2.68E-34	-33.572
H3AsO3	4.88E-07	4.93E-07	-6.307
H3AsO4	3.33E-10	3.36E-10	-9.474
H3PO4	1.19E-07	1.2E-07	-6.921
HAsO3-2	2.39E-24	1.15E-24	-23.939
HAsO4-2	3.83E-13	1.85E-13	-12.734
HCO3-	1.17E-06	9.82E-07	-6.008
HCrO4-	3.65E-07	3.04E-07	-6.517
HF (aq)	4.97E-09	5.01E-09	-8.3

Species	Concentration	Activity	Log activity
HF2-	9.12E-17	7.52E-17	-16.124
Hg(CO3)2-2	4.79E-35	2.31E-35	-34.637
Hg(HS)2 (aq)	4E-61	4.04E-61	-60.394
Hg(N3)2 (aq)	1.38E-14	1.39E-14	-13.857
Hg(NH3)2+2	1.12E-24	5.39E-25	-24.269
Hg(NH3)4+2	1.36E-42	6.54E-43	-42.184
Hg(NO2)2 (aq)	5.36E-98	5.41E-98	-97.267
Hg(NO2)3-	2.7E-138	2.3E-138	-137.643
Hg(NO2)4-2	1.5E-179	7.1E-180	-179.149
Hg(NO3)2 (aq)	4.6E-135	4.6E-135	-134.334
Hg(OH)2	3.1E-24	3.13E-24	-23.505
Hg(SO4)2-2	7.7E-26	3.71E-26	-25.43
Hg+2	1.66E-23	7.97E-24	-23.098
Hg2OH+3	1.36E-46	2.63E-47	-46.579
Hg3(OH)3+3	2.01E-67	3.88E-68	-67.412
HgCl+	4.73E-18	3.94E-18	-17.404
HgCl2 (aq)	5.21E-13	5.26E-13	-12.279
HgCl3-1	1.09E-13	9.1E-14	-13.041
HgCl4-2	1.47E-14	7.08E-15	-14.15
HgClOH (aq)	2.73E-18	2.75E-18	-17.56
HgCO3 (aq)	2.22E-25	2.24E-25	-24.65
HgF+	1.42E-30	1.19E-30	-29.926
HgHCO3+	4.46E-24	3.71E-24	-23.43
HgHS2-	1.57E-64	1.31E-64	-63.884
HgN3+	4.98E-10	4.15E-10	-9.382
HgNO2+	5.74E-60	4.78E-60	-59.32
HgNO3+	1.7E-79	1.42E-79	-78.848

Species	Concentration	Activity	Log activity
HgOH+	2.86E-24	2.39E-24	-23.622
HgOHCO3-	3.15E-29	2.63E-29	-28.581
HgS2-2	5.29E-70	2.55E-70	-69.594
HgSO4 (aq)	2.18E-24	2.2E-24	-23.657
HN3 (aq)	2.79E-05	2.82E-05	-4.55
HNO2 (aq)	1.7E-42	1.71E-42	-41.766
HPO4-2	1.17E-10	5.75E-11	-10.24
HS-1	2.23E-38	1.84E-38	-37.735
HSO4-	0.000147	0.000123	-3.912
K+1	0.000148	0.000122	-3.914
K2HPO4 (aq)	9.15E-18	9.24E-18	-17.034
K2PO4-	6.39E-26	5.32E-26	-25.274
KCl (aq)	1.11E-06	1.12E-06	-5.949
KCr2O7-	5.28E-15	4.4E-15	-14.357
KCrO4-	5.25E-14	4.37E-14	-13.359
KF (aq)	2.2E-13	2.22E-13	-12.653
KH2PO4 (aq)	1.77E-10	1.79E-10	-9.747
KHPO4-	5.14E-14	4.31E-14	-13.365
KNO3 (aq)	7.24E-60	7.31E-60	-59.136
KOH (aq)	9.66E-16	9.76E-16	-15.011
KPO4-2	1.09E-22	5.23E-23	-22.281
KSO4-	1.41E-06	1.19E-06	-5.926
Mg DOM1	5.68E-08	5.05E-08	-7.297
Mg(NH3)2+2	1.2E-22	5.79E-23	-22.237
Mg+2	0.002534	0.001333	-2.875
Mg2CO3+2	5.25E-16	2.53E-16	-15.597
MgCl+	0.000105	8.73E-05	-4.059
MgCO3 (aq)	3.45E-14	3.48E-14	-13.458

Species	Concentration	Activity	Log activity
MgF+	4.23E-10	3.52E-10	-9.453
MgHCO3+	1.53E-08	1.27E-08	-7.896
MgHPO4 (aq)	4.05E-11	4.09E-11	-10.388
MgOH+	2.45E-12	2.07E-12	-11.683
MgPO4-	1.17E-18	9.86E-19	-18.006
MgSO4 (aq)	0.000365	0.000368	-3.434
Mn+3	5.1E-06	1.34E-06	-5.872
N3-1	6.58E-07	5.48E-07	-6.261
Na+1	0.006844	0.005716	-2.243
Na2HPO4 (aq)	1.33E-14	1.34E-14	-13.872
Na2PO4-	3E-22	2.5E-22	-21.602
NaCl (aq)	5.52E-05	5.57E-05	-4.254
NaCO3-	6.17E-15	5.18E-15	-14.286
NaCrO4-	3.29E-12	2.74E-12	-11.562
NaF (aq)	2E-11	2.02E-11	-10.695
NaH2PO4 (aq)	8.31E-09	8.39E-09	-8.076
NaHCO3 (aq)	3.29E-09	3.33E-09	-8.478
NaHPO4-	3.73E-12	3.13E-12	-11.504
NaNO3 (aq)	1.25E-58	1.26E-58	-57.898
NaOH (aq)	3.1E-14	3.13E-14	-13.504
NaPO4-2	5.62E-21	2.71E-21	-20.568
NaSO4-	6.07E-05	5.1E-05	-4.292
NH3 (aq)	1.58E-10	1.6E-10	-9.797
NH4+1	0.000714	0.000582	-3.235
NH4Cr2O7-	2.93E-14	2.44E-14	-13.612
NH4SO4-	1.23E-05	1.03E-05	-4.988
Ni DOM1	1.68E-09	1.5E-09	-8.825
Ni(N3)2 (aq)	4.62E-17	4.66E-17	-16.331

Species	Concentration	Activity	Log activity
Ni(NH3)2+2	9.63E-21	4.64E-21	-20.334
Ni(NH3)3+2	8.91E-29	4.29E-29	-28.367
Ni(NH3)4+2	2.44E-37	1.18E-37	-36.929
Ni(NH3)5+2	2.17E-46	1.04E-46	-45.982
Ni(NH3)6+2	4.09E-56	1.97E-56	-55.706
Ni(NO2)2 (aq)	1.41E-88	1.42E-88	-87.846
Ni(OH)2 (aq)	1.58E-19	1.59E-19	-18.798
Ni(OH)3-	1.92E-27	1.6E-27	-26.796
Ni(SO4)2-2	5.85E-11	2.82E-11	-10.55
Ni+2	3.26E-06	1.57E-06	-5.804
NiCl+	1.19E-08	9.88E-09	-8.005
NiCl2 (aq)	6.07E-12	6.13E-12	-11.213
NiCO3 (aq)	2.12E-15	2.14E-15	-14.67
NiF+	1.36E-13	1.13E-13	-12.946
NiH2PO4+	1.17E-11	9.78E-12	-11.01
NiHCO3+	1.82E-10	1.51E-10	-9.82
NiHPO4 (aq)	6.55E-14	6.61E-14	-13.18
NiHS+	1.07E-38	8.94E-39	-38.049
NiN3+	1.95E-11	1.62E-11	-10.79
NiNH3+2	3.42E-13	1.65E-13	-12.784
NiNO2+	5.49E-47	4.57E-47	-46.34
NiNO3+	3.72E-61	3.1E-61	-60.509
NiOH+	1.16E-13	9.64E-14	-13.016
NiSO4 (aq)	4.72E-07	4.76E-07	-6.322
NO2-1	1.46E-42	1.21E-42	-41.916
NO3-1	9.56E-56	7.85E-56	-55.105
OH-	5.58E-12	4.61E-12	-11.337
Pb DOM1	1.34E-09	1.19E-09	-8.923

Species	Concentration	Activity	Log activity
Pb(CO3)2-2	3.82E-25	1.84E-25	-24.735
Pb(HS)2 (aq)	9.87E-69	9.97E-69	-68.001
Pb(HS)3-	4.4E-105	3.7E-105	-104.436
Pb(NO2)2 (aq)	2.96E-89	2.99E-89	-88.525
Pb(NO3)2 (aq)	2.7E-117	2.7E-117	-116.572
Pb(OH)2 (aq)	1.26E-19	1.27E-19	-18.896
Pb(OH)3-	1.53E-27	1.28E-27	-26.894
Pb(SO4)2-2	2.62E-10	1.26E-10	-9.898
Pb+2	3.28E-08	1.58E-08	-7.802
Pb2OH+3	5.16E-19	9.98E-20	-19.001
Pb3(OH)4+2	2.07E-36	9.97E-37	-36.001
Pb4(OH)4+4	4.51E-40	2.43E-41	-40.615
PbCl+	1.06E-08	8.83E-09	-8.054
PbCl2 (aq)	3.18E-10	3.21E-10	-9.494
PbCl3-	5.32E-12	4.43E-12	-11.353
PbCl4-2	5.85E-14	2.82E-14	-13.55
PbCO3 (aq)	1.94E-15	1.96E-15	-14.708
PbF+	1.07E-14	8.9E-15	-14.051
PbF2 (aq)	4.33E-22	4.37E-22	-21.36
PbH2PO4+	4.41E-13	3.67E-13	-12.435
PbHCO3+	1.18E-11	9.81E-12	-11.008
PbHPO4 (aq)	9.18E-16	9.27E-16	-15.033
PbNO2+	7.43E-48	6.19E-48	-47.208
PbNO3+	2.26E-62	1.88E-62	-61.725
PbOH+	3.43E-13	2.86E-13	-12.544
PbSO4 (aq)	1.26E-08	1.27E-08	-7.895
PO4-3	9.76E-20	1.97E-20	-19.706

Species	Concentration	Activity	Log activity
S-2	7.48E-53	3.67E-53	-52.435
SO4-2	0.003499	0.001647	-2.783
Zn DOM1	1.64E-08	1.46E-08	-7.835
Zn(CO3)2-2	5.38E-25	2.59E-25	-24.586
Zn(N3)2 (aq)	2.75E-16	2.78E-16	-15.557
Zn(N3)3-	1.04E-21	8.7E-22	-21.06
Zn(NH3)2+2	2.25E-20	1.08E-20	-19.966
Zn(NH3)3+2	1.06E-27	5.09E-28	-27.294
Zn(NH3)4+2	2.43E-35	1.17E-35	-34.932
Zn(NO2)2 (aq)	2.24E-88	2.26E-88	-87.646
Zn(NO3)2 (aq)	3E-116	3E-116	-115.524
Zn(OH)2 (aq)	1.22E-16	1.24E-16	-15.908
Zn(OH)3-	4.72E-25	3.93E-25	-24.405
Zn(OH)4-2	1.3E-34	6.27E-35	-34.203
Zn(SO4)2-2	1.04E-07	5.01E-08	-7.3
Zn+2	1.91E-05	9.7E-06	-5.013
Zn2OH+3	2E-16	3.87E-17	-16.412
Zn2S3-2	2.7E-114	1.3E-114	-113.881
Zn4S6-4	5.4E-226	2.9E-227	-226.533
ZnCl+	5.44E-07	4.51E-07	-6.346
ZnCl2 (aq)	4.98E-09	5.02E-09	-8.299
ZnCl3-	1.11E-10	9.22E-11	-10.035
ZnCl4-2	1.54E-12	7.4E-13	-12.131
ZnCO3 (aq)	2.02E-14	2.04E-14	-13.69
ZnF+	7.94E-13	6.62E-13	-12.179
ZnHCO3+	2.87E-10	2.39E-10	-9.621
ZnHPO4 (aq)	9.25E-13	9.34E-13	-12.03

Species	Concentration	Activity	Log activity
ZnN3+	9.17E-11	7.64E-11	-10.117
ZnNH3+2	6.07E-13	2.93E-13	-12.534
ZnNO2+	8.5E-47	7.08E-47	-46.15
ZnNO3+	2.45E-60	2.04E-60	-59.691
ZnOH+	5.36E-12	4.47E-12	-11.35
ZnS (aq)	6.57E-42	6.63E-42	-41.178
ZnSO4 (aq)	3.17E-06	3.2E-06	-5.494

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Species	Concentration	Activity	Log activity
Al DOM1	1.02E-05	1.01E-05	-4.995
Al(OH)2+	3.4E-08	2.89E-08	-7.539
Al(OH)3 (aq)	5.41E-11	5.45E-11	-10.264
Al(OH)4-	2.88E-13	2.43E-13	-12.614
Al(SO4)2-	3.19E-05	2.69E-05	-4.57
Al+3	0.00011	3.16E-05	-4.5
Al2(OH)2+4	1.06E-08	7.11E-10	-9.148
Al2(OH)2CO3+2	1.46E-08	7.43E-09	-8.129
Al2PO4+3	9.24E-08	2.02E-08	-7.695
Al3(OH)4+5	3.93E-11	5.74E-13	-12.241
AlCl+2	4.34E-07	2.21E-07	-6.656
AlF+2	1.3E-05	6.8E-06	-5.167
AlF2+	7.09E-08	6.03E-08	-7.22
AlF3 (aq)	1.57E-11	1.58E-11	-10.802
AlF4-	2.1E-16	1.77E-16	-15.751
AlHPO4+	8.09E-07	6.83E-07	-6.165
AlOH+2	3.11E-06	1.63E-06	-5.788
AlSO4+	0.000407	0.000343	-3.464
As3S4(HS)-	1.4E-249	1.1E-249	-248.942
AsO4-3	1.85E-17	4.04E-18	-17.394
AsS(OH)HS-	4.92E-87	4.16E-87	-86.381
Ca DOM1	3.28E-06	2.94E-06	-5.532
Ca(NH3)2+2	3.24E-20	1.65E-20	-19.783
Ca(NO3)2	3.65E-98	3.68E-98	-97.434
Ca+2	0.003399	0.001835	-2.736
CaCl+	8.84E-05	7.46E-05	-4.127
CaCO3 (aq)	9.46E-12	9.53E-12	-11.021

Species	Concentration	Activity	Log activity
CaCrO4 (aq)	1.04E-09	1.05E-09	-8.978
CaF+	5.5E-10	4.67E-10	-9.331
CaH2PO4+	4.15E-08	3.53E-08	-7.452
CaHCO3+	2.21E-07	1.89E-07	-6.724
CaHPO4 (aq)	4.34E-10	4.38E-10	-9.359
CaNH3+2	1.95E-11	9.89E-12	-11.005
CaNO3+	5.9E-48	4.99E-48	-47.302
CaOH+	1.76E-12	1.5E-12	-11.823
CaPO4-	1.09E-14	9.31E-15	-14.031
CaSO4 (aq)	0.000703	0.000709	-3.149
Cd DOM1	1.19E-11	1.07E-11	-10.972
Cd(CO3)2-2	1.17E-24	5.95E-25	-24.225
Cd(HS)2 (aq)	2.33E-87	2.34E-87	-86.63
Cd(HS)3-	3.6E-132	3.1E-132	-131.512
Cd(HS)4-2	2E-176	1E-176	-175.993
Cd(NH3)2+2	7.27E-22	3.7E-22	-21.432
Cd(NH3)3+2	3.05E-29	1.55E-29	-28.81
Cd(NH3)4+2	3.76E-37	1.91E-37	-36.718
Cd(NO2)2 (aq)	1.75E-73	1.76E-73	-72.754
Cd(NO3)2 (aq)	2.6E-99	2.7E-99	-98.575
Cd(OH)2 (aq)	1.33E-21	1.34E-21	-20.872
Cd(OH)3-	1.57E-30	1.32E-30	-29.878
Cd(OH)4-2	2.67E-40	1.36E-40	-39.867
Cd(SO4)2-2	5.71E-11	2.9E-11	-10.537
Cd+2	5.21E-09	2.65E-09	-8.577
Cd2OH+3	6.77E-23	1.48E-23	-22.83
CdCl+	4.98E-09	4.21E-09	-8.376

Species	Concentration	Activity	Log activity
CdCl2 (aq)	2.87E-10	2.9E-10	-9.538
CdCO3 (aq)	2.24E-16	2.26E-16	-15.646
CdF+	1.04E-15	8.77E-16	-15.057
CdHCO3+	7.71E-13	6.51E-13	-12.186
CdHPO4 (aq)	6.66E-15	6.72E-15	-14.173
CdHS+	6.68E-48	5.64E-48	-47.249
CdNH3+2	3.59E-15	1.82E-15	-14.739
CdNO2+	3.88E-41	3.28E-41	-40.484
CdNO3+	1.06E-53	8.95E-54	-53.048
CdOH+	1.16E-15	9.82E-16	-15.008
CdSO4 (aq)	1.02E-09	1.02E-09	-8.99
Cl-1	0.020503	0.01712	-1.766
CO3-2	6.94E-12	3.64E-12	-11.439
Cr2O7-2	8.34E-12	4.24E-12	-11.373
CrO3Cl-	4.02E-12	3.39E-12	-11.47
CrO3H2PO4-	5.61E-14	4.74E-14	-13.324
CrO3HPO4-2	1.94E-12	9.84E-13	-12.007
CrO3SO4-2	3.51E-11	1.79E-11	-10.748
CrO4-2	1.94E-09	9.72E-10	-9.012
Cu DOM1	4.55E-09	4.08E-09	-8.389
Cu(CO3)2-2	1.05E-20	5.35E-21	-20.272
Cu(N3)2 (aq)	1.77E-14	1.78E-14	-13.749
Cu(N3)3-	4.8E-18	4.06E-18	-17.392
Cu(N3)4-2	9.53E-23	4.85E-23	-22.315
Cu(NH3)2+2	5.99E-18	3.04E-18	-17.517
Cu(NH3)3+2	8.22E-24	4.18E-24	-23.379
Cu(NH3)4+2	2.33E-30	1.19E-30	-29.926
Cu(NO2)2 (aq)	4.1E-73	4.13E-73	-72.384

Species	Concentration	Activity	Log activity
Cu(NO3)2 (aq)	6.4E-99	6.4E-99	-98.191
Cu(OH)2 (aq)	4.04E-17	4.07E-17	-16.391
Cu(OH)3-	6.89E-23	5.82E-23	-22.235
Cu(OH)4-2	7.64E-33	3.89E-33	-32.411
Cu+2	4.78E-08	2.55E-08	-7.594
Cu2(OH)2+2	1.46E-18	7.44E-19	-18.129
Cu2OH+3	3.97E-18	8.67E-19	-18.062
Cu2S3-2	4.1E-146	2.1E-146	-145.682
Cu3(OH)4+2	1.19E-28	6.07E-29	-28.217
CuCl+	9.21E-10	7.75E-10	-9.111
CuCl2 (aq)	2.19E-12	2.21E-12	-11.655
CuCl3-	3.49E-16	2.94E-16	-15.532
CuCl4-2 1	6.89E-20	3.57E-20	-19.448
CuCO3 (aq)	5.42E-13	5.46E-13	-12.263
CuF+	2.82E-14	2.38E-14	-13.623
CuHCO3+	1.48E-11	1.25E-11	-10.904
CuHPO4 (aq)	1.69E-13	1.7E-13	-12.77
CuHSO4+	1.23E-12	1.04E-12	-11.984
CuN3+	9.93E-11	8.38E-11	-10.077
CuNH3+2	1.14E-12	5.8E-13	-12.237
CuNO2+	3.89E-40	3.28E-40	-39.484
CuNO3+	8.05E-53	6.8E-53	-52.168
CuOH+	5.84E-12	4.91E-12	-11.309
CuS(aq)	8.34E-54	8.41E-54	-53.075
CuSO4 (aq)	9.55E-09	9.62E-09	-8.017
DOC (Gaussian DOM)	0.000333	0.000336	-3.474
DOM1	1.23E-05	3.27E-06	-5.485

Species	Concentration	Activity	Log activity
F-1	2.67E-08	2.24E-08	-7.65
Fe DOM1	5E-12	4.96E-12	-11.304
Fe(N3)2+	4.55E-16	3.84E-16	-15.415
Fe(N3)3 (aq)	3.71E-19	3.74E-19	-18.427
Fe(NH3)2+2	6.18E-21	3.14E-21	-20.503
Fe(NH3)3+2	3.05E-29	1.55E-29	-28.809
Fe(NH3)4+2	6.44E-38	3.27E-38	-37.485
Fe(NO2)2+	4.62E-77	3.9E-77	-76.409
Fe(NO2)3 (aq)	5.5E-109	5.5E-109	-108.259
Fe(OH)2 (aq)	3.23E-19	3.26E-19	-18.487
Fe(OH)2+	6.04E-12	5.14E-12	-11.289
Fe(OH)3-	1.11E-25	9.43E-26	-25.026
Fe(OH)3 (aq)	1.69E-17	1.71E-17	-16.768
Fe(OH)4-	1.31E-21	1.12E-21	-20.952
Fe(SO4)2-	3.7E-14	3.12E-14	-13.506
Fe+2	1.02E-05	5.44E-06	-5.265
Fe+3	1.71E-13	4.91E-14	-13.309
Fe2(OH)2+4	2.08E-21	1.39E-22	-21.856
Fe3(OH)4+5	1.67E-29	2.44E-31	-30.613
FeCl+	6.95E-08	5.87E-08	-7.231
FeCl+2	3.55E-14	1.84E-14	-13.735
FeCrO4+	2.08E-15	1.75E-15	-14.756
FeF+	2.34E-12	1.97E-12	-11.704
FeF+2	2.03E-15	1.05E-15	-14.98
FeF2+	1.05E-18	8.88E-19	-18.052
FeF3 (aq)	1.83E-23	1.84E-23	-22.734
FeH2PO4+	2.53E-09	2.15E-09	-8.667
FeH2PO4+2	1.4E-15	7.33E-16	-15.135

Species	Concentration	Activity	Log activity
FeHCO3+	6.21E-10	5.31E-10	-9.275
FeHPO4 (aq)	1.07E-11	1.08E-11	-10.965
FeHPO4+	3.6E-13	3.06E-13	-12.514
FeHS+	5.59E-47	4.72E-47	-46.326
FeN3+2	6.84E-14	3.48E-14	-13.459
FeNH3+2	4.92E-13	2.5E-13	-12.601
FeNO2+2	1.88E-44	9.57E-45	-44.019
FeOH+	1.18E-11	9.97E-12	-11.001
FeOH+2	6.37E-12	3.3E-12	-11.482
FeSO4 (aq)	2.2E-06	2.22E-06	-5.653
FeSO4+	1.35E-12	1.15E-12	-11.941
H DOM1	2.59E-06	1.5E-06	-5.825
H+1	0.000115	0.0001	-4
H2AsO3-	4.77E-13	4.03E-13	-12.395
H2AsO4-	3.97E-07	3.35E-07	-6.475
H2CO3* (aq)	0.002541	0.002561	-2.592
H2CrO4 (aq)	1.14E-11	1.15E-11	-10.939
H2PO4-	1.19E-06	1.02E-06	-5.993
H2S (aq)	3.01E-44	3.03E-44	-43.518
H3AsO3	8.7E-08	8.77E-08	-7.057
H3AsO4	5.93E-09	5.98E-09	-8.223
H3PO4	1.28E-08	1.29E-08	-7.891
HAsO3-2	4.03E-23	2.05E-23	-22.688
HAsO4-2	6.47E-10	3.29E-10	-9.483
HCO3-	1.15E-05	9.76E-06	-5.011
HCrO4-	3.62E-07	3.06E-07	-6.514
HF (aq)	2.79E-09	2.82E-09	-8.551
HF2-	2.83E-16	2.37E-16	-15.625

Species	Concentration	Activity	Log activity
Hg(CO3)2-2	5.49E-36	2.79E-36	-35.554
Hg(HS)2 (aq)	6.27E-84	6.32E-84	-83.199
Hg(N3)2 (aq)	1.16E-15	1.17E-15	-14.932
Hg(NH3)2+2	1.34E-27	6.8E-28	-27.168
Hg(NH3)4+2	1.67E-43	8.5E-44	-43.071
Hg(NO2)2 (aq)	6.77E-87	6.83E-87	-86.166
Hg(NO2)3-	3.4E-119	2.9E-119	-118.536
Hg(NO2)4-2	1.8E-152	9.2E-153	-152.036
Hg(NO3)2 (aq)	5.8E-120	5.8E-120	-119.234
Hg(OH)2	3.8E-27	3.83E-27	-26.417
Hg(SO4)2-2	1.14E-30	5.81E-31	-30.236
Hg+2	1.92E-28	9.76E-29	-28.011
Hg2OH+3	1.81E-55	3.95E-56	-55.404
Hg3(OH)3+3	3.25E-79	7.11E-80	-79.148
HgCl+	5.62E-23	4.75E-23	-22.324
HgCl2 (aq)	6.19E-18	6.23E-18	-17.205
HgCl3-1	1.26E-18	1.06E-18	-17.974
HgCl4-2	1.6E-19	8.14E-20	-19.09
HgClOH (aq)	3.29E-22	3.32E-22	-21.479
HgCO3 (aq)	2.7E-28	2.72E-28	-27.565
HgF+	9.66E-35	8.15E-35	-34.089
HgHCO3+	5.35E-28	4.52E-28	-27.345
HgHS2-	2.42E-86	2.05E-86	-85.689
HgN3+	4.99E-10	4.21E-10	-9.376
HgNO2+	7.04E-57	5.94E-57	-56.226
HgNO3+	2.09E-74	1.76E-74	-73.754
HgOH+	3.46E-28	2.92E-28	-27.535

Species	Concentration	Activity	Log activity
HgOHCO3-	3.78E-31	3.2E-31	-30.496
HgS2-2	7.85E-91	3.99E-91	-90.399
HgSO4 (aq)	3.02E-29	3.05E-29	-28.516
HN3 (aq)	2.32E-05	2.34E-05	-4.632
HNO2 (aq)	1.72E-35	1.74E-35	-34.76
HPO4-2	1.19E-09	6.17E-10	-9.209
HS-1	2.49E-47	2.08E-47	-46.681
HSO4-	1.64E-05	1.39E-05	-4.858
K+1	0.000148	0.000124	-3.908
K2HPO4 (aq)	1.01E-16	1.02E-16	-15.991
K2PO4-	6.96E-24	5.88E-24	-23.231
KCl (aq)	1.11E-06	1.12E-06	-5.95
KCr2O7-	5.36E-15	4.53E-15	-14.344
KCrO4-	5.29E-13	4.47E-13	-12.35
KF (aq)	1.26E-12	1.27E-12	-11.897
KH2PO4 (aq)	1.93E-10	1.95E-10	-9.71
KHPO4-	5.52E-13	4.7E-13	-12.328
KNO3 (aq)	7.47E-50	7.53E-50	-49.123
KOH (aq)	9.83E-15	9.9E-15	-14.004
KPO4-2	1.12E-20	5.7E-21	-20.244
KSO4-	1.6E-06	1.36E-06	-5.866
Mg DOM1	2.43E-07	2.18E-07	-6.662
Mg(NH3)2+2	1.2E-20	6.09E-21	-20.215
Mg+2	0.002478	0.00136	-2.866
Mg2CO3+2	5.15E-14	2.62E-14	-13.582
MgCl+	0.000104	8.77E-05	-4.057
MgCO3 (aq)	3.5E-12	3.53E-12	-11.452
MgF+	2.39E-09	2.02E-09	-8.695

Species	Concentration	Activity	Log activity
MgHCO3+	1.53E-07	1.29E-07	-6.89
MgHPO4 (aq)	4.44E-10	4.48E-10	-9.349
MgOH+	2.47E-11	2.12E-11	-10.675
MgPO4-	1.27E-16	1.08E-16	-15.967
MgSO4 (aq)	0.000422	0.000425	-3.372
Mn+3	5.1E-06	1.46E-06	-5.835
N3-1	5.38E-06	4.54E-06	-5.343
Na+1	0.006836	0.005786	-2.238
Na2HPO4 (aq)	1.46E-13	1.48E-13	-12.831
Na2PO4-	3.25E-20	2.75E-20	-19.561
NaCl (aq)	5.51E-05	5.55E-05	-4.255
NaCO3-	6.13E-13	5.21E-13	-12.283
NaCrO4-	3.31E-11	2.8E-11	-10.553
NaF (aq)	1.14E-10	1.15E-10	-9.94
NaH2PO4 (aq)	9.04E-09	9.11E-09	-8.04
NaHCO3 (aq)	3.32E-08	3.35E-08	-7.475
NaHPO4-	4E-11	3.4E-11	-10.468
NaNO3 (aq)	1.29E-48	1.3E-48	-47.886
NaOH (aq)	3.15E-13	3.17E-13	-12.499
NaPO4-2	5.78E-19	2.94E-19	-18.532
NaSO4-	6.86E-05	5.84E-05	-4.234
NH3 (aq)	1.61E-09	1.62E-09	-8.79
NH4+1	0.000712	0.000591	-3.228
NH4Cr2O7-	2.98E-14	2.51E-14	-13.6
NH4SO4-	1.4E-05	1.18E-05	-4.928
Ni DOM1	7.25E-09	6.5E-09	-8.187
Ni(N3)2 (aq)	3.27E-15	3.3E-15	-14.482
Ni(NH3)2+2	9.67E-19	4.92E-19	-18.308

Species	Concentration	Activity	Log activity
Ni(NH3)3+2	9.08E-26	4.62E-26	-25.336
Ni(NH3)4+2	2.53E-33	1.29E-33	-32.891
Ni(NH3)5+2	2.27E-41	1.16E-41	-40.937
Ni(NH3)6+2	4.35E-50	2.21E-50	-49.655
Ni(NO2)2 (aq)	1.5E-72	1.51E-72	-71.821
Ni(OH)2 (aq)	1.62E-17	1.64E-17	-16.786
Ni(OH)3-	1.95E-24	1.65E-24	-23.784
Ni(SO4)2-2	7.28E-11	3.7E-11	-10.431
Ni+2	3.18E-06	1.62E-06	-5.792
NiCl+	1.18E-08	9.99E-09	-8
NiCl2 (aq)	6.05E-12	6.1E-12	-11.215
NiCO3 (aq)	2.17E-13	2.18E-13	-12.661
NiF+	7.75E-13	6.54E-13	-12.184
NiH2PO4+	1.28E-11	1.08E-11	-10.967
NiHCO3+	1.83E-09	1.55E-09	-8.811
NiHPO4 (aq)	7.23E-13	7.29E-13	-12.137
NiHS+	1.23E-47	1.04E-47	-46.983
NiN3+	1.64E-10	1.38E-10	-9.859
NiNH3+2	3.38E-12	1.72E-12	-11.765
NiNO2+	5.65E-39	4.77E-39	-38.321
NiNO3+	3.83E-51	3.23E-51	-50.49
NiOH+	1.17E-12	9.91E-13	-12.004
NiSO4 (aq)	5.49E-07	5.54E-07	-6.257
NO2-1	1.46E-34	1.23E-34	-33.91
NO3-1	9.55E-46	7.97E-46	-45.099
OH-	5.5E-11	4.61E-11	-10.337
Pb DOM1	5.25E-09	4.71E-09	-8.327
Pb(CO3)2-2	3.34E-21	1.7E-21	-20.769

Species	Concentration	Activity	Log activity
Pb(HS)2 (aq)	1.18E-86	1.19E-86	-85.924
Pb(HS)3-	5.9E-132	4.9E-132	-131.306
Pb(NO2)2 (aq)	2.85E-73	2.88E-73	-72.541
Pb(NO3)2 (aq)	2.56E-97	2.58E-97	-96.589
Pb(OH)2 (aq)	1.18E-17	1.19E-17	-16.926
Pb(OH)3-	1.41E-24	1.19E-24	-23.923
Pb(SO4)2-2	2.97E-10	1.51E-10	-9.821
Pb+2	2.9E-08	1.47E-08	-7.831
Pb2OH+3	3.99E-18	8.71E-19	-18.06
Pb3(OH)4+2	1.6E-32	8.13E-33	-32.09
Pb4(OH)4+4	2.77E-36	1.85E-37	-36.733
PbCl+	9.61E-09	8.12E-09	-8.091
PbCl2 (aq)	2.88E-10	2.9E-10	-9.537
PbCl3-	4.67E-12	3.95E-12	-11.404
PbCl4-2	4.86E-14	2.47E-14	-13.607
PbCO3 (aq)	1.8E-13	1.82E-13	-12.74
PbF+	5.53E-14	4.67E-14	-13.331
PbF2 (aq)	1.28E-20	1.29E-20	-19.891
PbH2PO4+	4.36E-13	3.68E-13	-12.434
PbHCO3+	1.08E-10	9.11E-11	-10.04
PbHPO4 (aq)	9.22E-15	9.29E-15	-14.032
PbNO2+	6.95E-40	5.87E-40	-39.231
PbNO3+	2.12E-52	1.79E-52	-51.748
PbOH+	3.16E-12	2.67E-12	-11.573
PbSO4 (aq)	1.33E-08	1.35E-08	-7.871
PO4-3	9.29E-18	2.11E-18	-17.676
S-2	8.02E-61	4.15E-61	-60.382
SO4-2	0.003728	0.001863	-2.73

Species	Concentration	Activity	Log activity
Zn DOM1	7.02E-08	6.3E-08	-7.201
Zn(CO3)2-2	5.13E-21	2.61E-21	-20.583
Zn(N3)2 (aq)	1.93E-14	1.95E-14	-13.711
Zn(N3)3-	5.99E-19	5.05E-19	-18.296
Zn(NH3)2+2	2.23E-18	1.14E-18	-17.945
Zn(NH3)3+2	1.07E-24	5.42E-25	-24.266
Zn(NH3)4+2	2.49E-31	1.27E-31	-30.897
Zn(NO2)2 (aq)	2.35E-72	2.37E-72	-71.625
Zn(NO3)2 (aq)	3.12E-96	3.14E-96	-95.503
Zn(OH)2 (aq)	1.25E-14	1.26E-14	-13.9
Zn(OH)3-	4.74E-22	4.01E-22	-21.397
Zn(OH)4-2	1.26E-30	6.39E-31	-30.195
Zn(SO4)2-2	1.28E-07	6.53E-08	-7.185
Zn+2	1.85E-05	9.88E-06	-5.005
Zn2OH+3	1.84E-15	4.02E-16	-15.396
Zn2S3-2	3.9E-138	2E-138	-137.705
Zn4S6-4	9.9E-274	6.6E-275	-274.18
ZnCl+	5.38E-07	4.52E-07	-6.345
ZnCl2 (aq)	4.92E-09	4.96E-09	-8.305
ZnCl3-	1.06E-10	8.95E-11	-10.048
ZnCl4-2	1.39E-12	7.07E-13	-12.15
ZnCO3 (aq)	2.05E-12	2.07E-12	-11.684
ZnF+	4.48E-12	3.79E-12	-11.422
ZnHCO3+	2.87E-09	2.42E-09	-8.615
ZnHPO4 (aq)	1.01E-11	1.02E-11	-10.991
ZnN3+	7.64E-10	6.45E-10	-9.19
ZnNH3+2	5.95E-12	3.03E-12	-11.519
ZnNO2+	8.68E-39	7.33E-39	-38.135

Species	Concentration	Activity	Log activity
ZnNO3+	2.5E-50	2.11E-50	-49.676
ZnOH+	5.39E-11	4.55E-11	-10.342
ZnS (aq)	7.58E-50	7.64E-50	-49.117
ZnSO4 (aq)	3.66E-06	3.69E-06	-5.433

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Species	Concentration	Activity	Log activity
Al DOM1	3.49E-08	3.47E-08	-7.46
Al(OH)2+	3.41E-09	2.89E-09	-8.539
Al(OH)3 (aq)	5.4E-11	5.45E-11	-10.264
Al(OH)4-	2.89E-12	2.43E-12	-11.614
Al(SO4)2-	7.03E-08	5.91E-08	-7.228
Al+3	1.13E-07	3.16E-08	-7.5
Al2(OH)2+4	1.13E-12	7.11E-14	-13.148
Al2(OH)2CO3+2	1.42E-10	7.13E-11	-10.147
Al2PO4+3	1.62E-11	3.42E-12	-11.466
Al3(OH)4+5	4.34E-16	5.74E-18	-17.241
AlCl+2	4.39E-10	2.2E-10	-9.658
AlF+2	2.44E-06	1.26E-06	-5.9
AlF2+	2.44E-06	2.06E-06	-5.685
AlF3 (aq)	9.92E-08	1E-07	-7
AlF4-	2.47E-10	2.08E-10	-9.682
AlHPO4+	1.38E-08	1.16E-08	-7.936
AlOH+2	3.16E-08	1.63E-08	-7.788
AlSO4+	6.05E-07	5.09E-07	-6.293
AsO4-3	2.32E-15	4.88E-16	-15.311
AsS(OH)HS-	1.3E-108	1.1E-108	-107.957
Ca DOM1	1.03E-05	9.22E-06	-5.035
Ca(NH3)2+2	2.92E-18	1.46E-18	-17.835
Ca(NO3)2	3.24E-78	3.27E-78	-77.485
Ca+2	0.003149	0.001677	-2.775
CaCl+	8.08E-05	6.79E-05	-4.168
CaCO3 (aq)	8.29E-10	8.36E-10	-9.078
CaCrO4 (aq)	8.85E-09	8.92E-09	-8.05

Species	Concentration	Activity	Log activity
CaF+	9.34E-08	7.89E-08	-7.103
CaH2PO4+	6.45E-08	5.47E-08	-7.262
CaHCO3+	1.95E-06	1.66E-06	-5.78
CaHPO4 (aq)	6.73E-09	6.79E-09	-8.168
CaNH3+2	1.78E-10	8.91E-11	-10.05
CaNO3+	5.34E-38	4.49E-38	-37.348
CaOH+	1.61E-11	1.37E-11	-10.863
CaPO4-	1.7E-12	1.44E-12	-11.841
CaSO4 (aq)	0.000952	0.00096	-3.018
Cd DOM1	3.86E-11	3.45E-11	-10.462
Cd(CO3)2-2	1.04E-20	5.18E-21	-20.285
Cd(HS)2 (aq)	4.8E-105	4.9E-105	-104.313
Cd(HS)3-	1.1E-158	9.5E-159	-158.024
Cd(HS)4-2	9.3E-212	4.6E-212	-211.334
Cd(NH3)2+2	6.78E-20	3.39E-20	-19.469
Cd(NH3)3+2	2.8E-26	1.4E-26	-25.853
Cd(NH3)4+2	3.41E-33	1.71E-33	-32.768
Cd(NO2)2 (aq)	1.61E-57	1.62E-57	-56.791
Cd(NO3)2 (aq)	2.42E-79	2.44E-79	-78.612
Cd(OH)2 (aq)	1.26E-19	1.27E-19	-18.897
Cd(OH)3-	1.49E-27	1.25E-27	-26.903
Cd(OH)4-2	2.57E-36	1.28E-36	-35.891
Cd(SO4)2-2	1.2E-10	6.03E-11	-10.22
Cd+2	5E-09	2.5E-09	-8.602
Cd2OH+3	6.27E-22	1.32E-22	-21.879
CdCl+	4.71E-09	3.96E-09	-8.402
CdCl2 (aq)	2.69E-10	2.71E-10	-9.566

Species	Concentration	Activity	Log activity
CdCO3 (aq)	2.03E-14	2.05E-14	-13.689
CdF+	1.82E-13	1.53E-13	-12.815
CdHCO3+	7.02E-12	5.91E-12	-11.229
CdHPO4 (aq)	1.07E-13	1.08E-13	-12.968
CdHS+	9.39E-57	7.9E-57	-56.102
CdNH3+2	3.4E-14	1.7E-14	-13.77
CdNO2+	3.63E-33	3.06E-33	-32.515
CdNO3+	9.91E-44	8.33E-44	-43.079
CdOH+	1.1E-14	9.28E-15	-14.032
CdSO4 (aq)	1.42E-09	1.43E-09	-8.844
Cl-1	0.020517	0.01705	-1.768
CO3-2	6.77E-10	3.49E-10	-9.457
Cr2O7-2	7.31E-12	3.66E-12	-11.437
CrO3Cl-	3.73E-13	3.14E-13	-12.504
CrO3H2PO4-	8.88E-15	7.47E-15	-14.127
CrO3HPO4-2	3.1E-12	1.55E-12	-11.81
CrO3SO4-2	4.91E-12	2.46E-12	-11.609
CrO4-2	1.83E-08	9.03E-09	-8.044
Cu DOM1	1.23E-08	1.1E-08	-7.957
Cu(CO3)2-2	7.76E-17	3.89E-17	-16.411
Cu(N3)2 (aq)	1.91E-13	1.92E-13	-12.716
Cu(N3)3-	1.93E-16	1.62E-16	-15.791
Cu(N3)4-2	1.43E-20	7.16E-21	-20.145
Cu(NH3)2+2	4.66E-16	2.33E-16	-15.632
Cu(NH3)3+2	6.31E-21	3.16E-21	-20.501
Cu(NH3)4+2	1.77E-26	8.83E-27	-26.054
Cu(NO2)2 (aq)	3.14E-57	3.17E-57	-56.499
Cu(NO3)2 (aq)	4.89E-79	4.93E-79	-78.307

Species	Concentration	Activity	Log activity
Cu(OH)2 (aq)	3.18E-15	3.21E-15	-14.494
Cu(OH)3-	5.46E-20	4.59E-20	-19.338
Cu(OH)4-2	6.12E-29	3.06E-29	-28.514
Cu+2	3.82E-08	2.01E-08	-7.697
Cu2(OH)2+2	9.24E-17	4.62E-17	-16.335
Cu2OH+3	2.56E-17	5.39E-18	-17.269
Cu2S3-2	8.4E-170	4.2E-170	-169.376
Cu3(OH)4+2	5.94E-25	2.97E-25	-24.527
CuCl+	7.26E-10	6.08E-10	-9.216
CuCl2 (aq)	1.71E-12	1.73E-12	-11.762
CuCl3-	2.73E-16	2.29E-16	-15.64
CuCl4-2 1	5.43E-20	2.77E-20	-19.558
CuCO3 (aq)	4.1E-11	4.13E-11	-10.384
CuF+	4.14E-12	3.48E-12	-11.459
CuHCO3+	1.12E-10	9.44E-11	-10.025
CuHPO4 (aq)	2.25E-12	2.27E-12	-11.643
CuHSO4+	1.44E-13	1.21E-13	-12.916
CuN3+	2.91E-10	2.45E-10	-9.612
CuNH3+2	9E-12	4.5E-12	-11.346
CuNO2+	3.03E-32	2.55E-32	-31.593
CuNO3+	6.28E-43	5.28E-43	-42.277
CuOH+	4.62E-11	3.87E-11	-10.412
CuS(aq)	9.74E-62	9.82E-62	-61.008
CuSO4 (aq)	1.12E-08	1.12E-08	-7.949
DOC (Gaussian DOM)	0.000333	0.000336	-3.474
DOM1	1.64E-05	4.23E-06	-5.374
F-1	4.97E-06	4.15E-06	-5.382

Species	Concentration	Activity	Log activity
Fe DOM1	3.42E-14	3.4E-14	-13.469
Fe(N3)2+	1.25E-17	1.05E-17	-16.979
Fe(N3)3 (aq)	3.75E-20	3.78E-20	-19.422
Fe(NH3)2+2	1.22E-21	6.1E-22	-21.215
Fe(NH3)3+2	5.94E-29	2.97E-29	-28.527
Fe(NH3)4+2	1.23E-36	6.18E-37	-36.209
Fe(NO2)2+	9.01E-64	7.57E-64	-63.121
Fe(NO2)3 (aq)	1.05E-87	1.06E-87	-86.977
Fe(OH)2 (aq)	6.46E-20	6.51E-20	-19.186
Fe(OH)2+	1.21E-12	1.03E-12	-11.988
Fe(OH)3-	2.23E-25	1.88E-25	-24.725
Fe(OH)3 (aq)	3.38E-17	3.41E-17	-16.467
Fe(OH)4-	2.63E-20	2.23E-20	-19.651
Fe(SO4)2-	1.63E-16	1.37E-16	-15.863
Fe+2	2.07E-08	1.09E-08	-7.964
Fe+3	3.51E-16	9.81E-17	-16.009
Fe2(OH)2+4	8.87E-25	5.56E-26	-25.255
Fe3(OH)4+5	1.47E-33	1.94E-35	-34.712
FeCl+	1.39E-10	1.17E-10	-9.933
FeCl+2	7.18E-17	3.66E-17	-16.437
FeCrO4+	3.87E-17	3.25E-17	-16.488
FeF+	8.68E-13	7.3E-13	-12.137
FeF+2	7.6E-16	3.87E-16	-15.412
FeF2+	7.19E-17	6.07E-17	-16.217
FeF3 (aq)	2.31E-19	2.33E-19	-18.632
FeH2PO4+	8.6E-12	7.29E-12	-11.138
FeH2PO4+2	4.81E-18	2.48E-18	-17.605
FeHCO3+	1.2E-11	1.02E-11	-10.992

Species	Concentration	Activity	Log activity
FeHPO4 (aq)	3.64E-13	3.67E-13	-12.436
FeHPO4+	1.22E-14	1.04E-14	-13.984
FeHS+	1.66E-58	1.4E-58	-57.855
FeN3+2	5.14E-16	2.57E-16	-15.59
FeNH3+2	9.85E-15	4.93E-15	-14.307
FeNO2+2	3.77E-39	1.89E-39	-38.725
FeOH+	2.36E-13	1.99E-13	-12.701
FeOH+2	1.29E-13	6.58E-14	-13.182
FeSO4 (aq)	6.52E-09	6.58E-09	-8.182
FeSO4+	4.01E-15	3.39E-15	-14.47
H DOM1	8.99E-07	5.13E-07	-6.29
H+1	1.15E-05	0.00001	-5
H2AsO3-	5.79E-15	4.87E-15	-14.312
H2AsO4-	4.82E-07	4.05E-07	-6.392
H2CO3* (aq)	0.002438	0.002459	-2.609
H2CrO4 (aq)	1.06E-12	1.07E-12	-11.971
H2PO4-	2.03E-06	1.72E-06	-5.764
H2S (aq)	4.45E-54	4.49E-54	-53.348
H3AsO3	1.05E-10	1.06E-10	-9.974
H3AsO4	7.17E-10	7.23E-10	-9.141
H3PO4	2.16E-09	2.18E-09	-8.661
HAsO3-2	4.95E-24	2.48E-24	-23.606
HAsO4-2	7.94E-09	3.97E-09	-8.401
HCO3-	0.000111	9.37E-05	-4.028
HCrO4-	3.38E-07	2.84E-07	-6.546
HF (aq)	5.16E-08	5.21E-08	-7.283
HF2-	9.73E-13	8.12E-13	-12.091
Hg(CO3)2-2	1.38E-36	6.93E-37	-36.159

Species	Concentration	Activity	Log activity
Hg(HS)2 (aq)	3.7E-106	3.7E-106	-105.427
Hg(N3)2 (aq)	4.28E-17	4.31E-17	-16.365
Hg(NH3)2+2	3.55E-30	1.78E-30	-29.75
Hg(NH3)4+2	4.32E-44	2.16E-44	-43.665
Hg(NO2)2 (aq)	1.77E-75	1.79E-75	-74.748
Hg(NO2)3-	8.9E-100	7.5E-100	-99.124
Hg(NO2)4-2	4.7E-125	2.3E-125	-124.63
Hg(NO3)2 (aq)	1.5E-104	1.5E-104	-103.816
Hg(OH)2	1.02E-29	1.03E-29	-28.987
Hg(SO4)2-2	6.86E-35	3.44E-35	-34.464
Hg+2	5.25E-33	2.63E-33	-32.581
Hg2OH+3	1.36E-63	2.86E-64	-63.544
Hg3(OH)3+3	6.58E-90	1.39E-90	-89.858
HgCl+	1.51E-27	1.27E-27	-26.895
HgCl2 (aq)	1.65E-22	1.66E-22	-21.779
HgCl3-1	3.36E-23	2.82E-23	-22.549
HgCl4-2	4.31E-24	2.15E-24	-23.667
HgClOH (aq)	8.82E-26	8.89E-26	-25.051
HgCO3 (aq)	6.98E-31	7.03E-31	-30.153
HgF+	4.83E-37	4.06E-37	-36.391
HgHCO3+	1.39E-31	1.17E-31	-30.933
HgHS2-	1.4E-107	1.2E-107	-106.917
HgN3+	4.99E-10	4.19E-10	-9.377
HgNO2+	1.88E-53	1.58E-53	-52.802
HgNO3+	5.57E-69	4.68E-69	-68.33
HgOH+	9.35E-32	7.86E-32	-31.105
HgOHCO3-	9.82E-33	8.26E-33	-32.083

Species	Concentration	Activity	Log activity
HgS2-2	4.7E-111	2.4E-111	-110.627
HgSO4 (aq)	1.21E-33	1.22E-33	-32.915
HN3 (aq)	8.57E-06	8.64E-06	-5.063
HNO2 (aq)	1.7E-28	1.71E-28	-27.766
HPO4-2	2.05E-08	1.05E-08	-7.98
HS-1	3.7E-56	3.09E-56	-55.511
HSO4-	2.44E-06	2.05E-06	-5.688
K+1	0.000147	0.000123	-3.912
K2HPO4 (aq)	1.68E-15	1.7E-15	-14.77
K2PO4-	1.16E-21	9.78E-22	-21.01
KCl (aq)	1.1E-06	1.11E-06	-5.956
KCr2O7-	4.6E-15	3.87E-15	-14.412
KCrO4-	4.89E-12	4.11E-12	-11.386
KF (aq)	2.3E-10	2.32E-10	-9.634
KH2PO4 (aq)	3.25E-10	3.27E-10	-9.485
KHPO4-	9.31E-12	7.89E-12	-11.103
KNO3 (aq)	7.29E-40	7.35E-40	-39.134
KOH (aq)	9.73E-14	9.81E-14	-13.008
KPO4-2	1.91E-18	9.57E-19	-18.019
KSO4-	2.36E-06	2E-06	-5.699
Mg DOM1	7.74E-07	6.93E-07	-6.159
Mg(NH3)2+2	1.1E-18	5.49E-19	-18.261
Mg+2	0.002326	0.001261	-2.899
Mg2CO3+2	4.32E-12	2.16E-12	-11.666
MgCl+	9.62E-05	8.09E-05	-4.092
MgCO3 (aq)	3.12E-10	3.14E-10	-9.503
MgF+	4.11E-07	3.46E-07	-6.461
MgHCO3+	1.37E-06	1.15E-06	-5.94

Species	Concentration	Activity	Log activity
MgHPO4 (aq)	6.98E-09	7.04E-09	-8.152
MgOH+	2.29E-10	1.96E-10	-9.708
MgPO4-	2E-14	1.7E-14	-13.771
MgSO4 (aq)	0.000579	0.000584	-3.234
Mn+3	6.47E-08	1.81E-08	-7.743
N3-1	2E-05	1.68E-05	-4.775
Na+1	0.006804	0.005736	-2.241
Na2HPO4 (aq)	2.44E-12	2.46E-12	-11.609
Na2PO4-	5.45E-18	4.58E-18	-17.339
NaCl (aq)	5.44E-05	5.48E-05	-4.261
NaCO3-	5.85E-11	4.96E-11	-10.304
NaCrO4-	3.06E-10	2.57E-10	-9.589
NaF (aq)	2.09E-08	2.1E-08	-7.677
NaH2PO4 (aq)	1.52E-08	1.53E-08	-7.815
NaHCO3 (aq)	3.16E-07	3.19E-07	-6.497
NaHPO4-	6.75E-10	5.72E-10	-9.243
NaNO3 (aq)	1.26E-38	1.27E-38	-37.896
NaOH (aq)	3.12E-12	3.14E-12	-11.502
NaPO4-2	9.87E-17	4.94E-17	-16.306
NaSO4-	0.000101	8.58E-05	-4.066
NH3 (aq)	1.58E-08	1.6E-08	-7.796
NH4+1	0.000705	0.000583	-3.235
NH4Cr2O7-	2.54E-14	2.14E-14	-13.67
NH4SO4-	2.05E-05	1.72E-05	-4.764
Ni DOM1	2.28E-08	2.04E-08	-7.69
Ni(N3)2 (aq)	4.09E-14	4.13E-14	-13.384
Ni(NH3)2+2	8.73E-17	4.37E-17	-16.36
Ni(NH3)3+2	8.08E-23	4.04E-23	-22.393

Species	Concentration	Activity	Log activity
Ni(NH3)4+2	2.22E-29	1.11E-29	-28.955
Ni(NH3)5+2	1.97E-36	9.84E-37	-36.007
Ni(NH3)6+2	3.72E-44	1.86E-44	-43.731
Ni(NO2)2 (aq)	1.33E-56	1.34E-56	-55.872
Ni(OH)2 (aq)	1.48E-15	1.5E-15	-14.825
Ni(OH)3-	1.79E-21	1.51E-21	-20.822
Ni(SO4)2-2	1.49E-10	7.44E-11	-10.128
Ni+2	2.95E-06	1.48E-06	-5.83
NiCl+	1.08E-08	9.1E-09	-8.041
NiCl2 (aq)	5.49E-12	5.54E-12	-11.257
NiCO3 (aq)	1.9E-11	1.92E-11	-10.717
NiF+	1.32E-10	1.11E-10	-9.956
NiH2PO4+	1.99E-11	1.67E-11	-10.777
NiHCO3+	1.61E-08	1.36E-08	-7.867
NiHPO4 (aq)	1.12E-11	1.13E-11	-10.947
NiHS+	1.68E-56	1.41E-56	-55.851
NiN3+	5.56E-10	4.68E-10	-9.33
NiNH3+2	3.1E-11	1.55E-11	-10.81
NiNO2+	5.11E-31	4.3E-31	-30.366
NiNO3+	3.47E-41	2.92E-41	-40.535
NiOH+	1.08E-11	9.06E-12	-11.043
NiSO4 (aq)	7.44E-07	7.51E-07	-6.125
NO2-1	1.44E-26	1.21E-26	-25.916
NO3-1	9.46E-36	7.85E-36	-35.105
OH-	5.52E-10	4.61E-10	-9.337
Pb DOM1	1.32E-08	1.19E-08	-7.926
Pb(CO3)2-2	2.3E-17	1.15E-17	-16.939
Pb(HS)2 (aq)	1.9E-104	1.9E-104	-103.717

Species	Concentration	Activity	Log activity
Pb(HS)3-	1.4E-158	1.2E-158	-157.928
Pb(NO2)2 (aq)	2.03E-57	2.05E-57	-56.688
Pb(NO3)2 (aq)	1.82E-77	1.84E-77	-76.736
Pb(OH)2 (aq)	8.62E-16	8.7E-16	-15.061
Pb(OH)3-	1.04E-21	8.75E-22	-21.058
Pb(SO4)2-2	4.86E-10	2.43E-10	-9.614
Pb+2	2.16E-08	1.08E-08	-7.966
Pb2OH+3	2.22E-17	4.69E-18	-17.329
Pb3(OH)4+2	6.41E-29	3.21E-29	-28.494
Pb4(OH)4+4	8.54E-33	5.35E-34	-33.271
PbCl+	7.05E-09	5.93E-09	-8.227
PbCl2 (aq)	2.09E-10	2.11E-10	-9.675
PbCl3-	3.4E-12	2.86E-12	-11.544
PbCl4-2	3.56E-14	1.78E-14	-13.749
PbCO3 (aq)	1.27E-11	1.28E-11	-10.893
PbF+	7.53E-12	6.33E-12	-11.198
PbF2 (aq)	3.2E-16	3.23E-16	-15.491
PbH2PO4+	5.44E-13	4.58E-13	-12.339
PbHCO3+	7.63E-10	6.42E-10	-9.193
PbHPO4 (aq)	1.15E-13	1.16E-13	-12.937
PbNO2+	5.05E-32	4.25E-32	-31.372
PbNO3+	1.54E-42	1.29E-42	-41.889
PbOH+	2.33E-11	1.96E-11	-10.708
PbSO4 (aq)	1.45E-08	1.46E-08	-7.835
PO4-3	1.63E-15	3.58E-16	-15.446
S-2	1.21E-68	6.15E-69	-68.211
SO4-2	0.005623	0.00276	-2.559
Zn DOM1	2.19E-07	1.96E-07	-6.708

Species	Concentration	Activity	Log activity
Zn(CO3)2-2	4.35E-17	2.18E-17	-16.662
Zn(N3)2 (aq)	2.39E-13	2.41E-13	-12.618
Zn(N3)3-	2.76E-17	2.32E-17	-16.635
Zn(NH3)2+2	2E-16	1E-16	-16
Zn(NH3)3+2	9.4E-22	4.7E-22	-21.328
Zn(NH3)4+2	2.17E-27	1.08E-27	-26.965
Zn(NO2)2 (aq)	2.07E-56	2.09E-56	-55.68
Zn(NO3)2 (aq)	2.74E-76	2.77E-76	-75.558
Zn(OH)2 (aq)	1.13E-12	1.14E-12	-11.943
Zn(OH)3-	4.31E-19	3.63E-19	-18.44
Zn(OH)4-2	1.16E-26	5.78E-27	-26.238
Zn(SO4)2-2	2.6E-07	1.3E-07	-6.886
Zn+2	1.7E-05	8.95E-06	-5.048
Zn2OH+3	1.57E-14	3.3E-15	-14.482
Zn2S3-2	1.1E-161	5.3E-162	-161.278
ZnCl+	4.87E-07	4.08E-07	-6.389
ZnCl2 (aq)	4.42E-09	4.45E-09	-8.351
ZnCl3-	9.53E-11	8.01E-11	-10.096
ZnCl4-2	1.26E-12	6.3E-13	-12.2
ZnCO3 (aq)	1.78E-10	1.8E-10	-9.745
ZnF+	7.54E-10	6.34E-10	-9.198
ZnHCO3+	2.51E-08	2.11E-08	-7.676
ZnHPO4 (aq)	1.56E-10	1.57E-10	-9.805
ZnN3+	2.57E-09	2.16E-09	-8.665
ZnNH3+2	5.4E-11	2.7E-11	-10.568
ZnNO2+	7.78E-31	6.54E-31	-30.184
ZnNO3+	2.24E-40	1.88E-40	-39.725
ZnOH+	4.9E-10	4.12E-10	-9.385

Species	Concentration	Activity	Log activity
ZnS (aq)	1.02E-57	1.03E-57	-56.989
ZnSO4 (aq)	4.91E-06	4.95E-06	-5.305

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Species	Concentration	Activity	Log activity
Al DOM1	3.71E-11	3.68E-11	-10.434
Al(OH)2+	3.41E-10	2.89E-10	-9.539
Al(OH)3 (aq)	5.4E-11	5.45E-11	-10.264
Al(OH)4-	2.89E-11	2.43E-11	-10.614
Al(SO4)2-	7.02E-11	5.91E-11	-10.229
Al+3	1.14E-10	3.16E-11	-10.5
Al2(OH)2+4	1.15E-16	7.11E-18	-17.148
Al2(OH)2CO3+2	1.02E-12	5.08E-13	-12.294
Al2PO4+3	5.78E-16	1.21E-16	-15.917
Al3(OH)4+5	4.41E-21	5.74E-23	-22.241
AlCl+2	4.4E-13	2.2E-13	-12.658
AlF+2	5.53E-09	2.85E-09	-8.545
AlF2+	1.25E-08	1.06E-08	-7.976
AlF3 (aq)	1.15E-09	1.16E-09	-8.936
AlF4-	6.49E-12	5.45E-12	-11.263
AlHPO4+	4.88E-11	4.1E-11	-10.387
AlOH+2	3.17E-10	1.63E-10	-9.788
AlSO4+	6.05E-10	5.09E-10	-9.293
AsO4-3	2.04E-13	4.26E-14	-13.37
AsS(OH)HS-	1.1E-130	9.6E-131	-130.016
Ca DOM1	1.09E-05	9.73E-06	-5.012
Ca(NH3)2+2	2.91E-16	1.45E-16	-15.838
Ca(NO3)2	3.22E-58	3.25E-58	-57.488
Ca+2	0.003139	0.001669	-2.778
CaCl+	8.04E-05	6.75E-05	-4.17
CaCO3 (aq)	5.88E-08	5.93E-08	-7.227
CaCrO4 (aq)	5.25E-08	5.29E-08	-7.276

Species	Concentration	Activity	Log activity
CaF+	2.1E-07	1.78E-07	-6.75
CaH2PO4+	2.27E-08	1.92E-08	-7.716
CaHCO3+	1.38E-05	1.18E-05	-4.93
CaHPO4 (aq)	2.37E-08	2.39E-08	-7.622
CaNH3+2	1.77E-09	8.86E-10	-9.053
CaNO3+	5.31E-28	4.47E-28	-27.35
CaOH+	1.6E-10	1.37E-10	-9.865
CaPO4-	6E-11	5.08E-11	-10.294
CaSO4 (aq)	0.000947	0.000955	-3.02
Cd DOM1	4.07E-11	3.64E-11	-10.438
Cd(CO3)2-2	5.25E-17	2.62E-17	-16.582
Cd(HS)2 (aq)	4.8E-123	4.8E-123	-122.316
Cd(HS)3-	1.1E-185	9.4E-186	-185.027
Cd(HS)4-2	9.2E-248	4.6E-248	-247.337
Cd(NH3)2+2	6.75E-18	3.37E-18	-17.472
Cd(NH3)3+2	2.79E-23	1.39E-23	-22.857
Cd(NH3)4+2	3.39E-29	1.69E-29	-28.772
Cd(NO2)2 (aq)	1.59E-41	1.61E-41	-40.794
Cd(NO3)2 (aq)	2.41E-59	2.43E-59	-58.615
Cd(OH)2 (aq)	1.25E-17	1.26E-17	-16.899
Cd(OH)3-	1.48E-24	1.24E-24	-23.905
Cd(OH)4-2	2.56E-32	1.28E-32	-31.893
Cd(SO4)2-2	1.2E-10	5.99E-11	-10.223
Cd+2	4.99E-09	2.49E-09	-8.604
Cd2OH+3	6.24E-21	1.31E-21	-20.884
CdCl+	4.69E-09	3.94E-09	-8.405
CdCl2 (aq)	2.67E-10	2.7E-10	-9.569

Species	Concentration	Activity	Log activity
CdCO3 (aq)	1.44E-12	1.45E-12	-11.838
CdF+	4.11E-13	3.45E-13	-12.462
CdHCO3+	4.98E-11	4.19E-11	-10.378
CdHPO4 (aq)	3.76E-13	3.79E-13	-12.422
CdHS+	9.35E-66	7.86E-66	-65.105
CdNH3+2	3.38E-13	1.69E-13	-12.772
CdNO2+	3.61E-25	3.04E-25	-24.518
CdNO3+	9.86E-34	8.29E-34	-33.082
CdOH+	1.1E-13	9.23E-14	-13.035
CdSO4 (aq)	1.41E-09	1.43E-09	-8.846
Cl-1	0.020517	0.017039	-1.769
CO3-2	4.84E-08	2.49E-08	-7.604
Cr2O7-2	2.6E-12	1.3E-12	-11.886
CrO3Cl-	2.22E-14	1.87E-14	-13.729
CrO3H2PO4-	1.87E-16	1.57E-16	-15.803
CrO3HPO4-2	6.55E-13	3.27E-13	-12.486
CrO3SO4-2	2.93E-13	1.47E-13	-12.834
CrO4-2	1.1E-07	5.38E-08	-7.269
Cu DOM1	1.21E-08	1.08E-08	-7.965
Cu(CO3)2-2	3.66E-13	1.83E-13	-12.738
Cu(N3)2 (aq)	3.31E-13	3.34E-13	-12.476
Cu(N3)3-	4.58E-16	3.85E-16	-15.414
Cu(N3)4-2	4.67E-20	2.33E-20	-19.632
Cu(NH3)2+2	4.32E-14	2.16E-14	-13.666
Cu(NH3)3+2	5.84E-18	2.92E-18	-17.535
Cu(NH3)4+2	1.63E-22	8.15E-23	-22.089
Cu(NO2)2 (aq)	2.9E-41	2.93E-41	-40.533
Cu(NO3)2 (aq)	4.52E-59	4.56E-59	-58.341

Species	Concentration	Activity	Log activity
Cu(OH)2 (aq)	2.95E-13	2.97E-13	-12.527
Cu(OH)3-	5.06E-17	4.25E-17	-16.371
Cu(OH)4-2	5.68E-25	2.84E-25	-24.547
Cu+2	3.55E-08	1.86E-08	-7.73
Cu2(OH)2+2	7.95E-15	3.97E-15	-14.402
Cu2OH+3	2.21E-16	4.62E-17	-16.335
Cu2S3-2	7.2E-194	3.6E-194	- 193.443
Cu3(OH)4+2	4.73E-21	2.36E-21	-20.626
CuCl+	6.73E-10	5.63E-10	-9.249
CuCl2 (aq)	1.59E-12	1.6E-12	-11.796
CuCl3-	2.53E-16	2.12E-16	-15.674
CuCl4-2 1	5.03E-20	2.56E-20	-19.592
CuCO3 (aq)	2.7E-09	2.73E-09	-8.564
CuF+	8.68E-12	7.29E-12	-11.137
CuHCO3+	7.42E-10	6.23E-10	-9.205
CuHPO4 (aq)	7.39E-12	7.45E-12	-11.128
CuHSO4+	1.34E-14	1.12E-14	-13.95
CuN3+	3.69E-10	3.1E-10	-9.508
CuNH3+2	8.35E-11	4.17E-11	-10.38
CuNO2+	2.81E-24	2.36E-24	-23.627
CuNO3+	5.82E-33	4.89E-33	-32.311
CuOH+	4.28E-10	3.59E-10	-9.445
CuS(aq)	9.02E-70	9.09E-70	-69.041
CuSO4 (aq)	1.03E-08	1.04E-08	-7.983
DOC (Gaussian DOM)	0.000333	0.000336	-3.474
DOM1	1.66E-05	4.26E-06	-5.37
F-1	1.13E-05	9.38E-06	-5.028

Species	Concentration	Activity	Log activity
Fe DOM1	7.25E-17	7.2E-17	-16.143
Fe(N3)2+	4.68E-20	3.93E-20	-19.405
Fe(N3)3 (aq)	1.92E-22	1.94E-22	-21.712
Fe(NH3)2+2	2.43E-22	1.22E-22	-21.915
Fe(NH3)3+2	1.18E-28	5.92E-29	-28.228
Fe(NH3)4+2	2.46E-35	1.23E-35	-34.911
Fe(NO2)2+	1.79E-50	1.51E-50	-49.821
Fe(NO2)3 (aq)	2.08E-66	2.1E-66	-65.678
Fe(OH)2 (aq)	1.29E-20	1.3E-20	-19.886
Fe(OH)2+	2.42E-13	2.05E-13	-12.688
Fe(OH)3-	4.45E-25	3.76E-25	-24.425
Fe(OH)3 (aq)	6.74E-17	6.8E-17	-16.167
Fe(OH)4-	5.26E-19	4.46E-19	-18.351
Fe(SO4)2-	3.25E-19	2.73E-19	-18.564
Fe+2	4.13E-11	2.17E-11	-10.664
Fe+3	7.02E-19	1.96E-19	-18.708
Fe2(OH)2+4	3.57E-28	2.21E-29	-28.655
Fe3(OH)4+5	1.19E-37	1.54E-39	-38.811
FeCl+	2.77E-13	2.33E-13	-12.633
FeCl+2	1.44E-19	7.3E-20	-19.137
FeCrO4+	4.6E-19	3.87E-19	-18.412
FeF+	3.92E-15	3.3E-15	-14.482
FeF+2	3.44E-18	1.75E-18	-17.757
FeF2+	7.35E-19	6.21E-19	-18.207
FeF3 (aq)	5.35E-21	5.4E-21	-20.268
FeH2PO4+	6.07E-15	5.14E-15	-14.289
FeH2PO4+2	3.41E-21	1.75E-21	-20.756
FeHCO3+	1.7E-13	1.45E-13	-12.839

Species	Concentration	Activity	Log activity
FeHPO4 (aq)	2.57E-15	2.59E-15	-14.587
FeHPO4+	8.64E-17	7.32E-17	-16.135
FeHS+	3.31E-70	2.79E-70	-69.555
FeN3+2	1.41E-18	7.02E-19	-18.153
FeNH3+2	1.97E-16	9.83E-17	-16.007
FeNO2+2	7.53E-34	3.76E-34	-33.425
FeOH+	4.71E-15	3.97E-15	-14.401
FeOH+2	2.58E-15	1.31E-15	-14.881
FeSO4 (aq)	1.3E-11	1.31E-11	-10.882
FeSO4+	8.01E-18	6.77E-18	-17.17
H DOM1	9.55E-08	5.44E-08	-7.264
H+1	1.15E-06	0.000001	-6
H2AsO3-	5.06E-17	4.25E-17	-16.371
H2AsO4-	4.21E-07	3.54E-07	-6.451
H2CO3* (aq)	0.001737	0.001752	-2.756
H2CrO4 (aq)	6.31E-14	6.37E-14	-13.196
H2PO4-	7.19E-07	6.09E-07	-6.215
H2S (aq)	4.45E-64	4.49E-64	-63.348
H3AsO3	9.18E-14	9.26E-14	-13.033
H3AsO4	6.26E-11	6.31E-11	-10.2
H3PO4	7.65E-11	7.71E-11	-10.113
HAsO3-2	4.34E-25	2.16E-25	-24.665
HAsO4-2	6.95E-08	3.47E-08	-7.46
HCO3-	0.000788	0.000668	-3.175
HCrO4-	2.02E-07	1.69E-07	-6.771
HF (aq)	1.17E-08	1.18E-08	-7.929
HF2-	4.99E-13	4.16E-13	-12.381
Hg(CO3)2-2	5.14E-37	2.57E-37	-36.59

Species	Concentration	Activity	Log activity
Hg(HS)2 (aq)	2.7E-128	2.7E-128	-127.564
Hg(N3)2 (aq)	5.85E-19	5.9E-19	-18.229
Hg(NH3)2+2	2.59E-32	1.3E-32	-31.888
Hg(NH3)4+2	3.15E-44	1.57E-44	-43.804
Hg(NO2)2 (aq)	1.29E-63	1.3E-63	-62.886
Hg(NO2)3-	6.5E-80	5.47E-80	-79.262
Hg(NO2)4-2	3.41E-97	1.7E-97	-96.769
Hg(NO3)2 (aq)	1.1E-88	1.11E-88	-87.954
Hg(OH)2	7.46E-32	7.53E-32	-31.123
Hg(SO4)2-2	5.02E-39	2.5E-39	-38.601
Hg+2	3.84E-37	1.92E-37	-36.717
Hg2OH+3	7.27E-71	1.52E-71	-70.817
Hg3(OH)3+3	2.6E-99	5.4E-100	-99.268
HgCl+	1.1E-31	9.28E-32	-31.032
HgCl2 (aq)	1.2E-26	1.21E-26	-25.916
HgCl3-1	2.45E-27	2.06E-27	-26.687
HgCl4-2	3.14E-28	1.57E-28	-27.804
HgClOH (aq)	6.43E-29	6.49E-29	-28.188
HgCO3 (aq)	3.63E-33	3.66E-33	-32.437
HgF+	7.98E-41	6.71E-41	-40.173
HgHCO3+	7.22E-35	6.07E-35	-34.217
HgHS2-	1E-128	8.8E-129	-128.054
HgN3+	4.99E-10	4.19E-10	-9.378
HgNO2+	1.37E-49	1.15E-49	-48.939
HgNO3+	4.06E-63	3.41E-63	-62.467
HgOH+	6.83E-35	5.74E-35	-34.241
HgOHCO3-	5.11E-34	4.3E-34	-33.367

Species	Concentration	Activity	Log activity
HgS2-2	3.4E-131	1.7E-131	-130.764
HgSO4 (aq)	8.8E-38	8.87E-38	-37.052
HN3 (aq)	1.17E-06	1.18E-06	-5.927
HNO2 (aq)	1.7E-21	1.71E-21	-20.766
HPO4-2	7.29E-08	3.7E-08	-7.431
HS-1	3.7E-65	3.08E-65	-64.511
HSO4-	2.44E-07	2.05E-07	-6.688
K+1	0.000147	0.000122	-3.912
K2HPO4 (aq)	5.95E-15	6E-15	-14.222
K2PO4-	4.11E-20	3.45E-20	-19.462
KCl (aq)	1.1E-06	1.11E-06	-5.956
KCr2O7-	1.63E-15	1.37E-15	-14.862
KCrO4-	2.91E-11	2.45E-11	-10.611
KF (aq)	5.21E-10	5.25E-10	-9.28
KH2PO4 (aq)	1.15E-10	1.16E-10	-9.937
KHPO4-	3.29E-11	2.79E-11	-10.555
KNO3 (aq)	7.28E-30	7.34E-30	-29.134
KOH (aq)	9.72E-13	9.8E-13	-12.009
KPO4-2	6.77E-17	3.38E-17	-16.471
KSO4-	2.36E-06	2E-06	-5.7
Mg DOM1	8.17E-07	7.31E-07	-6.136
Mg(NH3)2+2	1.09E-16	5.45E-17	-16.263
Mg+2	0.00232	0.001255	-2.901
Mg2CO3+2	3.06E-10	1.53E-10	-9.816
MgCl+	9.58E-05	8.05E-05	-4.094
MgCO3 (aq)	2.21E-08	2.23E-08	-7.652
MgF+	9.27E-07	7.8E-07	-6.108
MgHCO3+	9.72E-06	8.14E-06	-5.089

Species	Concentration	Activity	Log activity
MgHPO4 (aq)	2.46E-08	2.48E-08	-7.606
MgOH+	2.29E-09	1.95E-09	-8.709
MgPO4-	7.05E-13	5.97E-13	-12.224
MgSO4 (aq)	0.000576	0.000581	-3.236
Mn+3	6.49E-12	1.81E-12	-11.743
N3-1	2.74E-05	2.3E-05	-4.638
Na+1	0.006802	0.005731	-2.242
Na2HPO4 (aq)	8.61E-12	8.69E-12	-11.061
Na2PO4-	1.92E-16	1.62E-16	-15.791
NaCl (aq)	5.43E-05	5.47E-05	-4.262
NaCO3-	4.17E-09	3.53E-09	-8.452
NaCrO4-	1.82E-09	1.53E-09	-8.814
NaF (aq)	4.72E-08	4.76E-08	-7.322
NaH2PO4 (aq)	5.37E-09	5.42E-09	-8.266
NaHCO3 (aq)	2.25E-06	2.27E-06	-5.644
NaHPO4-	2.39E-09	2.02E-09	-8.694
NaNO3 (aq)	1.26E-28	1.27E-28	-27.897
NaOH (aq)	3.12E-11	3.14E-11	-10.503
NaPO4-2	3.5E-15	1.75E-15	-14.758
NaSO4-	0.000101	8.57E-05	-4.067
NH3 (aq)	1.58E-07	1.6E-07	-6.797
NH4+1	0.000705	0.000582	-3.235
NH4Cr2O7-	9.03E-15	7.59E-15	-14.12
NH4SO4-	2.05E-05	1.72E-05	-4.764
Ni DOM1	2.35E-08	2.1E-08	-7.677
Ni(N3)2 (aq)	7.45E-14	7.52E-14	-13.124
Ni(NH3)2+2	8.49E-15	4.24E-15	-14.373
Ni(NH3)3+2	7.85E-20	3.92E-20	-19.407

Species	Concentration	Activity	Log activity
Ni(NH3)4+2	2.15E-25	1.08E-25	-24.969
Ni(NH3)5+2	1.91E-31	9.52E-32	-31.021
Ni(NH3)6+2	3.6E-38	1.8E-38	-37.746
Ni(NO2)2 (aq)	1.29E-40	1.3E-40	-39.886
Ni(OH)2 (aq)	1.44E-13	1.45E-13	-12.838
Ni(OH)3-	1.74E-18	1.46E-18	-17.835
Ni(SO4)2-2	1.45E-10	7.22E-11	-10.141
Ni+2	2.88E-06	1.44E-06	-5.843
NiCl+	1.05E-08	8.84E-09	-8.054
NiCl2 (aq)	5.33E-12	5.37E-12	-11.27
NiCO3 (aq)	1.32E-09	1.33E-09	-8.877
NiF+	2.9E-10	2.43E-10	-9.614
NiH2PO4+	6.84E-12	5.75E-12	-11.24
NiHCO3+	1.12E-07	9.4E-08	-7.027
NiHPO4 (aq)	3.85E-11	3.89E-11	-10.41
NiHS+	1.63E-65	1.37E-65	-64.864
NiN3+	7.4E-10	6.22E-10	-9.206
NiNH3+2	3.01E-10	1.5E-10	-9.823
NiNO2+	4.97E-23	4.18E-23	-22.379
NiNO3+	3.37E-31	2.83E-31	-30.548
NiOH+	1.05E-10	8.81E-11	-10.055
NiSO4 (aq)	7.23E-07	7.29E-07	-6.137
NO2-1	1.44E-18	1.21E-18	-17.916
NO3-1	9.46E-26	7.85E-26	-25.105
OH-	5.53E-09	4.61E-09	-8.337
Pb DOM1	1.26E-08	1.13E-08	-7.948
Pb(CO3)2-2	1.05E-13	5.24E-14	-13.281
Pb(HS)2 (aq)	1.7E-122	1.7E-122	-121.765

Species	Concentration	Activity	Log activity
Pb(HS)3-	1.3E-185	1.1E-185	-184.976
Pb(NO2)2 (aq)	1.82E-41	1.84E-41	-40.736
Pb(NO3)2 (aq)	1.63E-57	1.65E-57	-56.784
Pb(OH)2 (aq)	7.74E-14	7.8E-14	-13.108
Pb(OH)3-	9.34E-19	7.85E-19	-18.105
Pb(SO4)2-2	4.37E-10	2.18E-10	-9.662
Pb+2	1.94E-08	9.7E-09	-8.013
Pb2OH+3	1.8E-16	3.77E-17	-16.423
Pb3(OH)4+2	4.64E-25	2.32E-25	-24.635
Pb4(OH)4+4	5.58E-29	3.47E-30	-29.46
PbCl+	6.32E-09	5.31E-09	-8.275
PbCl2 (aq)	1.88E-10	1.89E-10	-9.723
PbCl3-	3.05E-12	2.56E-12	-11.592
PbCl4-2	3.19E-14	1.59E-14	-13.797
PbCO3 (aq)	8.12E-10	8.19E-10	-9.087
PbF+	1.53E-11	1.29E-11	-10.891
PbF2 (aq)	1.47E-15	1.48E-15	-14.828
PbH2PO4+	1.73E-13	1.45E-13	-12.838
PbHCO3+	4.88E-09	4.1E-09	-8.387
PbHPO4 (aq)	3.64E-13	3.67E-13	-12.436
PbNO2+	4.53E-24	3.81E-24	-23.42
PbNO3+	1.38E-32	1.16E-32	-31.936
PbOH+	2.09E-10	1.76E-10	-9.755
PbSO4 (aq)	1.3E-08	1.31E-08	-7.882
PO4-3	5.8E-14	1.27E-14	-13.898
S-2	1.21E-76	6.15E-77	-76.211
SO4-2	0.005634	0.002759	-2.559
Zn DOM1	2.3E-07	2.06E-07	-6.687

Species	Concentration	Activity	Log activity
Zn(CO3)2-2	2.2E-13	1.1E-13	-12.96
Zn(N3)2 (aq)	4.44E-13	4.48E-13	-12.349
Zn(N3)3-	7.02E-17	5.9E-17	-16.229
Zn(NH3)2+2	1.98E-14	9.88E-15	-14.005
Zn(NH3)3+2	9.31E-19	4.65E-19	-18.333
Zn(NH3)4+2	2.14E-23	1.07E-23	-22.971
Zn(NO2)2 (aq)	2.05E-40	2.06E-40	-39.685
Zn(NO3)2 (aq)	2.71E-56	2.73E-56	-55.563
Zn(OH)2 (aq)	1.12E-10	1.13E-10	-9.947
Zn(OH)3-	4.27E-16	3.59E-16	-15.445
Zn(OH)4-2	1.15E-22	5.73E-23	-22.242
Zn(SO4)2-2	2.57E-07	1.29E-07	-6.891
Zn+2	1.69E-05	8.86E-06	-5.052
Zn2OH+3	1.54E-13	3.23E-14	-13.49
Zn2S3-2	1E-185	5.2E-186	-185.287
ZnCl+	4.82E-07	4.04E-07	-6.394
ZnCl2 (aq)	4.37E-09	4.41E-09	-8.356
ZnCl3-	9.42E-11	7.92E-11	-10.101
ZnCl4-2	1.25E-12	6.23E-13	-12.206
ZnCO3 (aq)	1.26E-08	1.27E-08	-7.896
ZnF+	1.69E-09	1.42E-09	-8.847
ZnHCO3+	1.77E-07	1.49E-07	-6.827
ZnHPO4 (aq)	5.45E-10	5.5E-10	-9.26
ZnN3+	3.49E-09	2.93E-09	-8.533
ZnNH3+2	5.36E-10	2.67E-10	-9.573
ZnNO2+	7.7E-23	6.47E-23	-22.189
ZnNO3+	2.22E-30	1.86E-30	-29.73
ZnOH+	4.86E-09	4.08E-09	-8.389

Species	Concentration	Activity	Log activity
ZnS (aq)	1.01E-65	1.02E-65	-64.993
ZnSO4 (aq)	4.86E-06	4.9E-06	-5.309

C2: Species distribution

C2.1: pH 2

Component	% of total concentration	Species name
Hg(OH)2	80.107	HgCl2 (aq)
	16.786	HgCl3-1
	2.296	HgCl4-2
	0.809	HgN3+
NH4+1	98.64	NH4+1
	1.36	NH4SO4-
Cl-1	98.758	Cl-1
	0.014	AlCl+2
	0.418	CaCl+
	0.06	FeCl+
	0.488	MgCl+
	0.253	NaCl (aq)
Fe+2	87.152	Fe+2
	0.564	FeCl+
	12.27	FeSO4 (aq)
	0.014	FeH2PO4+
Zn+2	86.188	Zn+2
	0.02	Zn DOM1
	2.377	ZnCl+
	0.021	ZnCl2 (aq)
	11.091	ZnSO4 (aq)
	0.302	Zn(SO4)2-2
F-1	0.031	F-1
	0.311	HF (aq)
	99.505	AlF+2
	0.15	AlF2+

Component	% of total concentration	Species name
SO4-2	39.946	SO4-2
	16.295	HSO4-
	25.486	AlSO4+
	2.827	Al(SO4)2-
	0.035	ZnSO4 (aq)
	3.859	FeSO4 (aq)
	4.005	MgSO4 (aq)
	6.721	CaSO4 (aq)
	0.668	NaSO4-
	0.016	KSO4-
	0.136	NH4SO4-
Ni+2	89.666	Ni+2
	0.013	Ni DOM1
	0.314	NiCl+
	10.006	NiSO4 (aq)
N3-1	0.237	N3-1
	99.762	HN3 (aq)
PO4-3	39.829	H2PO4-
	41.538	H3PO4
	15.252	FeH2PO4+
	1.365	CaH2PO4+
	1.705	AlHPO4+
	0.015	Al2PO4+3
	0.289	NaH2PO4 (aq)
AsO4-3	59.312	H3AsO4
	40.687	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)

Component	% of total concentration	Species name
DOM1	19.827	DOM1
	64.427	H DOM1
	14.909	Al DOM1
	0.761	Ca DOM1
	0.056	Mg DOM1
	0.016	Zn DOM1
Ca+2	86.179	Ca+2
	2.138	CaCl+
	11.677	CaSO4 (aq)
Mg+2	86.796	Mg+2
	3.486	MgCl+
	9.717	MgSO4 (aq)
K+1	98.528	K+1
	0.723	KCl (aq)
	0.749	KSO4-
Na+1	98.522	Na+1
	0.779	NaCl (aq)
	0.699	NaSO4-
CO3-2	99.995	H2CO3* (aq)
Al+3	28.739	Al+3
	0.154	Al DOM1
	0.471	AlF+2
	0.108	AlCl+2
	66.813	AlSO4+
	3.706	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	48.007	Cd+2
	43.235	CdCl+

Component	% of total concentration	Species name
	2.444	CdCl2 (aq)
	6.044	CdSO4 (aq)
	0.264	Cd(SO4)2-2
CrO4-2	98.847	HCrO4-
	0.304	H2CrO4 (aq)
	0.11	CrO3Cl-
	0.724	CrO3SO4-2
Cu+2	86.494	Cu+2
	0.513	Cu DOM1
	1.585	CuCl+
	11.254	CuSO4 (aq)
	0.149	CuHSO4+
Pb+2	61.181	Pb+2
	0.684	Pb DOM1
	19.072	PbCl+
	0.56	PbCl2 (aq)
	18.176	PbSO4 (aq)
	0.314	Pb(SO4)2-2
Fe+3	11.984	Fe+3
	20.293	Fe DOM1
	4.245	FeOH+2
	0.038	Fe(OH)2+
	0.02	FeF+2
	2.38	FeCl+2
	59.604	FeSO4+
	1.155	Fe(SO4)2-
	0.056	FeN3+2
	0.066	FeH2PO4+2

Component	% of total concentration	Species name
	0.158	FeHPO4+
NO2-1	7.975	NO2-1
	92.024	HNO2 (aq)
NO3-1	99.259	NO3-1
	0.603	CaNO3+
	0.128	NaNO3 (aq)
HS-1	99.655	H2S (aq)
	0.343	FeHS+
H3AsO3	100	H3AsO3

C2.2: pH 3

Component	% of total concentration	Species name
Hg(OH)2	0.104	HgCl2 (aq)
	0.022	HgCl3-1
	99.868	HgN3+
NH4+1	98.301	NH4+1
	1.699	NH4SO4-
Cl-1	98.757	Cl-1
	0.012	AlCl+2
	0.417	CaCl+
	0.06	FeCl+
	0.489	MgCl+
	0.257	NaCl (aq)
Fe+2	84.129	Fe+2
	0.563	FeCl+
	15.289	FeSO4 (aq)
	0.019	FeH2PO4+
Zn+2	83.251	Zn+2
	0.072	Zn DOM1
	2.371	ZnCl+
	0.022	ZnCl2 (aq)
	13.828	ZnSO4 (aq)
	0.454	Zn(SO4)2-2
F-1	0.037	F-1
	0.038	HF (aq)
	99.734	AlF+2
	0.187	AlF2+
SO4-2	48.017	SO4-2
	2.018	HSO4-

Component	% of total concentration	Species name
	26.97	AlSO4+
	3.738	Al(SO4)2-
	0.044	ZnSO4 (aq)
	4.809	FeSO4 (aq)
	5.005	MgSO4 (aq)
	8.368	CaSO4 (aq)
	0.833	NaSO4-
	0.019	KSO4-
	0.169	NH4SO4-
Ni+2	87.05	Ni+2
	0.045	Ni DOM1
	0.316	NiCl+
	12.582	NiSO4 (aq)
N3-1	2.303	N3-1
	97.695	HN3 (aq)
PO4-3	52.101	H2PO4-
	5.486	H3PO4
	19.869	FeH2PO4+
	1.777	CaH2PO4+
	19.048	AlHPO4+
	1.307	Al2PO4+3
	0.384	NaH2PO4 (aq)
AsO4-3	12.832	H3AsO4
	0.015	HAsO4-2
	87.153	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	29.502	DOM1

Component	% of total concentration	Species name
	22.272	H DOM1
	45.28	Al DOM1
	2.676	Ca DOM1
	0.198	Mg DOM1
	0.057	Zn DOM1
Ca+2	83.309	Ca+2
	0.018	Ca DOM1
	2.131	CaCl+
	14.54	CaSO4 (aq)
Mg+2	84.368	Mg+2
	3.488	MgCl+
	12.143	MgSO4 (aq)
K+1	98.326	K+1
	0.738	KCl (aq)
	0.936	KSO4-
Na+1	98.334	Na+1
	0.793	NaCl (aq)
	0.873	NaSO4-
CO3-2	0.046	HCO3-
	99.952	H2CO3* (aq)
Al+3	23.286	Al+3
	0.467	Al DOM1
	0.064	AlOH+2
	0.472	AlF+2
	0.09	AlCl+2
	70.703	AlSO4+
	4.9	Al(SO4)2-
	0.015	AlHPO4+

Component	% of total concentration	Species name
Mn+3	100	Mn+3
Cd+2	46.296	Cd+2
	0.024	Cd DOM1
	43.239	CdCl+
	2.494	CdCl2 (aq)
	7.549	CdSO4 (aq)
	0.397	Cd(SO4)2-2
CrO4-2	0.056	CrO4-2
	99.779	HCrO4-
	0.031	H2CrO4 (aq)
	0.028	CaCrO4 (aq)
	0.011	CrO3Cl-
	0.089	CrO3SO4-2
Cu+2	82.71	Cu+2
	1.788	Cu DOM1
	1.565	CuCl+
	13.891	CuSO4 (aq)
	0.018	CuHSO4+
	0.02	CuN3+
Pb+2	56.584	Pb+2
	2.316	Pb DOM1
	18.294	PbCl+
	0.548	PbCl2 (aq)
	21.774	PbSO4 (aq)
	0.453	Pb(SO4)2-2
	0.02	PbHCO3+
Fe+3	5.44	Fe+3
	34.528	Fe DOM1

Component	% of total concentration	Species name
	19.619	FeOH+2
	1.788	Fe(OH)2+
	0.011	FeF+2
	1.112	FeCl+2
	35.354	FeSO4+
	0.856	Fe(SO4)2-
	0.254	FeN3+2
	0.04	FeH2PO4+2
	0.992	FeHPO4+
NO2-1	46.179	NO2-1
	53.816	HNO2 (aq)
NO3-1	99.259	NO3-1
	0.601	CaNO3+
	0.13	NaNO3 (aq)
HS-1	96.7	H2S (aq)
	3.286	FeHS+
H3AsO3	100	H3AsO3

C2.3: pH 4

Component	% of total concentration	Species name
Hg(OH)2	100	HgN3+
NH4+1	98.076	NH4+1
	1.924	NH4SO4-
Cl-1	98.798	Cl-1
	0.426	CaCl+
	0.5	MgCl+
	0.265	NaCl (aq)
Pb+2	50.076	Pb+2
	9.072	Pb DOM1
	16.595	PbCl+
	0.497	PbCl2 (aq)
	23.047	PbSO4 (aq)
	0.513	Pb(SO4)2-2
	0.186	PbHCO3+
Zn+2	80.792	Zn+2
	0.306	Zn DOM1
	2.343	ZnCl+
	0.021	ZnCl2 (aq)
	15.961	ZnSO4 (aq)
	0.56	Zn(SO4)2-2
	0.013	ZnHCO3+
F-1	0.203	F-1
	0.021	HF (aq)
	98.674	AlF+2
	1.078	AlF2+
	0.018	MgF+
CrO4-2	0.531	CrO4-2

Component	% of total concentration	Species name
	99.156	HCrO4-
	0.285	CaCrO4 (aq)
Ni+2	84.779	Ni+2
	0.193	Ni DOM1
	0.316	NiCl+
	14.656	NiSO4 (aq)
	0.049	NiHCO3+
N3-1	18.836	N3-1
	81.158	HN3 (aq)
PO4-3	0.055	HPO4-2
	55.181	H2PO4-
	0.59	H3PO4
	0.117	FeH2PO4+
	0.021	MgHPO4 (aq)
	0.02	CaHPO4 (aq)
	1.917	CaH2PO4+
	37.399	AlHPO4+
	4.271	Al2PO4+3
	0.418	NaH2PO4 (aq)
AsO4-3	1.471	H3AsO4
	0.16	HAsO4-2
	98.369	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	42.914	DOM1
	9.014	H DOM1

Component	% of total concentration	Species name
	35.5	Al DOM1
	11.422	Ca DOM1
	0.016	Cu DOM1
	0.846	Mg DOM1
	0.025	Ni DOM1
	0.018	Pb DOM1
	0.245	Zn DOM1
Ca+2	81.037	Ca+2
	0.078	Ca DOM1
	2.107	CaCl+
	16.771	CaSO4 (aq)
Mg+2	82.492	Mg+2
	3.456	MgCl+
	14.039	MgSO4 (aq)
K+1	98.201	K+1
	0.738	KCl (aq)
	1.061	KSO4-
Na+1	98.221	Na+1
	0.792	NaCl (aq)
	0.986	NaSO4-
CO3-2	0.449	HCO3-
	99.534	H2CO3* (aq)
Cu+2	75.942	Cu+2
	7.227	Cu DOM1
	1.463	CuCl+
	15.17	CuSO4 (aq)
	0.158	CuN3+
	0.023	CuHCO3+

Component	% of total concentration	Species name
Mn+3	100	Mn+3
Cd+2	45.025	Cd+2
	0.103	Cd DOM1
	43.106	CdCl+
	2.485	CdCl2 (aq)
	8.781	CdSO4 (aq)
	0.494	Cd(SO4)2-2
Fe+2	81.748	Fe+2
	0.557	FeCl+
	17.669	FeSO4 (aq)
	0.02	FeH2PO4+
NO2-1	89.41	NO2-1
	10.581	HNO2 (aq)
NO3-1	99.242	NO3-1
	0.614	CaNO3+
	0.134	NaNO3 (aq)
HS-1	0.082	HS-1
	99.669	H2S (aq)
	0.041	NiHS+
	0.185	FeHS+
	0.022	CdHS+
H3AsO3	99.999	H3AsO3
Fe+3	0.881	Fe+3
	25.708	Fe DOM1
	32.764	FeOH+2
	31.09	Fe(OH)2+
	0.01	FeF+2
	0.183	FeCl+2

Component	% of total concentration	Species name
	6.95	FeSO4+
	0.19	Fe(SO4)2-
	0.352	FeN3+2
	1.852	FeHPO4+
	0.011	FeCrO4+
SO4-2	68.645	SO4-2
	0.302	HSO4-
	7.487	AlSO4+
	1.174	Al(SO4)2-
	0.067	ZnSO4 (aq)
	0.01	NiSO4 (aq)
	0.041	FeSO4 (aq)
	7.765	MgSO4 (aq)
	12.954	CaSO4 (aq)
	1.264	NaSO4-
	0.029	KSO4-
	0.257	NH4SO4-
Al+3	19.138	Al+3
	1.766	Al DOM1
	0.54	AlOH+2
	2.252	AlF+2
	0.012	AlF2+
	0.075	AlCl+2
	70.504	AlSO4+
	5.526	Al(SO4)2-
	0.14	AlHPO4+
	0.032	Al2PO4+3

C2.4: pH 5

Component	% of total concentration	Species name
Hg(OH)2	100	HgN3+
NH4+1	97.176	NH4+1
	2.822	NH4SO4-
Cl-1	98.877	Cl-1
	0.389	CaCl+
	0.464	MgCl+
	0.262	NaCl (aq)
Pb+2	37.318	Pb+2
	22.876	Pb DOM1
	0.04	PbOH+
	0.013	PbF+
	12.169	PbCl+
	0.361	PbCl2 (aq)
	25.036	PbSO4 (aq)
	0.839	Pb(SO4)2-2
	0.022	PbCO3 (aq)
	1.317	PbHCO3+
Zn+2	74.232	Zn+2
	0.953	Zn DOM1
	2.122	ZnCl+
	0.019	ZnCl2 (aq)
	21.413	ZnSO4 (aq)
	1.132	Zn(SO4)2-2
	0.011	ZnN3+
	0.109	ZnHCO3+
F-1	37.772	F-1
	0.392	HF (aq)

Component	% of total concentration	Species name
	18.535	AlF+2
	37.03	AlF2+
	2.261	AlF3 (aq)
	3.125	MgF+
	0.71	CaF+
	0.159	NaF (aq)
CrO4-2	5.018	CrO4-2
	0.084	NaCrO4-
	92.47	HCrO4-
	2.421	CaCrO4 (aq)
Ni+2	78.793	Ni+2
	0.608	Ni DOM1
	0.289	NiCl+
	19.855	NiSO4 (aq)
	0.015	NiN3+
	0.431	NiHCO3+
N3-1	69.973	N3-1
	30.013	HN3 (aq)
PO4-3	0.95	HPO4-2
	93.939	H2PO4-
	0.1	H3PO4
	0.323	MgHPO4 (aq)
	0.311	CaHPO4 (aq)
	2.982	CaH2PO4+
	0.031	NaHPO4-
	0.637	AlHPO4+
	0.015	KH2PO4 (aq)

Component	% of total concentration	Species name
	0.702	NaH2PO4 (aq)
AsO4-3	0.146	H3AsO4
	1.62	HAsO4-2
	98.234	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	57.223	DOM1
	3.132	H DOM1
	0.122	Al DOM1
	35.895	Ca DOM1
	0.043	Cu DOM1
	2.698	Mg DOM1
	0.079	Ni DOM1
	0.046	Pb DOM1
	0.762	Zn DOM1
Ca+2	75.073	Ca+2
	0.246	Ca DOM1
	1.926	CaCl+
	22.705	CaSO4 (aq)
	0.046	CaHCO3+
Mg+2	77.437	Mg+2
	0.026	Mg DOM1
	0.014	MgF+
	3.203	MgCl+
	19.275	MgSO4 (aq)
	0.046	MgHCO3+
K+1	97.709	K+1
	0.728	KCl (aq)

Component	% of total concentration	Species name
	1.563	KSO4-
Na+1	97.759	Na+1
	0.781	NaCl (aq)
	1.455	NaSO4-
CO3-2	4.332	HCO3-
	95.524	H2CO3* (aq)
	0.054	MgHCO3+
	0.076	CaHCO3+
	0.012	NaHCO3 (aq)
Cu+2	60.735	Cu+2
	19.59	Cu DOM1
	0.073	CuOH+
	1.154	CuCl+
	17.714	CuSO4 (aq)
	0.014	CuNH3+2
	0.462	CuN3+
	0.065	CuCO3 (aq)
	0.178	CuHCO3+
SO4-2	77.156	SO4-2
	0.033	HSO4-
	0.067	ZnSO4 (aq)
	0.01	NiSO4 (aq)
	7.944	MgSO4 (aq)
	13.068	CaSO4 (aq)
	1.389	NaSO4-
	0.032	KSO4-
	0.281	NH4SO4-

Component	% of total concentration	Species name
Cd+2	43.226	Cd+2
	0.334	Cd DOM1
	40.72	CdCl+
	2.328	CdCl2 (aq)
	12.288	CdSO4 (aq)
	1.042	Cd(SO4)2-2
	0.061	CdHCO3+
Fe+2	75.563	Fe+2
	0.508	FeCl+
	23.848	FeSO4 (aq)
	0.031	FeH2PO4+
	0.044	FeHCO3+
NO2-1	98.826	NO2-1
	1.164	HNO2 (aq)
NO3-1	99.297	NO3-1
	0.561	CaNO3+
	0.132	NaNO3 (aq)
HS-1	0.819	HS-1
	98.576	H2S (aq)
	0.371	NiHS+
	0.208	CdHS+
	0.023	ZnS (aq)
H3AsO3	99.994	H3AsO3
Fe+3	0.025	Fe+3
	2.457	Fe DOM1
	9.274	FeOH+2
	86.957	Fe(OH)2+
	0.055	FeF+2

Component	% of total concentration	Species name
	0.288	FeSO4+
	0.012	Fe(SO4)2-
	0.037	FeN3+2
	0.878	FeHPO4+
Al+3	1.935	Al+3
	0.597	Al DOM1
	0.54	AlOH+2
	0.058	Al(OH)2+
	41.709	AlF+2
	41.663	AlF2+
	1.696	AlF3 (aq)
	10.346	AlSO4+
	1.202	Al(SO4)2-
	0.236	AlHPO4+
Mn+3	100	Mn+3

C2.5: pH 6

Component	% of total concentration	Species name
Hg(OH)2	100	HgN3+
NH4+1	97.158	NH4+1
	2.82	NH4SO4-
	0.022	NH3 (aq)
Cl-1	98.882	Cl-1
	0.387	CaCl+
	0.462	MgCl+
	0.262	NaCl (aq)
Pb+2	33.562	Pb+2
	21.773	Pb DOM1
	0.361	PbOH+
	0.026	PbF+
	10.917	PbCl+
	0.324	PbCl2 (aq)
	22.448	PbSO4 (aq)
	0.754	Pb(SO4)2-2
	1.401	PbCO3 (aq)
	8.428	PbHCO3+
Zn+2	73.683	Zn+2
	1.002	Zn DOM1
	0.021	ZnOH+
	2.102	ZnCl+
	0.019	ZnCl2 (aq)
	21.196	ZnSO4 (aq)
	1.122	Zn(SO4)2-2
	0.015	ZnN3+
	0.055	ZnCO3 (aq)

Component	% of total concentration	Species name
	0.772	ZnHCO3+
F-1	90.127	F-1
	0.094	HF (aq)
	0.044	AlF+2
	0.2	AlF2+
	0.028	AlF3 (aq)
	0.014	ZnF+
	7.424	MgF+
	1.685	CaF+
	0.378	NaF (aq)
CrO4-2	29.985	CrO4-2
	0.499	NaCrO4-
	55.15	HCrO4-
	14.357	CaCrO4 (aq)
Ni+2	76.748	Ni+2
	0.627	Ni DOM1
	0.281	NiCl+
	19.281	NiSO4 (aq)
	0.02	NiN3+
	0.035	NiCO3 (aq)
	2.985	NiHCO3+
N3-1	95.873	N3-1
	0.012	ZnN3+
	4.109	HN3 (aq)
Cd+2	43.112	Cd+2
	0.352	Cd DOM1
	40.513	CdCl+
	2.313	CdCl2 (aq)

Component	% of total concentration	Species name
	12.219	CdSO4 (aq)
	1.038	Cd(SO4)2-2
	0.431	CdHCO3+
	0.012	CdCO3 (aq)
AsO4-3	0.013	H3AsO4
	14.173	HAsO4-2
	85.814	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	57.961	DOM1
	0.333	H DOM1
	37.888	Ca DOM1
	0.042	Cu DOM1
	2.849	Mg DOM1
	0.082	Ni DOM1
	0.044	Pb DOM1
	0.801	Zn DOM1
Ca+2	74.894	Ca+2
	0.259	Ca DOM1
	1.917	CaCl+
	22.591	CaSO4 (aq)
	0.33	CaHCO3+
Mg+2	77.249	Mg+2
	0.027	Mg DOM1
	0.031	MgF+
	3.189	MgCl+
	19.179	MgSO4 (aq)
	0.324	MgHCO3+

Component	% of total concentration	Species name
K+1	97.711	K+1
	0.727	KCl (aq)
	1.562	KSO4-
Na+1	97.734	Na+1
	0.78	NaCl (aq)
	1.453	NaSO4-
	0.032	NaHCO3 (aq)
CO3-2	30.894	HCO3-
	68.078	H2CO3* (aq)
	0.381	MgHCO3+
	0.541	CaHCO3+
	0.088	NaHCO3 (aq)
Cu+2	56.379	Cu+2
	19.25	Cu DOM1
	0.68	CuOH+
	0.014	CuF+
	1.069	CuCl+
	16.398	CuSO4 (aq)
	0.133	CuNH3+2
	0.586	CuN3+
	0.012	CuHPO4 (aq)
	4.296	CuCO3 (aq)
	1.178	CuHCO3+
SO4-2	77.312	SO4-2
	0.067	ZnSO4 (aq)
	7.905	MgSO4 (aq)

Component	% of total concentration	Species name
	12.995	CaSO4 (aq)
	1.388	NaSO4-
	0.032	KSO4-
	0.281	NH4SO4-
Fe+2	75.416	Fe+2
	0.506	FeCl+
	23.735	FeSO4 (aq)
	0.011	FeH2PO4+
	0.311	FeHCO3+
NO2-1	99.873	NO2-1
	0.118	HNO2 (aq)
NO3-1	99.3	NO3-1
	0.558	CaNO3+
	0.132	NaNO3 (aq)
HS-1	7.146	HS-1
	85.96	H2S (aq)
	3.145	NiHS+
	1.805	CdHS+
	1.945	ZnS (aq)
H3AsO3	99.945	H3AsO3
	0.055	H2AsO3-
Fe+3	0.03	Fe DOM1
	1.056	FeOH+2
	98.845	Fe(OH)2+
	0.028	Fe(OH)3 (aq)
	0.035	FeHPO4+
Al+3	0.546	Al+3
	0.178	Al DOM1

Component	% of total concentration	Species name
	1.522	AlOH+2
	1.64	Al(OH)2+
	0.26	Al(OH)3 (aq)
	0.139	Al(OH)4-
	26.605	AlF+2
	60.055	AlF2+
	5.529	AlF3 (aq)
	0.031	AlF4-
	2.909	AlSO4+
	0.338	Al(SO4)2-
	0.234	AlHPO4+
Mn+3	100	Mn+3
PO4-3	8.356	HPO4-2
	82.504	H2PO4-
	2.82	MgHPO4 (aq)
	2.716	CaHPO4 (aq)
	2.606	CaH2PO4+
	0.274	NaHPO4-
	0.062	ZnHPO4 (aq)
	0.013	KH2PO4 (aq)
	0.616	NaH2PO4 (aq)

C3 Saturation indicies

C3.1: pH 2

Mineral	log IAP	Sat. index
Al(OH)3 (am)	2.3	-9.175
Al(OH)3 (Soil)	2.3	-6.628
Al2O3(s)	4.6	-16.624
Al4(OH)10SO4(s)	2.321	-20.379
AlAsO4:2H2O(s)	-30.341	-14.541
AlOHF2(s)	-18.665	-19.072
AlOHSO4(s)	-4.58	-1.35
Alunite	-8.777	-8.654
Anglesite	-10.663	-2.8
Anhydrite	-5.622	-1.306
Antlerite	-17.596	-26.384
Aragonite	-18.178	-9.899
Arsenolite	-12.609	-11.046
Artinite	-17.185	-27.516
As2O5(s)	-65.282	-30.573
As2S3(am)	-105.109	-58.724
Atacamite	-10.908	-18.867
Azurite	-49.587	-32.434
Bianchite	-7.892	-6.131
Birnessite	7.352	-10.739
Bixbyite	0.21	0.098
Boehmite	2.3	-6.993
Brochantite	-21.168	-37.623
Brucite	1.125	-16.668
Ca3(AsO4)2:4H2O(s)	-61.508	-42.608
Ca3(PO4)2 (am1)	-51.879	-26.95
Ca3(PO4)2 (am2)	-51.879	-24.158

Mineral	log IAP	Sat. index
Ca3(PO4)2 (beta)	-51.879	-22.631
Ca4H(PO4)3:3H2O(s)	-78.447	-31.136
CaCO3xH2O(s)	-18.178	-11.091
CaCrO4(s)	-13.765	-11.663
CaHPO4(s)	-26.568	-7.105
CaHPO4:2H2O(s)	-26.568	-7.434
Calcite	-18.178	-9.747
CaS(s)	-29.575	-40.755
Cd metal (alpha)	-19.082	-33.055
Cd metal (gamma)	-19.082	-33.162
Cd(OH)2(s)	-4.588	-18.807
Cd3(OH)4SO4(s)	-20.643	-43.203
Cd3(PO4)2(s)	-69.416	-36.816
Cd3OH2(SO4)2(s)	-27.524	-34.234
Cd4(OH)6SO4(s)	-25.231	-53.631
CdCl2(s)	-12.116	-11.57
CdCl2:1H2O(s)	-12.116	-10.468
CdCl2:2.5H2O(s)	-12.116	-10.159
CdF2(s)	-25.553	-24.622
CdOHCl(s)	-8.352	-12.077
CdSO4(s)	-11.468	-11.612
CdSO4:1H2O(s)	-11.468	-9.934
CdSO4:2.67H2O(s)	-11.468	-9.704
Cerrusite	-23.219	-9.868
Chalcanthite	-10.452	-7.775
Chalcopyrite	-64.246	-28.073
Chloropyromorphite(c)	-106.158	-21.728
Chloropyromorphite(soil)	-106.158	-25.758
Cinnabar	-53.443	-6.62

Mineral	log IAP	Sat. index
Claudetite	-12.609	-11.096
Cotunnite	-11.311	-6.372
Covellite	-34.405	-11.595
Cr(VI)-Ettringite	-32.921	-96.322
Cr(VI)-Jarosite	-47.119	-28.603
CrO3(s)	-15.023	-11.844
Cryolite	-61.333	-27.262
Cu azide	-22.075	-14.234
Cu(OH)2(s)	-3.572	-13.185
Cu2(OH)3NO3(s)	-74.252	-83.944
Cu3(AsO4)2:2H2O(s)	-75.998	-40.898
Cu3(PO4)2(s)	-66.369	-29.519
Cu3(PO4)2:3H2O(s)	-66.369	-31.249
CuCO3(s)	-23.008	-11.508
CuCrO4(s)	-18.595	-13.155
CuF2(s)	-24.537	-26.059
CuF2:2H2O(s)	-24.537	-20.08
CuOCuSO4(s)	-14.024	-25.165
Cupric Ferrite	-13.675	-20.942
CuSO4(s)	-10.452	-13.836
Diaspore	2.3	-5.199
Dolomite (disordered)	-36.488	-20.23
Dolomite (ordered)	-36.488	-19.638
Epsomite	-5.755	-3.558
Ettringite	-8.492	-67.68
FCO3-Apatite	-171.093	-55.691
Fe(OH)2 (am)	0.993	-13.054
Fe(OH)2 (c)	0.993	-11.897
Fe(OH)2.7Cl.3(s)	-6.181	-3.141

Mineral	log IAP	Sat. index
Fe2(SO4)3(s)	-30.744	-28.481
Fe3(OH)8(s)	-9.111	-29.333
FeAsO4:2H2O(s)	-37.693	-17.493
Ferrihydrite	-5.052	-8.862
Ferrihydrite (aged)	-5.052	-8.352
FeS (ppt)	-29.841	-26.957
Fluorite	-19.707	-9.134
Galena	-34.616	-19.21
Gibbsite (C)	2.3	-6.078
Goethite	-5.052	-5.911
Goslarite	-7.892	-5.794
Greenockite	-35.421	-21.067
Greigite	-132.443	-87.408
Gypsum	-5.622	-1.006
Halite	-4.01	-5.537
Hematite	-10.103	-9.47
Hercynite	5.593	-19.209
Hg(OH)2(s)	-22.609	-19.113
Hg3O2CO3(s)	-87.264	-57.684
HgCl2(s)	-30.138	-8.22
HgSO4(s)	-29.49	-19.981
Hinsdalite	-31.589	-29.089
H-Jarosite	-28.915	-24.883
Huntite	-73.109	-43.796
Hydrocerrusite	-50.22	-31.46
Hydromagnesite	-72.116	-64.678
Hydroxyapatite	-77.189	-32.856
Hydroxylpyromorphite	-102.394	-39.604
Hydrozincite	-43.931	-54.069

Mineral	log IAP	Sat. index
K2Cr2O7(s)	-33.882	-16.148
K2CrO4(s)	-18.858	-18.234
K-Alum	-13.378	-8.024
KCl(s)	-5.682	-6.582
K-Jarosite	-30.833	-20.452
Langite	-21.168	-39.663
Larnakite	-14.446	-14.144
Laurionite	-7.547	-8.17
Lepidocrocite	-5.052	-6.423
Lime	1.258	-32.62
Litharge	-3.783	-16.871
Mackinawite	-29.841	-26.241
Maghemite	-10.103	-16.489
Magnesioferrite	-8.978	-27.534
Magnesite	-18.31	-10.729
Magnetite	-9.111	-13.781
Malachite	-26.58	-21.379
Massicot	-3.783	-17.079
Matlockite	-18.03	-8.854
Melanothallite	-11.1	-17.743
Melanterite	-5.888	-3.554
Metacinnabar	-53.443	-7.018
Mg(OH)2 (active)	1.125	-17.669
Mg2(OH)3Cl:4H2O(s)	-1.514	-27.514
Mg3(PO4)2(s)	-52.277	-28.997
MgCO3:5H2O(s)	-18.31	-13.77
MgCrO4(s)	-13.898	-19.819
MgF2(s)	-19.84	-11.779
MgHPO4:3H2O(s)	-26.701	-8.526

Mineral	log IAP	Sat. index
MgS(s)	-29.708	-47.388
Minium	3.146	-72.941
Mirabilite	-7.372	-5.775
Mn2(SO4)3(s)	-20.43	-15.713
Montroydite	-22.609	-18.893
Morenosite	-8.686	-6.467
Na2Cr2O7(s)	-30.538	-20.508
Na2CrO4(s)	-15.515	-18.564
NaF(s)	-10.728	-10.234
Na-Jarosite	-29.161	-24.666
Natron	-19.927	-18.216
Nesquehonite	-18.31	-13.788
Ni(OH)2 (am)	-1.806	-15.279
Ni(OH)2 (c)	-1.806	-12.596
Ni3(AsO4)2:8H2O(s)	-70.7	-45.2
Ni3(PO4)2(s)	-61.07	-29.77
Ni4(OH)6SO4(s)	-14.103	-46.103
NiCO3(s)	-21.242	-10.294
NiS (alpha)	-32.639	-27.119
NiS (beta)	-32.639	-21.619
NiS (gamma)	-32.639	-19.919
Nsutite	7.352	-10.152
Orpiment	-105.109	-57.209
Otavite	-24.024	-11.972
Pb azide (alpha)	-22.286	-13.312
Pb metal	-18.278	-22.518
Pb(OH)2(s)	-3.783	-12.289
Pb10(OH)6O(CO3)6(s)	-154.443	-145.683
Pb2(OH)3Cl(s)	-11.33	-20.123

Mineral	log IAP	Sat. index
Pb2O(OH)2(s)	-7.566	-33.756
Pb2O3(s)	6.929	-54.111
Pb2OCO3(s)	-27.001	-26.692
Pb3(AsO4)2(s)	-76.631	-41.131
Pb3(PO4)2(s)	-67.001	-23.471
Pb3O2CO3(s)	-30.784	-42.477
Pb3O2SO4(s)	-18.229	-29.396
Pb4(OH)6SO4(s)	-22.011	-43.111
Pb4O3SO4(s)	-22.011	-44.718
PbCrO4(s)	-18.806	-5.937
PbF2(s)	-24.748	-17.186
PbHPO4(s)	-31.609	-7.804
PbO:0.3H2O(s)	-3.783	-16.763
Periclase	1.125	-21.378
Phosgenite	-34.53	-14.72
Plattnerite	10.712	-40.69
Plumbgummite	-52.535	-19.745
Portlandite	1.258	-22.228
Pyrite	-46.179	-27.368
Realgar	-44.385	-23.655
Retgersite	-8.686	-6.618
Siderite	-18.443	-7.898
Smithsonite	-20.448	-9.571
Spharelite	-31.845	-20.843
Spinel	5.726	-33.481
Strengite	-32.878	-6.535
Struvite	-27.94	-14.68
Sulfur	-16.338	-14.293
Tenorite(am)	-3.572	-12.456

Mineral	log IAP	Sat. index
Tenorite(c)	-3.572	-11.607
Thenardite	-7.372	-7.749
Thermonatrite	-19.927	-20.628
Tsumebite	-38.964	-29.174
Vaterite	-18.178	-10.341
Vivianite	-52.675	-14.884
Wurtzite	-31.845	-23.096
Zincite	-1.012	-12.787
Zincosite	-7.892	-12.324
Zn metal	-15.507	-42.228
Zn(NO3)2:6H2O(s)	-135.227	-138.393
Zn(OH)2 (am)	-1.012	-14.006
Zn(OH)2 (beta)	-1.012	-13.271
Zn(OH)2 (delta)	-1.012	-12.856
Zn(OH)2 (epsilon)	-1.012	-13.024
Zn(OH)2 (gamma)	-1.012	-13.243
Zn2(OH)2SO4(s)	-8.904	-16.404
Zn2(OH)3Cl(s)	-5.788	-20.979
Zn3(PO4)2:4H2O(s)	-58.688	-23.268
Zn3AsO42:2.5H2O(s)	-68.318	-40.818
Zn3O(SO4)2(s)	-16.796	-37.278
Zn4(OH)6SO4(s)	-10.927	-39.327
Zn5(OH)8Cl2(s)	-12.587	-51.087
Zn-Al LDH(s)	-9.441	-29.271
ZnCl2(s)	-8.54	-16.031
ZnCO3(s)	-20.448	-9.648
ZnCO3:1H2O(s)	-20.448	-10.188
ZnF2(s)	-21.977	-21.806
ZnSO4:1H2O(s)	-7.892	-7.522

C3.2: pH 3

Mineral	log IAP	Sat. index
Al(OH)3 (am)	5.231	-6.244
Al(OH)3 (Soil)	5.231	-3.698
Al2O3(s)	10.463	-10.762
Al4(OH)10SO4(s)	12.141	-10.559
AlAsO4:2H2O(s)	-25.413	-9.613
AlOHF2(s)	-17.566	-17.973
AlOHSO4(s)	-3.552	-0.322
Alunite	-2.787	-2.664
Anglesite	-10.585	-2.722
Anhydrite	-5.527	-1.211
Antlerite	-13.518	-22.306
Aragonite	-16.181	-7.902
Arsenolite	-12.614	-11.051
Artinite	-13.189	-23.52
As2O5(s)	-61.288	-26.578
As2S3(am)	-134.817	-88.433
Atacamite	-7.916	-15.875
Azurite	-43.607	-26.454
Bianchite	-7.799	-6.038
Birnessite	11.375	-6.716
Bixbyite	6.255	6.143
Boehmite	5.231	-4.062
Brochantite	-15.097	-31.552
Brucite	3.124	-14.669
Ca3(AsO4)2:4H2O(s)	-51.522	-32.622
Ca3(PO4)2 (am1)	-47.645	-22.716
Ca3(PO4)2 (am2)	-47.645	-19.924
Ca3(PO4)2 (beta)	-47.645	-18.396

Mineral	log IAP	Sat. index
Ca4H(PO4)3:3H2O(s)	-73.096	-25.785
CaCO3xH2O(s)	-16.181	-9.094
CaCrO4(s)	-12.759	-10.658
CaHPO4(s)	-25.45	-5.987
CaHPO4:2H2O(s)	-25.451	-6.316
Calcite	-16.181	-7.75
CaS(s)	-37.479	-48.659
Cd metal (alpha)	-19.083	-33.056
Cd metal (gamma)	-19.083	-33.163
Cd(OH)2(s)	-2.589	-16.809
Cd3(OH)4SO4(s)	-16.55	-39.11
Cd3(PO4)2(s)	-65.178	-32.578
Cd3OH2(SO4)2(s)	-25.333	-32.043
Cd4(OH)6SO4(s)	-19.14	-47.54
CdCl2(s)	-12.108	-11.562
CdCl2:1H2O(s)	-12.108	-10.46
CdCl2:2.5H2O(s)	-12.109	-10.151
CdF2(s)	-25.387	-24.455
CdOHCl(s)	-7.349	-11.074
CdSO4(s)	-11.372	-11.516
CdSO4:1H2O(s)	-11.372	-9.838
CdSO4:2.67H2O(s)	-11.373	-9.609
Cerrusite	-21.238	-7.888
Chalcanthite	-10.363	-7.686
Chalcopyrite	-80.057	-43.884
Chloropyromorphite(c)	-99.887	-15.457
Chloropyromorphite(soil)	-99.887	-19.487
Cinnabar	-64.239	-17.416
Claudetite	-12.614	-11.101

Mineral	log IAP	Sat. index
Cotunnite	-11.321	-6.382
Covellite	-42.313	-19.503
Cr(VI)-Ettringite	-18.061	-81.462
Cr(VI)-Jarosite	-39.107	-20.591
CrO3(s)	-16.015	-12.836
Cryolite	-60.891	-26.82
Cu azide	-20.101	-12.259
Cu(OH)2(s)	-1.579	-11.192
Cu2(OH)3NO3(s)	-61.262	-70.955
Cu3(AsO4)2:2H2O(s)	-66.023	-30.923
Cu3(PO4)2(s)	-62.146	-25.296
Cu3(PO4)2:3H2O(s)	-62.147	-27.027
CuCO3(s)	-21.014	-9.514
CuCrO4(s)	-17.593	-12.153
CuF2(s)	-24.376	-25.898
CuF2:2H2O(s)	-24.377	-19.919
CuOCuSO4(s)	-11.939	-23.08
Cupric Ferrite	-5.686	-12.953
CuSO4(s)	-10.361	-13.745
Diaspore	5.231	-2.268
Dolomite (disordered)	-32.492	-16.234
Dolomite (ordered)	-32.492	-15.643
Epsomite	-5.661	-3.464
Ettringite	3.635	-55.553
FCO3-Apatite	-158.329	-42.927
Fe(OH)2 (am)	2.99	-11.057
Fe(OH)2 (c)	2.99	-9.9
Fe(OH)2.7Cl.3(s)	-3.482	-0.442
Fe2(SO4)3(s)	-30.457	-28.194

Mineral	log IAP	Sat. index
Fe3(OH)8(s)	-1.119	-21.341
FeAsO4:2H2O(s)	-32.699	-12.499
Ferrihydrite	-2.055	-5.865
Ferrihydrite (aged)	-2.055	-5.355
FeS (ppt)	-37.744	-34.861
Fluorite	-19.542	-8.969
Galena	-42.537	-27.13
Gibbsite (C)	5.231	-3.148
Goethite	-2.054	-2.914
Goslarite	-7.799	-5.702
Greenockite	-43.323	-28.969
Greigite	-164.056	-119.021
Gypsum	-5.528	-0.912
Halite	-4.003	-5.53
Hematite	-4.108	-3.474
Hercynite	13.453	-11.348
Hg(OH)2(s)	-23.505	-20.008
Hg3O2CO3(s)	-89.949	-60.369
HgCl2(s)	-33.023	-11.105
HgSO4(s)	-32.287	-22.779
Hinsdalite	-23.598	-21.098
H-Jarosite	-23.73	-19.697
Huntite	-65.116	-35.803
Hydrocerrusite	-44.279	-25.519
Hydromagnesite	-62.125	-54.687
Hydroxyapatite	-69.84	-25.507
Hydroxylpyromorphite	-95.128	-32.338
Hydrozincite	-33.942	-44.08
K2Cr2O7(s)	-33.858	-16.125

Mineral	log IAP	Sat. index
K2CrO4(s)	-17.843	-17.219
K-Alum	-13.253	-7.899
KCl(s)	-5.674	-6.574
K-Jarosite	-24.643	-14.262
Langite	-15.097	-33.593
Larnakite	-12.387	-12.086
Laurionite	-6.562	-7.185
Lepidocrocite	-2.054	-3.425
Lime	3.256	-30.623
Litharge	-1.802	-14.89
Mackinawite	-37.744	-34.144
Maghemite	-4.108	-10.494
Magnesioferrite	-0.984	-19.539
Magnesite	-16.312	-8.73
Magnetite	-1.118	-5.788
Malachite	-22.593	-17.393
Massicot	-1.802	-15.099
Matlockite	-17.96	-8.785
Melanothallite	-11.097	-17.74
Melanterite	-5.795	-3.462
Metacinnabar	-64.239	-17.814
Mg(OH)2 (active)	3.124	-15.67
Mg2(OH)3Cl:4H2O(s)	1.487	-24.513
Mg3(PO4)2(s)	-48.038	-24.758
MgCO3:5H2O(s)	-16.314	-11.774
MgCrO4(s)	-12.891	-18.812
MgF2(s)	-19.673	-11.612
MgHPO4:3H2O(s)	-25.583	-7.408
MgS(s)	-37.61	-55.29

Mineral	log IAP	Sat. index
Minium	11.088	-64.999
Mirabilite	-7.273	-5.676
Mn2(SO4)3(s)	-20.094	-15.376
Montroydite	-23.504	-19.787
Morenosite	-8.59	-6.371
Na2Cr2O7(s)	-30.516	-20.486
Na2CrO4(s)	-14.501	-17.551
NaF(s)	-10.642	-10.147
Na-Jarosite	-22.972	-18.478
Natron	-17.926	-16.215
Nesquehonite	-16.313	-11.79
Ni(OH)2 (am)	0.196	-13.278
Ni(OH)2 (c)	0.196	-10.594
Ni3(AsO4)2:8H2O(s)	-60.703	-35.203
Ni3(PO4)2(s)	-56.823	-25.523
Ni4(OH)6SO4(s)	-8	-40
NiCO3(s)	-19.24	-8.293
NiS (alpha)	-40.539	-35.019
NiS (beta)	-40.539	-29.519
NiS (gamma)	-40.539	-27.819
Nsutite	11.375	-6.129
Orpiment	-134.817	-86.918
Otavite	-22.025	-9.974
Pb azide (alpha)	-20.324	-11.35
Pb metal	-18.296	-22.537
Pb(OH)2(s)	-1.802	-10.308
Pb10(OH)6O(CO3)6(s)	-134.639	-125.879
Pb2(OH)3Cl(s)	-8.364	-17.157
Pb2O(OH)2(s)	-3.605	-29.795

Mineral	log IAP	Sat. index
Pb2O3(s)	12.89	-48.15
Pb2OCO3(s)	-23.04	-22.731
Pb3(AsO4)2(s)	-66.694	-31.194
Pb3(PO4)2(s)	-62.818	-19.288
Pb3O2CO3(s)	-24.842	-36.535
Pb3O2SO4(s)	-14.189	-25.357
Pb4(OH)6SO4(s)	-15.993	-37.093
Pb4O3SO4(s)	-15.991	-38.698
PbCrO4(s)	-17.817	-4.948
PbF2(s)	-24.6	-17.038
PbHPO4(s)	-30.508	-6.703
PbO:0.3H2O(s)	-1.802	-14.782
Periclase	3.124	-19.379
Phosgenite	-32.559	-12.749
Plattnerite	14.692	-36.709
Plumbgummite	-43.521	-10.731
Portlandite	3.255	-20.231
Pyrite	-61.984	-43.173
Realgar	-55.289	-34.559
Retgersite	-8.589	-6.521
Siderite	-16.446	-5.9
Smithsonite	-18.45	-7.573
Spharelite	-39.748	-28.746
Spinel	13.587	-25.62
Strengite	-30.76	-4.417
Struvite	-25.816	-12.556
Sulfur	-24.24	-22.194
Tenorite(am)	-1.578	-10.463
Tenorite(c)	-1.578	-9.613

Mineral	log IAP	Sat. index
Thenardite	-7.269	-7.646
Thermonatrite	-17.923	-18.623
Tsumebite	-33.89	-24.1
Vaterite	-16.181	-8.344
Vivianite	-48.443	-10.652
Wurtzite	-39.748	-31
Zincite	0.986	-10.789
Zincosite	-7.797	-12.228
Zn metal	-15.508	-42.229
Zn(NO3)2:6H2O(s)	-115.226	-118.392
Zn(OH)2 (am)	0.986	-12.009
Zn(OH)2 (beta)	0.986	-11.274
Zn(OH)2 (delta)	0.986	-10.858
Zn(OH)2 (epsilon)	0.986	-11.026
Zn(OH)2 (gamma)	0.986	-11.245
Zn2(OH)2SO4(s)	-6.811	-14.311
Zn2(OH)3Cl(s)	-2.787	-17.978
Zn3(PO4)2:4H2O(s)	-54.454	-19.034
Zn3AsO42:2.5H2O(s)	-58.33	-30.83
Zn3O(SO4)2(s)	-14.607	-35.09
Zn4(OH)6SO4(s)	-4.839	-33.239
Zn5(OH)8Cl2(s)	-4.589	-43.089
Zn-Al LDH(s)	-2.515	-22.345
ZnCl2(s)	-8.533	-16.023
ZnCO3(s)	-18.45	-7.65
ZnCO3:1H2O(s)	-18.45	-8.19
ZnF2(s)	-21.811	-21.64
ZnSO4:1H2O(s)	-7.797	-7.427

C3.3: pH 4

Mineral	log IAP	Sat. index
Al(OH)3 (am)	7.499	-3.976
Al(OH)3 (Soil)	7.499	-1.429
Al2O3(s)	14.999	-6.225
Al4(OH)10SO4(s)	19.268	-3.432
AlAsO4:2H2O(s)	-21.894	-6.094
AlOHF2(s)	-15.799	-16.206
AlOHSO4(s)	-3.23	0
Alunite	1.131	1.255
Anglesite	-10.561	-2.698
Anhydrite	-5.466	-1.15
Antlerite	-9.513	-18.301
Aragonite	-14.175	-5.896
Arsenolite	-14.113	-12.55
Artinite	-9.174	-19.505
As2O5(s)	-58.786	-24.077
As2S3(am)	-166.156	-119.771
Atacamite	-4.955	-12.914
Azurite	-37.66	-20.507
Bianchite	-7.737	-5.976
Birnessite	15.411	-2.68
Bixbyite	12.328	12.216
Boehmite	7.5	-1.794
Brochantite	-9.107	-25.563
Brucite	5.133	-12.66
Ca3(AsO4)2:4H2O(s)	-42.998	-24.098
Ca3(PO4)2 (am1)	-43.56	-18.632
Ca3(PO4)2 (am2)	-43.56	-15.839
Ca3(PO4)2 (beta)	-43.56	-14.312

Mineral	log IAP	Sat. index
Ca4H(PO4)3:3H2O(s)	-67.973	-20.662
CaCO3xH2O(s)	-14.176	-7.089
CaCrO4(s)	-11.748	-9.647
CaHPO4(s)	-24.412	-4.949
CaHPO4:2H2O(s)	-24.413	-5.278
Calcite	-14.175	-5.745
CaS(s)	-45.418	-56.598
Cd metal (alpha)	-19.072	-33.044
Cd metal (gamma)	-19.072	-33.151
Cd(OH)2(s)	-0.578	-14.797
Cd3(OH)4SO4(s)	-12.463	-35.023
Cd3(PO4)2(s)	-61.083	-28.483
Cd3OH2(SO4)2(s)	-23.192	-29.902
Cd4(OH)6SO4(s)	-13.041	-41.441
CdCl2(s)	-12.11	-11.564
CdCl2:1H2O(s)	-12.11	-10.463
CdCl2:2.5H2O(s)	-12.111	-10.154
CdF2(s)	-23.876	-22.945
CdOHCl(s)	-6.344	-10.069
CdSO4(s)	-11.307	-11.451
CdSO4:1H2O(s)	-11.307	-9.773
CdSO4:2.67H2O(s)	-11.308	-9.544
Cerrusite	-19.27	-5.92
Chalcanthite	-10.326	-7.649
Chalcopyrite	-98.222	-62.049
Chloropyromorphite(c)	-93.95	-9.52
Chloropyromorphite(soil)	-93.95	-13.55
Cinnabar	-77.098	-30.275
Claudetite	-14.113	-12.6

Mineral	log IAP	Sat. index
Cotunnite	-11.364	-6.425
Covellite	-50.275	-27.466
Cr(VI)-Ettringite	-4.468	-67.869
Cr(VI)-Jarosite	-37.861	-19.345
CrO3(s)	-17.012	-13.833
Cryolite	-57.111	-23.039
Cu azide	-18.279	-10.438
Cu(OH)2(s)	0.405	-9.208
Cu2(OH)3NO3(s)	-48.288	-57.98
Cu3(AsO4)2:2H2O(s)	-57.57	-22.47
Cu3(PO4)2(s)	-58.133	-21.283
Cu3(PO4)2:3H2O(s)	-58.134	-23.014
CuCO3(s)	-19.033	-7.533
CuCrO4(s)	-16.606	-11.166
CuF2(s)	-22.893	-24.415
CuF2:2H2O(s)	-22.894	-18.437
CuOCuSO4(s)	-9.918	-21.059
Cupric Ferrite	-2.213	-9.48
CuSO4(s)	-10.324	-13.707
Diaspore	7.5	0
Dolomite (disordered)	-28.481	-12.223
Dolomite (ordered)	-28.481	-11.631
Epsomite	-5.599	-3.402
Ettringite	14.379	-44.809
FCO3-Apatite	-144.251	-28.849
Fe(OH)2 (am)	2.734	-11.313
Fe(OH)2 (c)	2.734	-10.156
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-34.808	-32.545

Mineral	log IAP	Sat. index
Fe3(OH)8(s)	0.114	-20.108
FeAsO4:2H2O(s)	-30.704	-10.504
Ferrihydrite	-1.31	-5.121
Ferrihydrite (aged)	-1.31	-4.611
FeS (ppt)	-47.946	-45.063
Fluorite	-18.036	-7.463
Galena	-50.513	-35.106
Gibbsite (C)	7.499	-0.879
Goethite	-1.31	-2.169
Goslarite	-7.738	-5.64
Greenockite	-51.259	-36.904
Greigite	-202.609	-157.574
Gypsum	-5.467	-0.851
Halite	-4.004	-5.532
Hematite	-2.619	-1.985
Hercynite	17.734	-7.067
Hg(OH)2(s)	-26.417	-22.92
Hg3O2CO3(s)	-98.688	-69.108
HgCl2(s)	-37.949	-16.031
HgSO4(s)	-37.146	-27.638
Hinsdalite	-17.738	-15.238
H-Jarosite	-25.39	-21.357
Huntite	-57.092	-27.779
Hydrocerrusite	-38.373	-19.613
Hydromagnesite	-52.091	-44.653
Hydroxyapatite	-62.709	-18.376
Hydroxylpyromorphite	-88.184	-25.394
Hydrozincite	-23.907	-34.045
K2Cr2O7(s)	-33.839	-16.106

Mineral	log IAP	Sat. index
K2CrO4(s)	-16.827	-16.203
K-Alum	-13.871	-8.518
KCl(s)	-5.674	-6.574
K-Jarosite	-25.297	-14.916
Langite	-9.108	-27.603
Larnakite	-10.393	-10.091
Laurionite	-5.598	-6.221
Lepidocrocite	-1.31	-2.681
Lime	5.263	-28.615
Litharge	0.168	-12.92
Mackinawite	-47.946	-44.346
Maghemite	-2.619	-9.005
Magnesioferrite	2.514	-16.042
Magnesite	-14.306	-6.724
Magnetite	0.116	-4.555
Malachite	-18.627	-13.427
Massicot	0.168	-13.128
Matlockite	-17.247	-8.072
Melanothallite	-11.127	-17.77
Melanterite	-7.997	-5.664
Metacinnabar	-77.098	-30.673
Mg(OH)2 (active)	5.133	-13.661
Mg2(OH)3Cl:4H2O(s)	4.498	-21.502
Mg3(PO4)2(s)	-43.951	-20.671
MgCO3:5H2O(s)	-14.307	-9.767
MgCrO4(s)	-11.879	-17.8
MgF2(s)	-18.166	-10.104
MgHPO4:3H2O(s)	-24.543	-6.368
MgS(s)	-45.548	-63.228

Mineral	log IAP	Sat. index
Minium	18.999	-57.087
Mirabilite	-7.209	-5.612
Mn2(SO4)3(s)	-19.86	-15.143
Montroydite	-26.416	-22.7
Morenosite	-8.524	-6.305
Na2Cr2O7(s)	-30.499	-20.469
Na2CrO4(s)	-13.487	-16.537
NaF(s)	-9.887	-9.392
Na-Jarosite	-23.627	-19.132
Natron	-15.918	-14.206
Nesquehonite	-14.307	-9.784
Ni(OH)2 (am)	2.208	-11.266
Ni(OH)2 (c)	2.208	-8.582
Ni3(AsO4)2:8H2O(s)	-52.165	-26.665
Ni3(PO4)2(s)	-52.726	-21.426
Ni4(OH)6SO4(s)	-1.898	-33.898
NiCO3(s)	-17.231	-6.284
NiS (alpha)	-48.473	-42.953
NiS (beta)	-48.473	-37.453
NiS (gamma)	-48.473	-35.753
Nsutite	15.411	-2.093
Orpiment	-166.156	-118.256
Otavite	-20.016	-7.965
Pb azide (alpha)	-18.517	-9.542
Pb metal	-18.326	-22.567
Pb(OH)2(s)	0.168	-8.338
Pb10(OH)6O(CO3)6(s)	-114.95	-106.19
Pb2(OH)3Cl(s)	-5.43	-14.223
Pb2O(OH)2(s)	0.336	-25.854

Mineral	log IAP	Sat. index
Pb2O3(s)	18.831	-42.209
Pb2OCO3(s)	-19.102	-18.792
Pb3(AsO4)2(s)	-58.281	-22.781
Pb3(PO4)2(s)	-58.845	-15.315
Pb3O2CO3(s)	-18.934	-30.626
Pb3O2SO4(s)	-10.224	-21.392
Pb4(OH)6SO4(s)	-10.057	-31.157
Pb4O3SO4(s)	-10.056	-32.763
PbCrO4(s)	-16.843	-3.975
PbF2(s)	-23.131	-15.569
PbHPO4(s)	-29.507	-5.702
PbO:0.3H2O(s)	0.168	-12.812
Periclase	5.133	-17.37
Phosgenite	-30.635	-10.825
Plattnerite	18.663	-32.739
Plumbgummite	-36.684	-3.894
Portlandite	5.263	-18.223
Pyrite	-80.133	-61.322
Realgar	-66.985	-46.255
Retgersite	-8.524	-6.456
Siderite	-16.704	-6.158
Smithsonite	-16.444	-5.567
Spharelite	-47.687	-36.684
Spinel	20.133	-19.074
Strengite	-30.985	-4.642
Struvite	-23.771	-10.511
Sulfur	-32.187	-30.141
Tenorite(am)	0.406	-8.479
Tenorite(c)	0.406	-7.629

Mineral	log IAP	Sat. index
Thenardite	-7.205	-7.582
Thermonatrite	-15.915	-16.615
Tsumebite	-28.934	-19.144
Vaterite	-14.175	-6.339
Vivianite	-51.149	-13.358
Wurtzite	-47.687	-38.938
Zincite	2.994	-8.781
Zincosite	-7.735	-12.167
Zn metal	-15.5	-42.221
Zn(NO3)2:6H2O(s)	-95.205	-98.371
Zn(OH)2 (am)	2.994	-10.001
Zn(OH)2 (beta)	2.994	-9.265
Zn(OH)2 (delta)	2.994	-8.85
Zn(OH)2 (epsilon)	2.994	-9.018
Zn(OH)2 (gamma)	2.994	-9.237
Zn2(OH)2SO4(s)	-4.741	-12.241
Zn2(OH)3Cl(s)	0.222	-14.969
Zn3(PO4)2:4H2O(s)	-50.369	-14.949
Zn3AsO42:2.5H2O(s)	-49.804	-22.304
Zn3O(SO4)2(s)	-12.476	-32.959
Zn4(OH)6SO4(s)	1.247	-27.153
Zn5(OH)8Cl2(s)	3.438	-35.062
Zn-Al LDH(s)	3.768	-16.062
ZnCl2(s)	-8.538	-16.029
ZnCO3(s)	-16.444	-5.644
ZnCO3:1H2O(s)	-16.445	-6.185
ZnF2(s)	-20.305	-20.133
ZnSO4:1H2O(s)	-7.736	-7.365

C3.4: pH 5

Mineral	log IAP	Sat. index
Al(OH)3 (am)	7.499	-3.976
Al(OH)3 (Soil)	7.499	-1.429
Al2O3(s)	14.999	-6.225
Al4(OH)10SO4(s)	17.438	-5.262
AlAsO4:2H2O(s)	-22.812	-7.012
AlOHF2(s)	-13.265	-13.672
AlOHSO4(s)	-5.059	-1.829
Alunite	-1.531	-1.408
Anglesite	-10.525	-2.662
Anhydrite	-5.334	-1.018
Antlerite	-5.652	-14.44
Aragonite	-12.232	-3.953
Arsenolite	-19.948	-18.385
Artinite	-5.257	-15.589
As2O5(s)	-60.622	-25.912
As2S3(am)	-201.479	-155.094
Atacamite	-2.164	-10.123
Azurite	-32.006	-14.852
Bianchite	-7.61	-5.849
Birnessite	17.504	-0.587
Bixbyite	14.514	14.401
Boehmite	7.5	-1.794
Brochantite	-3.35	-19.805
Brucite	7.1	-10.693
Ca3(AsO4)2:4H2O(s)	-38.95	-20.05
Ca3(PO4)2 (am1)	-39.219	-14.29
Ca3(PO4)2 (am2)	-39.219	-11.498
Ca3(PO4)2 (beta)	-39.219	-9.97

Mineral	log IAP	Sat. index
Ca4H(PO4)3:3H2O(s)	-62.441	-15.13
CaCO3xH2O(s)	-12.232	-5.146
CaCrO4(s)	-10.82	-8.718
CaHPO4(s)	-23.222	-3.758
CaHPO4:2H2O(s)	-23.222	-4.088
Calcite	-12.232	-3.802
CaS(s)	-53.286	-64.466
Cd metal (alpha)	-19.096	-33.069
Cd metal (gamma)	-19.096	-33.176
Cd(OH)2(s)	1.397	-12.822
Cd3(OH)4SO4(s)	-8.366	-30.926
Cd3(PO4)2(s)	-56.698	-24.098
Cd3OH2(SO4)2(s)	-20.924	-27.634
Cd4(OH)6SO4(s)	-6.968	-35.368
CdCl2(s)	-12.138	-11.592
CdCl2:1H2O(s)	-12.139	-10.491
CdCl2:2.5H2O(s)	-12.139	-10.182
CdF2(s)	-19.367	-18.435
CdOHCl(s)	-5.37	-9.096
CdSO4(s)	-11.161	-11.305
CdSO4:1H2O(s)	-11.161	-9.627
CdSO4:2.67H2O(s)	-11.162	-9.398
Cerrusite	-17.423	-4.072
Chalcanthite	-10.258	-7.581
Chalcopyrite	-116.683	-80.51
Chloropyromorphite(c)	-87.937	-3.507
Chloropyromorphite(soil)	-87.937	-7.537
Cinnabar	-89.497	-42.674
Claudetite	-19.948	-18.435

Mineral	log IAP	Sat. index
Cotunnite	-11.502	-6.563
Covellite	-58.208	-35.398
Cr(VI)-Ettringite	4.202	-59.199
Cr(VI)-Jarosite	-38.028	-19.512
CrO3(s)	-18.044	-14.865
Cryolite	-46.519	-12.448
Cu azide	-17.246	-9.405
Cu(OH)2(s)	2.302	-7.311
Cu2(OH)3NO3(s)	-35.5	-45.193
Cu3(AsO4)2:2H2O(s)	-53.715	-18.615
Cu3(PO4)2(s)	-53.984	-17.134
Cu3(PO4)2:3H2O(s)	-53.985	-18.865
CuCO3(s)	-17.154	-5.654
CuCrO4(s)	-15.741	-10.301
CuF2(s)	-18.462	-19.984
CuF2:2H2O(s)	-18.463	-14.006
CuOCuSO4(s)	-7.954	-19.094
Cupric Ferrite	0.284	-6.982
CuSO4(s)	-10.256	-13.64
Diaspore	7.5	0
Dolomite (disordered)	-24.588	-8.33
Dolomite (ordered)	-24.588	-7.738
Epsomite	-5.461	-3.264
Ettringite	20.657	-38.531
FCO3-Apatite	-125.918	-10.516
Fe(OH)2 (am)	2.035	-12.012
Fe(OH)2 (c)	2.035	-10.855
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-39.694	-37.431

Mineral	log IAP	Sat. index
Fe3(OH)8(s)	0.016	-20.206
FeAsO4:2H2O(s)	-31.321	-11.121
Ferrihydrite	-1.01	-4.82
Ferrihydrite (aged)	-1.01	-4.31
FeS (ppt)	-58.475	-55.592
Fluorite	-13.54	-2.967
Galena	-58.477	-43.07
Gibbsite (C)	7.499	-0.879
Goethite	-1.009	-1.869
Goslarite	-7.61	-5.512
Greenockite	-59.112	-44.758
Greigite	-242.024	-196.989
Gypsum	-5.335	-0.719
Halite	-4.01	-5.537
Hematite	-2.018	-1.384
Hercynite	17.035	-7.767
Hg(OH)2(s)	-28.987	-25.49
Hg3O2CO3(s)	-106.415	-76.835
HgCl2(s)	-42.523	-20.605
HgSO4(s)	-41.545	-32.037
Hinsdalite	-18.473	-15.973
H-Jarosite	-28.146	-24.114
Huntite	-49.301	-19.988
Hydrocerrusite	-32.812	-14.052
Hydromagnesite	-42.326	-34.888
Hydroxyapatite	-55.216	-10.883
Hydroxylpyromorphite	-81.169	-18.379
Hydrozincite	-14.157	-24.295
K2Cr2O7(s)	-33.912	-16.178

Mineral	log IAP	Sat. index
K2CrO4(s)	-15.868	-15.243
K-Alum	-16.534	-11.18
KCl(s)	-5.68	-6.58
K-Jarosite	-27.058	-16.677
Langite	-3.35	-21.845
Larnakite	-8.491	-8.19
Laurionite	-4.735	-5.358
Lepidocrocite	-1.009	-2.38
Lime	7.224	-26.654
Litharge	2.034	-11.055
Mackinawite	-58.475	-54.875
Maghemite	-2.018	-8.404
Magnesioferrite	5.082	-13.473
Magnesite	-12.356	-4.775
Magnetite	0.017	-4.653
Malachite	-14.852	-9.651
Massicot	2.034	-11.263
Matlockite	-15.117	-5.942
Melanothallite	-11.234	-17.876
Melanterite	-10.526	-8.192
Metacinnabar	-89.497	-43.072
Mg(OH)2 (active)	7.1	-11.694
Mg2(OH)3Cl:4H2O(s)	7.43	-18.57
Mg3(PO4)2(s)	-39.591	-16.311
MgCO3:5H2O(s)	-12.358	-7.818
MgCrO4(s)	-10.944	-16.865
MgF2(s)	-13.664	-5.603
MgHPO4:3H2O(s)	-23.347	-5.172
MgS(s)	-53.41	-71.09

Mineral	log IAP	Sat. index
Minium	26.595	-49.491
Mirabilite	-7.045	-5.448
Mn2(SO4)3(s)	-23.162	-18.445
Montroydite	-28.986	-25.269
Morenosite	-8.392	-6.173
Na2Cr2O7(s)	-30.571	-20.541
Na2CrO4(s)	-12.527	-15.577
NaF(s)	-7.624	-7.129
Na-Jarosite	-25.387	-20.893
Natron	-13.943	-12.232
Nesquehonite	-12.357	-7.835
Ni(OH)2 (am)	4.169	-9.304
Ni(OH)2 (c)	4.169	-6.621
Ni3(AsO4)2:8H2O(s)	-48.117	-22.617
Ni3(PO4)2(s)	-48.384	-17.084
Ni4(OH)6SO4(s)	4.117	-27.883
NiCO3(s)	-15.287	-4.34
NiS (alpha)	-56.341	-50.821
NiS (beta)	-56.341	-45.321
NiS (gamma)	-56.341	-43.621
Nsutite	17.504	0
Orpiment	-201.479	-153.579
Otavite	-18.059	-6.007
Pb azide (alpha)	-17.515	-8.541
Pb metal	-18.461	-22.701
Pb(OH)2(s)	2.033	-6.473
Pb10(OH)6O(CO3)6(s)	-96.402	-87.642
Pb2(OH)3Cl(s)	-2.701	-11.494
Pb2O(OH)2(s)	4.067	-22.123

Mineral	log IAP	Sat. index
Pb2O3(s)	24.562	-36.478
Pb2OCO3(s)	-15.389	-15.079
Pb3(AsO4)2(s)	-54.521	-19.021
Pb3(PO4)2(s)	-54.79	-11.26
Pb3O2CO3(s)	-13.355	-25.048
Pb3O2SO4(s)	-6.458	-17.625
Pb4(OH)6SO4(s)	-4.425	-25.525
Pb4O3SO4(s)	-4.424	-27.131
PbCrO4(s)	-16.01	-3.142
PbF2(s)	-18.731	-11.169
PbHPO4(s)	-28.412	-4.607
PbO:0.3H2O(s)	2.034	-10.946
Periclase	7.1	-15.403
Phosgenite	-28.925	-9.115
Plattnerite	22.528	-28.873
Plumbgummite	-36.36	-3.57
Portlandite	7.224	-16.262
Pyrite	-98.491	-79.68
Realgar	-80.731	-60.001
Retgersite	-8.392	-6.324
Siderite	-17.421	-6.875
Smithsonite	-14.505	-3.628
Spharelite	-55.559	-44.556
Spinel	22.1	-17.107
Strengite	-31.456	-5.112
Struvite	-21.58	-8.32
Sulfur	-40.016	-37.97
Tenorite(am)	2.303	-6.582
Tenorite(c)	2.303	-5.732

Mineral	log IAP	Sat. index
Thenardite	-7.042	-7.419
Thermonatrite	-13.94	-14.641
Tsumebite	-24.077	-14.287
Vaterite	-12.232	-4.396
Vivianite	-54.788	-16.998
Wurtzite	-55.559	-46.81
Zincite	4.951	-6.824
Zincosite	-7.607	-12.039
Zn metal	-15.543	-42.264
Zn(NO3)2:6H2O(s)	-75.26	-78.426
Zn(OH)2 (am)	4.951	-8.044
Zn(OH)2 (beta)	4.951	-7.308
Zn(OH)2 (delta)	4.951	-6.893
Zn(OH)2 (epsilon)	4.951	-7.061
Zn(OH)2 (gamma)	4.951	-7.28
Zn2(OH)2SO4(s)	-2.656	-10.156
Zn2(OH)3Cl(s)	3.134	-12.057
Zn3(PO4)2:4H2O(s)	-46.039	-10.619
Zn3AsO42:2.5H2O(s)	-45.768	-18.268
Zn3O(SO4)2(s)	-10.263	-30.746
Zn4(OH)6SO4(s)	7.246	-21.154
Zn5(OH)8Cl2(s)	11.219	-27.281
Zn-Al LDH(s)	7.673	-12.157
ZnCl2(s)	-8.585	-16.076
ZnCO3(s)	-14.505	-3.705
ZnCO3:1H2O(s)	-14.505	-4.245
ZnF2(s)	-15.813	-15.642
ZnSO4:1H2O(s)	-7.608	-7.238

C3.5: pH 6

Mineral	log IAP	Sat. index
Al(OH)3 (am)	7.499	-3.976
Al(OH)3 (Soil)	7.499	-1.429
Al2O3(s)	14.999	-6.225
Al4(OH)10SO4(s)	15.438	-7.262
AlAsO4:2H2O(s)	-23.871	-8.071
AlOHF2(s)	-14.555	-14.962
AlOHSO4(s)	-7.059	-3.829
Alunite	-4.532	-4.409
Anglesite	-10.572	-2.709
Anhydrite	-5.337	-1.021
Antlerite	-1.752	-10.54
Aragonite	-10.381	-2.102
Arsenolite	-26.066	-24.503
Artinite	-1.408	-11.739
As2O5(s)	-62.739	-28.03
As2S3(am)	-237.597	-191.212
Atacamite	0.77	-7.189
Azurite	-26.4	-9.246
Bianchite	-7.614	-5.853
Birnessite	17.504	-0.587
Bixbyite	12.514	12.401
Boehmite	7.5	-1.794
Brochantite	2.517	-13.938
Brucite	9.098	-8.695
Ca3(AsO4)2:4H2O(s)	-35.075	-16.175
Ca3(PO4)2 (am1)	-36.128	-11.199
Ca3(PO4)2 (am2)	-36.128	-8.407
Ca3(PO4)2 (beta)	-36.128	-6.879

Mineral	log IAP	Sat. index
Ca4H(PO4)3:3H2O(s)	-58.804	-11.492
CaCO3xH2O(s)	-10.382	-3.295
CaCrO4(s)	-10.046	-7.945
CaHPO4(s)	-22.675	-3.212
CaHPO4:2H2O(s)	-22.676	-3.541
Calcite	-10.381	-1.951
CaS(s)	-61.288	-72.468
Cd metal (alpha)	-19.099	-33.071
Cd metal (gamma)	-19.099	-33.178
Cd(OH)2(s)	3.395	-10.824
Cd3(OH)4SO4(s)	-4.373	-26.933
Cd3(PO4)2(s)	-53.607	-21.007
Cd3OH2(SO4)2(s)	-18.931	-25.641
Cd4(OH)6SO4(s)	-0.977	-29.377
CdCl2(s)	-12.141	-11.595
CdCl2:1H2O(s)	-12.141	-10.494
CdCl2:2.5H2O(s)	-12.142	-10.185
CdF2(s)	-18.659	-17.728
CdOHCl(s)	-4.373	-8.098
CdSO4(s)	-11.163	-11.307
CdSO4:1H2O(s)	-11.164	-9.629
CdSO4:2.67H2O(s)	-11.164	-9.401
Cerrusite	-15.617	-2.266
Chalcanthite	-10.291	-7.615
Chalcopyrite	-135.416	-99.244
Chloropyromorphite(c)	-83.527	0.903
Chloropyromorphite(soil)	-83.527	-3.127
Cinnabar	-101.634	-54.811
Claudetite	-26.066	-24.553

Mineral	log IAP	Sat. index
Cotunnite	-11.55	-6.611
Covellite	-66.241	-43.431
Cr(VI)-Ettringite	12.515	-50.886
Cr(VI)-Jarosite	-38.577	-20.061
CrO3(s)	-19.269	-16.09
Cryolite	-47.391	-13.32
Cu azide	-17.006	-9.165
Cu(OH)2(s)	4.269	-5.344
Cu2(OH)3NO3(s)	-22.567	-32.26
Cu3(AsO4)2:2H2O(s)	-49.932	-14.832
Cu3(PO4)2(s)	-50.986	-14.136
Cu3(PO4)2:3H2O(s)	-50.987	-15.867
CuCO3(s)	-15.334	-3.834
CuCrO4(s)	-14.999	-9.559
CuF2(s)	-17.786	-19.307
CuF2:2H2O(s)	-17.786	-13.329
CuOCuSO4(s)	-6.02	-17.161
Cupric Ferrite	2.851	-4.415
CuSO4(s)	-10.29	-13.673
Diaspore	7.5	0
Dolomite (disordered)	-20.887	-4.629
Dolomite (ordered)	-20.887	-4.037
Epsomite	-5.463	-3.266
Ettringite	26.644	-32.545
FCO3-Apatite	-115.402	0
Fe(OH)2 (am)	1.335	-12.712
Fe(OH)2 (c)	1.335	-11.555
Fe(OH)2.7Cl.3(s)	-3.04	0
Fe2(SO4)3(s)	-45.095	-42.832

Mineral	log IAP	Sat. index
Fe3(OH)8(s)	-0.084	-20.306
FeAsO4:2H2O(s)	-32.079	-11.879
Ferrihydrite	-0.71	-4.52
Ferrihydrite (aged)	-0.71	-4.01
FeS (ppt)	-69.175	-66.292
Fluorite	-12.833	-2.26
Galena	-66.524	-51.118
Gibbsite (C)	7.499	-0.879
Goethite	-0.709	-1.569
Goslarite	-7.614	-5.517
Greenockite	-67.115	-52.76
Greigite	-282.125	-237.09
Gypsum	-5.338	-0.721
Halite	-4.01	-5.538
Hematite	-1.418	-0.784
Hercynite	16.335	-8.467
Hg(OH)2(s)	-31.123	-27.627
Hg3O2CO3(s)	-112.973	-83.393
HgCl2(s)	-46.66	-24.742
HgSO4(s)	-45.682	-36.174
Hinsdalite	-19.971	-17.471
H-Jarosite	-31.246	-27.214
Huntite	-41.897	-12.584
Hydrocerrusite	-27.248	-8.488
Hydromagnesite	-32.924	-25.486
Hydroxyapatite	-49.581	-5.248
Hydroxylpyromorphite	-75.758	-12.968
Hydrozincite	-4.472	-14.61
K2Cr2O7(s)	-34.362	-16.628

Mineral	log IAP	Sat. index
K2CrO4(s)	-15.093	-14.469
K-Alum	-19.535	-14.181
KCl(s)	-5.681	-6.581
K-Jarosite	-29.158	-18.777
Langite	2.517	-15.978
Larnakite	-6.586	-6.284
Laurionite	-3.782	-4.405
Lepidocrocite	-0.709	-2.08
Lime	9.222	-24.656
Litharge	3.987	-9.102
Mackinawite	-69.175	-65.575
Maghemite	-1.418	-7.804
Magnesioferrite	7.68	-10.875
Magnesite	-10.505	-2.924
Magnetite	-0.083	-4.753
Malachite	-11.065	-5.865
Massicot	3.987	-9.31
Matlockite	-14.809	-5.634
Melanothallite	-11.267	-17.91
Melanterite	-13.226	-10.892
Metacinnabar	-101.634	-55.209
Mg(OH)2 (active)	9.098	-9.696
Mg2(OH)3Cl:4H2O(s)	10.426	-15.574
Mg3(PO4)2(s)	-36.499	-13.219
MgCO3:5H2O(s)	-10.507	-5.967
MgCrO4(s)	-10.17	-16.091
MgF2(s)	-12.957	-4.895
MgHPO4:3H2O(s)	-22.8	-4.625
MgS(s)	-61.412	-79.092

Mineral	log IAP	Sat. index
Minium	34.454	-41.633
Mirabilite	-7.046	-5.449
Mn2(SO4)3(s)	-31.163	-26.446
Montroydite	-31.123	-27.406
Morenosite	-8.405	-6.186
Na2Cr2O7(s)	-31.021	-20.991
Na2CrO4(s)	-11.752	-14.802
NaF(s)	-7.269	-6.775
Na-Jarosite	-27.488	-22.993
Natron	-12.091	-10.38
Nesquehonite	-10.506	-5.984
Ni(OH)2 (am)	6.156	-7.317
Ni(OH)2 (c)	6.156	-4.634
Ni3(AsO4)2:8H2O(s)	-44.272	-18.772
Ni3(PO4)2(s)	-45.324	-14.024
Ni4(OH)6SO4(s)	10.067	-21.933
NiCO3(s)	-13.447	-2.5
NiS (alpha)	-64.354	-58.834
NiS (beta)	-64.354	-53.334
NiS (gamma)	-64.354	-51.634
Nsutite	17.504	0
Orpiment	-237.597	-189.698
Otavite	-16.208	-4.156
Pb azide (alpha)	-17.289	-8.315
Pb metal	-18.508	-22.748
Pb(OH)2(s)	3.986	-4.52
Pb10(OH)6O(CO3)6(s)	-77.756	-68.996
Pb2(OH)3Cl(s)	0.204	-8.589
Pb2O(OH)2(s)	7.973	-18.217

Mineral	log IAP	Sat. index
Pb2O3(s)	30.467	-30.573
Pb2OCO3(s)	-11.63	-11.321
Pb3(AsO4)2(s)	-50.78	-15.28
Pb3(PO4)2(s)	-51.834	-8.304
Pb3O2CO3(s)	-7.644	-19.336
Pb3O2SO4(s)	-2.599	-13.767
Pb4(OH)6SO4(s)	1.386	-19.714
Pb4O3SO4(s)	1.387	-21.319
PbCrO4(s)	-15.282	-2.413
PbF2(s)	-18.068	-10.507
PbHPO4(s)	-27.911	-4.106
PbO:0.3H2O(s)	3.986	-8.994
Periclase	9.098	-13.405
Phosgenite	-27.167	-7.357
Plattnerite	26.481	-24.92
Plumbgummite	-37.31	-4.52
Portlandite	9.222	-14.264
Pyrite	-117.191	-98.38
Realgar	-94.79	-74.061
Retgersite	-8.404	-6.336
Siderite	-18.268	-7.722
Smithsonite	-12.656	-1.779
Spharelite	-63.563	-52.561
Spinel	24.098	-15.109
Strengite	-32.607	-6.264
Struvite	-20.034	-6.774
Sulfur	-48.016	-45.97
Tenorite(am)	4.269	-4.615
Tenorite(c)	4.269	-3.765

Mineral	log IAP	Sat. index
Thenardite	-7.043	-7.42
Thermonatrite	-12.088	-12.788
Tsumebite	-19.656	-9.866
Vaterite	-10.381	-2.545
Vivianite	-59.791	-22
Wurtzite	-63.563	-54.815
Zincite	6.947	-4.828
Zincosite	-7.612	-12.044
Zn metal	-15.547	-42.268
Zn(NO3)2:6H2O(s)	-55.265	-58.431
Zn(OH)2 (am)	6.947	-6.048
Zn(OH)2 (beta)	6.947	-5.313
Zn(OH)2 (delta)	6.947	-4.897
Zn(OH)2 (epsilon)	6.947	-5.065
Zn(OH)2 (gamma)	6.947	-5.284
Zn2(OH)2SO4(s)	-0.665	-8.165
Zn2(OH)3Cl(s)	6.125	-9.066
Zn3(PO4)2:4H2O(s)	-42.954	-7.534
Zn3AsO42:2.5H2O(s)	-41.899	-14.399
Zn3O(SO4)2(s)	-8.276	-28.759
Zn4(OH)6SO4(s)	13.229	-15.171
Zn5(OH)8Cl2(s)	19.198	-19.302
Zn-Al LDH(s)	11.591	-8.239
ZnCl2(s)	-8.59	-16.08
ZnCO3(s)	-12.656	-1.856
ZnCO3:1H2O(s)	-12.657	-2.397
ZnF2(s)	-15.108	-14.936
ZnSO4:1H2O(s)	-7.612	-7.242

C4 Mass distribution

C4.1: pH 2

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	5.64E-12	100	0	0	0	0
Ca+2	0.004194	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021436	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	2.96E-10	100	0	0	0	0
H+1	0.01801	100	0	0	0	0
H3AsO3	4.91E-07	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	2.12E-24	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003003	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	1.83E-49	100	0	0	0	0
NO3-1	9.69E-66	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Pb+2	5.79E-08	100	0	0	0	0
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

C4.2: pH 3

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	2.59E-09	100	0	0	0	0
Ca+2	0.004194	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021437	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	6.17E-10	100	0	0	0	0
H+1	0.006447	100	0	0	0	0
H3AsO3	4.88E-07	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	2.74E-34	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003003	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	3.15E-42	100	0	0	0	0
NO3-1	9.64E-56	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

C4.3: pH 4

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.000577	20.744	0	0	0.002203	79.256
AsO4-3	4.03E-07	100	0	0	0	0
Ca+2	0.004194	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.020753	96.81	0	0	0.000684	3.19
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	1.25E-05	100	0	0	0	0
Fe+3	1.94E-11	0	0	0	0.00228	100
H+1	0.005251	100	0	0	0	0
H3AsO3	8.7E-08	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	3.02E-44	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003003	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	1.63E-34	100	0	0	0	0
NO3-1	9.62E-46	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.00543	74.517	0	0	0.001857	25.483
Zn+2	2.29E-05	100	0	0	0	0

C4.4: pH 5

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	5.85E-06	0.21	0	0	0.002774	99.79
AsO4-3	4.9E-07	100	0	0	0	0
Ca+2	0.004194	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.020749	96.792	0	0	0.000688	3.208
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	2.74E-08	100	0	0	0	0
Fe+3	1.39E-12	0	0	0	0.002292	100
H+1	0.00502	100	0	0	0	0
H3AsO3	1.05E-10	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	4.52E-54	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	100	0	0	0	0
Mn+3	6.47E-08	1.269	0	0	5.03E-06	98.731
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	1.46E-26	100	0	0	0	0
NO3-1	9.53E-36	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

C4.5: pH 6

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	2.08E-08	0.001	0	0	0.00278	99.999
AsO4-3	4.91E-07	100	0	0	0	0
Ca+2	0.004192	99.94	0	0	2.51E-06	0.06
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.020749	96.792	0	0	0.000688	3.208
CO3-2	0.002552	99.987	0	0	3.23E-07	0.013
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.25E-05	94.929	0	0	6.67E-07	5.071
Fe+2	5.48E-11	100	0	0	0	0
Fe+3	2.45E-13	0	0	0	0.002292	100
H+1	0.004295	100	0	0	0	0
H3AsO3	9.19E-14	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	5.18E-64	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	99.999	0	0	3.87E-08	0.001
Mn+3	6.49E-12	0	0	0	5.1E-06	100
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	99.999	0	0	9.69E-08	0.001
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	1.44E-18	100	0	0	0	0
NO3-1	9.53E-26	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	8.72E-07	40.299	0	0	1.29E-06	59.701
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

C5 Finite solids

C5.1: pH 2

No mineral solids precipitate from solution

C5.2: pH 3

No mineral solids precipitate from solution

C5.3: pH 4

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.28E-03
AlOHSO4(s)	1.86E-03
Diaspore	3.46E-04

C5.4: pH 5

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.29E-03
Diaspore	2.77E-03
Nsutite	5.03E-06

C5.5: pH 6

Solid	Equilibrium amount (mol/l)
Fe(OH)2.7Cl.3(s)	2.29E-03
Diaspore	2.78E-03
Nsutite	5.10E-06

Solid	Equilibrium amount (mol/l)
FCO3-Apatite	2.69E-07

Appendix D - Anaerobic treatment system for water discharge from Big Swamp into Reach 3 of Boundary Creek

D1 Aqueous species

D1.1: Eh 150

Species	Concentration	Activity	Log activity
Al DOM1	8.78E-06	8.71E-06	-5.06
Al(OH)2+	2.85E-10	2.37E-10	-9.625
Al(OH)3 (aq)	1.83E-14	1.85E-14	-13.732
Al(OH)4-	4.11E-18	3.42E-18	-17.466
Al(SO4)2-	0.000134	0.000112	-3.952
Al+3	0.000782	0.000152	-3.819
Al2(OH)2+4	5.17E-10	2.8E-11	-10.553
Al2(OH)2CO3+2	1.04E-12	5.04E-13	-12.298
Al2PO4+3	4.08E-09	7.92E-10	-9.101
Al3(OH)4+5	1.77E-14	1.86E-16	-15.731
AlCl+2	2.26E-06	1.09E-06	-5.962
AlF+2	1.31E-05	6.33E-06	-5.199
AlF2+	1.31E-08	1.09E-08	-7.963
AlF3 (aq)	5.47E-13	5.52E-13	-12.258
AlF4-	1.44E-18	1.2E-18	-17.92
AlHPO4+	1.62E-07	1.35E-07	-6.869
AlOH+2	6.71E-07	3.24E-07	-6.49
AlSO4+	0.001838	0.001532	-2.815
As3S4(HS)-	5.59E-40	4.66E-40	-39.332
AsO4-3	8.07E-29	1.57E-29	-28.805
AsS(OH)HS-	4.43E-18	3.69E-18	-17.433
Ca DOM1	3.9E-07	3.47E-07	-6.459
Ca(NH3)2+2	3.89E-23	1.88E-23	-22.727
Ca(NO3)2	5.5E-168	5.6E-168	-167.253
Ca+2	0.002503	0.001208	-2.918
CaCl+	6.08E-05	5.07E-05	-4.295

Species	Concentration	Activity	Log activity
CaCO3 (aq)	1.07E-14	1.08E-14	-13.966
CaCrO4 (aq)	2.81E-11	2.84E-11	-10.547
CaF+	7.14E-11	5.95E-11	-10.225
CaH2PO4+	2.77E-08	2.31E-08	-7.636
CaHCO3+	6.21E-09	5.18E-09	-8.286
CaHPO4 (aq)	1.18E-11	1.19E-11	-10.925
CaNH3+2	5.61E-13	2.71E-13	-12.567
CaNO3+	5.97E-83	4.98E-83	-82.303
CaOH+	4.91E-14	4.09E-14	-13.388
CaPO4-	1.25E-17	1.05E-17	-16.981
CaSO4 (aq)	0.00043	0.000434	-3.363
Cd DOM1	2.07E-12	1.84E-12	-11.734
Cd(CO3)2-2	3.53E-30	1.7E-30	-29.769
Cd(HS)2 (aq)	1.45E-20	1.47E-20	-19.833
Cd(HS)3-	5.9E-32	4.92E-32	-31.308
Cd(HS)4-2	8.58E-43	4.14E-43	-42.383
Cd(NH3)2+2	1.28E-24	6.16E-25	-24.21
Cd(NH3)3+2	2.23E-33	1.07E-33	-32.969
Cd(NH3)4+2	1.14E-42	5.52E-43	-42.258
Cd(NO2)2 (aq)	4.1E-127	4.2E-127	-126.38
Cd(NO3)2 (aq)	5.8E-169	5.9E-169	-168.229
Cd(OH)2 (aq)	2.19E-24	2.22E-24	-23.655
Cd(OH)3-	1.08E-34	9.03E-35	-34.044
Cd(OH)4-2	7.96E-46	3.84E-46	-45.416
Cd(SO4)2-2	5.02E-11	2.42E-11	-10.616
Cd+2	5.29E-09	2.55E-09	-8.593
Cd2OH+3	2.93E-24	5.68E-25	-24.246
CdCl+	5.02E-09	4.19E-09	-8.378

Species	Concentration	Activity	Log activity
CdCl2 (aq)	2.95E-10	2.97E-10	-9.527
CdCO3 (aq)	3.71E-19	3.75E-19	-18.426
CdF+	1.97E-16	1.64E-16	-15.786
CdHCO3+	3.14E-14	2.61E-14	-13.583
CdHPO4 (aq)	2.64E-16	2.67E-16	-15.574
CdHS+	1.66E-14	1.39E-14	-13.858
CdNH3+2	1.52E-16	7.31E-17	-16.136
CdNO2+	5.94E-68	4.95E-68	-67.305
CdNO3+	1.57E-88	1.31E-88	-87.883
CdOH+	4.7E-17	3.92E-17	-16.407
CdSO4 (aq)	9.08E-10	9.17E-10	-9.038
Cl-1	0.021205	0.017673	-1.753
CO3-2	1.3E-14	6.27E-15	-14.203
Cr2O7-2	8.64E-12	4.17E-12	-11.38
CrO3Cl-	1.01E-10	8.39E-11	-10.076
CrO3H2PO4-	1.36E-12	1.13E-12	-11.946
CrO3HPO4-2	2.02E-12	9.72E-13	-12.012
CrO3SO4-2	8.25E-10	3.98E-10	-9.4
CrO4-2	8.27E-11	3.99E-11	-10.399
Cu DOM1	2.28E-14	2.03E-14	-13.693
Cu(CO3)2-2	9.11E-31	4.4E-31	-30.357
Cu(N3)2 (aq)	1.25E-21	1.26E-21	-20.899
Cu(N3)3-	1.74E-26	1.45E-26	-25.838
Cu(N3)4-2	1.82E-32	8.79E-33	-32.056
Cu(NH3)2+2	3.02E-25	1.46E-25	-24.836
Cu(NH3)3+2	1.73E-32	8.33E-33	-32.079
Cu(NH3)4+2	2.04E-40	9.83E-41	-40.007
Cu(NO2)2 (aq)	2.8E-131	2.8E-131	-130.552

Species	Concentration	Activity	Log activity
Cu(NO3)2 (aq)	4.1E-173	4.1E-173	-172.387
Cu(OH)2 (aq)	1.91E-24	1.93E-24	-23.715
Cu(OH)3-	1.37E-31	1.14E-31	-30.942
Cu(OH)4-2	6.54E-43	3.15E-43	-42.501
Cu+2	1.46E-12	7.05E-13	-12.152
Cu2(OH)2+2	2.02E-30	9.76E-31	-30.011
Cu2OH+3	1.42E-28	2.75E-29	-28.561
Cu2S3-2	3.88E-59	1.87E-59	-58.728
Cu3(OH)4+2	7.82E-48	3.77E-48	-47.423
CuCl+	2.66E-14	2.21E-14	-13.655
CuCl2 (aq)	6.46E-17	6.52E-17	-16.186
CuCl3-	1.07E-20	8.96E-21	-20.048
CuCl4-2 1	2.32E-24	1.12E-24	-23.95
CuCO3 (aq)	2.58E-20	2.6E-20	-19.584
CuF+	1.54E-19	1.28E-19	-18.893
CuHCO3+	1.73E-17	1.44E-17	-16.842
CuHPO4 (aq)	1.92E-19	1.94E-19	-18.712
CuHSO4+	7.75E-16	6.46E-16	-15.19
CuN3+	1.41E-16	1.17E-16	-15.93
CuNH3+2	1.38E-18	6.67E-19	-18.176
CuNO2+	1.71E-71	1.42E-71	-70.847
CuNO3+	3.43E-92	2.86E-92	-91.544
CuOH+	6.75E-18	5.62E-18	-17.25
CuS(aq)	2.43E-26	2.46E-26	-25.61
CuSO4 (aq)	2.45E-13	2.48E-13	-12.606
DOC (Gaussian DOM)	0.000333	0.000336	-3.473
DOM1	7.76E-06	1.86E-06	-5.73

Species	Concentration	Activity	Log activity
F-1	5.21E-09	4.34E-09	-8.362
Fe DOM1	3.66E-13	3.63E-13	-12.44
Fe(N3)2+	4.81E-19	4E-19	-18.397
Fe(N3)3 (aq)	1.95E-23	1.97E-23	-22.705
Fe(NH3)2+2	1.93E-21	9.31E-22	-21.031
Fe(NH3)3+2	3.97E-31	1.91E-31	-30.718
Fe(NH3)4+2	3.48E-41	1.68E-41	-40.775
Fe(NO2)2+	4.7E-131	3.9E-131	-130.409
Fe(NO2)3 (aq)	8.5E-190	8.6E-190	-189.064
Fe(OH)2 (aq)	9.46E-20	9.56E-20	-19.02
Fe(OH)2+	4.3E-15	3.58E-15	-14.446
Fe(OH)3-	1.37E-27	1.14E-27	-26.942
Fe(OH)3 (aq)	4.88E-22	4.92E-22	-21.308
Fe(OH)4-	1.6E-27	1.33E-27	-26.875
Fe(SO4)2-	1.32E-14	1.1E-14	-13.959
Fe+2	0.001929	0.000931	-3.031
Fe+3	1.03E-13	2E-14	-13.699
Fe2(OH)2+4	7.3E-25	3.96E-26	-25.403
Fe3(OH)4+5	4.59E-36	4.82E-38	-37.317
FeCl+	1.25E-05	1.04E-05	-4.984
FeCl+2	1.6E-14	7.73E-15	-14.112
FeCrO4+	3.51E-17	2.93E-17	-16.533
FeF+	7.87E-11	6.56E-11	-10.183
FeF+2	1.72E-16	8.28E-17	-16.082
FeF2+	1.63E-20	1.36E-20	-19.867
FeF3 (aq)	5.42E-26	5.48E-26	-25.262
FeH2PO4+	4.4E-07	3.67E-07	-6.436

Species	Concentration	Activity	Log activity
FeH2PO4+2	6.17E-16	2.97E-16	-15.527
FeHCO3+	4.54E-09	3.79E-09	-8.422
FeHPO4 (aq)	7.57E-11	7.64E-11	-10.117
FeHPO4+	6.17E-15	5.14E-15	-14.289
FeHS+	2.47E-11	2.06E-11	-10.686
FeN3+2	1.48E-15	7.16E-16	-15.145
FeNH3+2	3.7E-12	1.78E-12	-11.749
FeNO2+2	1.27E-71	6.11E-72	-71.214
FeOH+	8.47E-11	7.06E-11	-10.151
FeOH+2	1.15E-13	5.55E-14	-13.255
FeSO4 (aq)	0.00035	0.000354	-3.451
FeSO4+	5.21E-13	4.34E-13	-12.363
H DOM1	1.17E-05	6.49E-06	-5.188
H+1	0.002899	0.002416	-2.617
H2AsO3-	1.13E-13	9.41E-14	-13.026
H2AsO4-	9.1E-16	7.59E-16	-15.12
H2CO3* (aq)	0.002552	0.002577	-2.589
H2CrO4 (aq)	2.73E-10	2.76E-10	-9.56
H2PO4-	1.21E-06	1.01E-06	-5.995
H2S (aq)	1.85E-09	1.87E-09	-8.729
H3AsO3	4.91E-07	4.95E-07	-6.305
H3AsO4	3.24E-16	3.27E-16	-15.485
H3PO4	3.06E-07	3.09E-07	-6.509
HAsO3-2	4.11E-25	1.98E-25	-24.703
HAsO4-2	6.38E-20	3.08E-20	-19.511
HCO3-	4.88E-07	4.06E-07	-6.391
HCrO4-	3.64E-07	3.03E-07	-6.518
HF (aq)	1.31E-08	1.32E-08	-7.88

Species	Concentration	Activity	Log activity
HF2-	2.59E-16	2.15E-16	-15.667
Hg(CO3)2-2	7.67E-43	3.7E-43	-42.432
Hg(HS)2 (aq)	1.82E-18	1.84E-18	-17.736
Hg(N3)2 (aq)	2.27E-22	2.29E-22	-21.64
Hg(NH3)2+2	1.09E-31	5.25E-32	-31.28
Hg(NH3)4+2	2.36E-50	1.14E-50	-49.944
Hg(NO2)2 (aq)	7.4E-142	7.5E-142	-141.126
Hg(NO2)3-	6E-201	5E-201	-200.301
Hg(NO2)4-2	5.1E-261	2.5E-261	-260.606
Hg(NO3)2 (aq)	5.9E-191	6E-191	-190.221
Hg(OH)2	2.9E-31	2.93E-31	-30.533
Hg(SO4)2-2	4.65E-32	2.24E-32	-31.649
Hg+2	9.03E-30	4.36E-30	-29.361
Hg2OH+3	1.68E-59	3.26E-60	-59.487
Hg3(OH)3+3	2.31E-87	4.49E-88	-87.348
HgCl+	2.63E-24	2.19E-24	-23.66
HgCl2 (aq)	2.94E-19	2.97E-19	-18.528
HgCl3-1	6.26E-20	5.21E-20	-19.283
HgCl4-2	8.55E-21	4.13E-21	-20.384
HgClOH (aq)	6.27E-25	6.33E-25	-24.199
HgCO3 (aq)	2.07E-32	2.09E-32	-31.679
HgF+	8.47E-37	7.06E-37	-36.151
HgHCO3+	1.01E-30	8.4E-31	-30.076
HgHS2-	2.95E-22	2.46E-22	-21.609
HgN3+	3.35E-18	2.79E-18	-17.555
HgNO2+	4.99E-85	4.16E-85	-84.381

Species	Concentration	Activity	Log activity
HgNO3+	1.4E-110	1.2E-110	-109.923
HgOH+	6.48E-31	5.4E-31	-30.268
HgOHCO3-	1.22E-36	1.02E-36	-35.992
HgS2-2	4.11E-28	1.98E-28	-27.702
HgSO4 (aq)	1.25E-30	1.27E-30	-29.898
HN3 (aq)	2.83E-05	2.86E-05	-4.544
HNO2 (aq)	6.52E-61	6.58E-61	-60.182
HPO4-2	5.27E-11	2.54E-11	-10.594
HS-1	6.37E-14	5.31E-14	-13.275
HSO4-	0.000374	0.000311	-3.507
K+1	0.000148	0.000124	-3.908
K2HPO4 (aq)	4.16E-18	4.2E-18	-17.377
K2PO4-	1.2E-26	1E-26	-26
KCl (aq)	1.15E-06	1.16E-06	-5.937
KCr2O7-	5.34E-15	4.45E-15	-14.352
KCrO4-	2.2E-14	1.83E-14	-13.737
KF (aq)	2.43E-13	2.45E-13	-12.61
KH2PO4 (aq)	1.92E-10	1.94E-10	-9.713
KHPO4-	2.32E-14	1.93E-14	-13.714
KNO3 (aq)	1.13E-84	1.14E-84	-83.943
KOH (aq)	4.05E-16	4.09E-16	-15.388
KPO4-2	2.01E-23	9.7E-24	-23.013
KSO4-	1.52E-06	1.26E-06	-5.898
Mg DOM1	3.98E-08	3.54E-08	-7.451
Mg(NH3)2+2	1.98E-23	9.54E-24	-23.021
Mg+2	0.002551	0.001231	-2.91
Mg2CO3+2	7.66E-17	3.7E-17	-16.432
MgCl+	9.82E-05	8.19E-05	-4.087

Species	Concentration	Activity	Log activity
MgCO3 (aq)	5.45E-15	5.51E-15	-14.259
MgF+	4.25E-10	3.54E-10	-9.451
MgHCO3+	5.83E-09	4.86E-09	-8.314
MgHPO4 (aq)	1.65E-11	1.67E-11	-10.777
MgOH+	9.5E-13	7.92E-13	-12.101
MgPO4-	2E-19	1.67E-19	-18.778
MgSO4 (aq)	0.000354	0.000358	-3.447
Mn+3	5.1E-06	9.89E-07	-6.005
N3-1	2.76E-07	2.3E-07	-6.639
Na+1	0.00684	0.0057	-2.244
Na2HPO4 (aq)	5.85E-15	5.9E-15	-14.229
Na2PO4-	5.46E-23	4.55E-23	-22.342
NaCl (aq)	5.59E-05	5.65E-05	-4.248
NaCO3-	1.06E-15	8.85E-16	-15.053
NaCrO4-	1.36E-12	1.13E-12	-11.947
NaF (aq)	2.17E-11	2.19E-11	-10.659
NaH2PO4 (aq)	8.86E-09	8.94E-09	-8.049
NaHCO3 (aq)	1.36E-09	1.37E-09	-8.862
NaHPO4-	1.66E-12	1.38E-12	-11.86
NaNO3 (aq)	1.92E-83	1.94E-83	-82.712
NaOH (aq)	1.28E-14	1.29E-14	-13.888
NaPO4-2	1.02E-21	4.94E-22	-21.306
NaSO4-	6.42E-05	5.35E-05	-4.272
NH3 (aq)	6.68E-11	6.74E-11	-10.171
NH4+1	0.000713	0.000594	-3.226
NH4Cr2O7-	2.98E-14	2.49E-14	-13.605
NH4SO4-	1.32E-05	1.1E-05	-4.958
Ni DOM1	1.27E-09	1.13E-09	-8.947

Species	Concentration	Activity	Log activity
Ni(N3)2 (aq)	8.08E-18	8.16E-18	-17.088
Ni(NH3)2+2	1.71E-21	8.23E-22	-21.085
Ni(NH3)3+2	6.66E-30	3.22E-30	-29.493
Ni(NH3)4+2	7.72E-39	3.72E-39	-38.429
Ni(NH3)5+2	2.89E-48	1.39E-48	-47.856
Ni(NH3)6+2	2.3E-58	1.11E-58	-57.955
Ni(NO2)2 (aq)	3.5E-126	3.6E-126	-125.446
Ni(OH)2 (aq)	2.68E-20	2.71E-20	-19.567
Ni(OH)3-	1.35E-28	1.13E-28	-27.948
Ni(SO4)2-2	6.42E-11	3.1E-11	-10.509
Ni+2	3.24E-06	1.56E-06	-5.806
NiCl+	1.2E-08	9.98E-09	-8.001
NiCl2 (aq)	6.23E-12	6.29E-12	-11.201
NiCO3 (aq)	3.61E-16	3.64E-16	-15.439
NiF+	1.47E-13	1.23E-13	-12.911
NiH2PO4+	1.25E-11	1.04E-11	-10.983
NiHCO3+	7.48E-11	6.23E-11	-10.205
NiHPO4 (aq)	2.88E-14	2.91E-14	-13.536
NiHS+	3.08E-14	2.57E-14	-13.591
NiN3+	8.12E-12	6.77E-12	-11.17
NiNH3+2	1.43E-13	6.92E-14	-13.16
NiNO2+	8.68E-66	7.23E-66	-65.141
NiNO3+	5.7E-86	4.75E-86	-85.323
NiOH+	4.76E-14	3.97E-14	-13.401
NiSO4 (aq)	4.94E-07	4.98E-07	-6.303
NO2-1	2.31E-61	1.93E-61	-60.715
NO3-1	1.45E-80	1.21E-80	-79.918
OH-	2.29E-12	1.91E-12	-11.72

Species	Concentration	Activity	Log activity
Pb DOM1	1.01E-09	8.99E-10	-9.046
Pb(CO3)2-2	1.11E-26	5.36E-27	-26.271
Pb(HS)2 (aq)	8.14E-20	8.22E-20	-19.085
Pb(HS)3-	1.04E-31	8.71E-32	-31.06
Pb(NO2)2 (aq)	7.4E-127	7.5E-127	-126.125
Pb(NO3)2 (aq)	6.2E-167	6.3E-167	-166.2
Pb(OH)2 (aq)	2.13E-20	2.16E-20	-19.666
Pb(OH)3-	1.08E-28	8.97E-29	-28.047
Pb(SO4)2-2	2.87E-10	1.39E-10	-9.858
Pb+2	3.25E-08	1.57E-08	-7.805
Pb2OH+3	2.09E-19	4.06E-20	-19.391
Pb3(OH)4+2	5.91E-38	2.85E-38	-37.545
Pb4(OH)4+4	1.27E-41	6.89E-43	-42.162
PbCl+	1.07E-08	8.89E-09	-8.051
PbCl2 (aq)	3.25E-10	3.28E-10	-9.484
PbCl3-	5.53E-12	4.61E-12	-11.336
PbCl4-2	6.17E-14	2.98E-14	-13.526
PbCO3 (aq)	3.29E-16	3.33E-16	-15.478
PbF+	1.15E-14	9.61E-15	-14.017
PbF2 (aq)	5.09E-22	5.14E-22	-21.289
PbH2PO4+	4.67E-13	3.89E-13	-12.41
PbHCO3+	4.83E-12	4.03E-12	-11.395
PbHPO4 (aq)	4.03E-16	4.07E-16	-15.391
PbNO2+	1.17E-66	9.77E-67	-66.01
PbNO3+	3.45E-87	2.88E-87	-86.541
PbOH+	1.41E-13	1.17E-13	-12.931
PbSO4 (aq)	1.32E-08	1.33E-08	-7.877
PO4-3	1.86E-20	3.6E-21	-20.444

Species	Concentration	Activity	Log activity
S-2	9.08E-29	4.38E-29	-28.358
SO4-2	0.00359	0.001732	-2.761
Zn DOM1	1.19E-08	1.06E-08	-7.976
Zn(CO3)2-2	1.5E-26	7.24E-27	-26.14
Zn(N3)2 (aq)	4.6E-17	4.65E-17	-16.333
Zn(N3)3-	7.33E-23	6.11E-23	-22.214
Zn(NH3)2+2	3.8E-21	1.84E-21	-20.736
Zn(NH3)3+2	7.55E-29	3.64E-29	-28.439
Zn(NH3)4+2	7.34E-37	3.54E-37	-36.451
Zn(NO2)2 (aq)	5.4E-126	5.4E-126	-125.265
Zn(NO3)2 (aq)	6.7E-166	6.8E-166	-165.17
Zn(OH)2 (aq)	1.99E-17	2.01E-17	-16.696
Zn(OH)3-	3.18E-26	2.65E-26	-25.577
Zn(OH)4-2	3.62E-36	1.75E-36	-35.757
Zn(SO4)2-2	1.09E-07	5.27E-08	-7.278
Zn+2	1.91E-05	9.22E-06	-5.035
Zn2OH+3	7.47E-17	1.45E-17	-16.839
Zn2S3-2	4.19E-42	2.02E-42	-41.695
Zn4S6-4	1.28E-81	6.93E-83	-82.159
ZnCl+	5.23E-07	4.36E-07	-6.361
ZnCl2 (aq)	4.89E-09	4.93E-09	-8.307
ZnCl3-	1.1E-10	9.2E-11	-10.036
ZnCl4-2	1.55E-12	7.5E-13	-12.125
ZnCO3 (aq)	3.3E-15	3.33E-15	-14.478
ZnF+	8.23E-13	6.86E-13	-12.164
ZnHCO3+	1.13E-10	9.43E-11	-10.026
ZnHPO4 (aq)	3.89E-13	3.93E-13	-12.406
ZnN3+	3.66E-11	3.05E-11	-10.516

Species	Concentration	Activity	Log activity
ZnNH3+2	2.44E-13	1.18E-13	-12.93
ZnNO2+	1.29E-65	1.07E-65	-64.97
ZnNO3+	3.58E-85	2.99E-85	-84.525
ZnOH+	2.11E-12	1.76E-12	-11.755
ZnS (aq)	7.46E-18	7.53E-18	-17.123
ZnSO4 (aq)	3.17E-06	3.2E-06	-5.494

D1.2: Eh 200

Species	Concentration	Activity	Log activity
Al DOM1	8.77E-06	8.71E-06	-5.06
Al(OH)2+	2.85E-10	2.37E-10	-9.625
Al(OH)3 (aq)	1.83E-14	1.85E-14	-13.733
Al(OH)4-	4.1E-18	3.42E-18	-17.466
Al(SO4)2-	0.000134	0.000112	-3.952
Al+3	0.000782	0.000152	-3.819
Al2(OH)2+4	5.17E-10	2.8E-11	-10.553
Al2(OH)2CO3+2	1.04E-12	5.04E-13	-12.298
Al2PO4+3	4.08E-09	7.92E-10	-9.101
Al3(OH)4+5	1.77E-14	1.86E-16	-15.732
AlCl+2	2.26E-06	1.09E-06	-5.962
AlF+2	1.31E-05	6.33E-06	-5.199
AlF2+	1.31E-08	1.09E-08	-7.963
AlF3 (aq)	5.47E-13	5.52E-13	-12.258
AlF4-	1.44E-18	1.2E-18	-17.92
AlHPO4+	1.62E-07	1.35E-07	-6.869
AlOH+2	6.71E-07	3.24E-07	-6.49
AlSO4+	0.001838	0.001532	-2.815
As3S4(HS)-	5.88E-82	4.9E-82	-81.31
AsO4-3	4.53E-27	8.79E-28	-27.056
AsS(OH)HS-	4.5E-32	3.75E-32	-31.426
Ca DOM1	3.9E-07	3.47E-07	-6.459
Ca(NH3)2+2	3.89E-23	1.88E-23	-22.727
Ca(NO3)2	5.4E-154	5.5E-154	-153.261
Ca+2	0.002503	0.001208	-2.918
CaCl+	6.08E-05	5.07E-05	-4.295
CaCO3 (aq)	1.07E-14	1.08E-14	-13.966

Species	Concentration	Activity	Log activity
CaCrO4 (aq)	2.81E-11	2.84E-11	-10.547
CaF+	7.14E-11	5.95E-11	-10.225
CaH2PO4+	2.77E-08	2.31E-08	-7.636
CaHCO3+	6.21E-09	5.18E-09	-8.286
CaHPO4 (aq)	1.18E-11	1.19E-11	-10.925
CaNH3+2	5.61E-13	2.71E-13	-12.567
CaNO3+	5.92E-76	4.94E-76	-75.307
CaOH+	4.91E-14	4.09E-14	-13.388
CaPO4-	1.25E-17	1.05E-17	-16.981
CaSO4 (aq)	0.00043	0.000434	-3.363
Cd DOM1	2.07E-12	1.84E-12	-11.734
Cd(CO3)2-2	3.53E-30	1.7E-30	-29.769
Cd(HS)2 (aq)	1.48E-34	1.49E-34	-33.826
Cd(HS)3-	6.05E-53	5.04E-53	-52.297
Cd(HS)4-2	8.87E-71	4.28E-71	-70.369
Cd(NH3)2+2	1.28E-24	6.16E-25	-24.21
Cd(NH3)3+2	2.23E-33	1.07E-33	-32.969
Cd(NH3)4+2	1.14E-42	5.52E-43	-42.258
Cd(NO2)2 (aq)	1.3E-116	1.3E-116	-115.886
Cd(NO3)2 (aq)	5.8E-155	5.8E-155	-154.236
Cd(OH)2 (aq)	2.19E-24	2.22E-24	-23.655
Cd(OH)3-	1.08E-34	9.03E-35	-34.044
Cd(OH)4-2	7.96E-46	3.84E-46	-45.416
Cd(SO4)2-2	5.02E-11	2.42E-11	-10.616
Cd+2	5.29E-09	2.55E-09	-8.593
Cd2OH+3	2.93E-24	5.68E-25	-24.246
CdCl+	5.02E-09	4.19E-09	-8.378

Species	Concentration	Activity	Log activity
CdCl2 (aq)	2.95E-10	2.97E-10	-9.527
CdCO3 (aq)	3.71E-19	3.75E-19	-18.426
CdF+	1.97E-16	1.64E-16	-15.786
CdHCO3+	3.14E-14	2.61E-14	-13.583
CdHPO4 (aq)	2.64E-16	2.67E-16	-15.574
CdHS+	1.68E-21	1.4E-21	-20.855
CdNH3+2	1.52E-16	7.31E-17	-16.136
CdNO2+	1.05E-62	8.75E-63	-62.058
CdNO3+	1.56E-81	1.3E-81	-80.887
CdOH+	4.7E-17	3.92E-17	-16.407
CdSO4 (aq)	9.08E-10	9.17E-10	-9.038
Cl-1	0.021205	0.017673	-1.753
CO3-2	1.3E-14	6.27E-15	-14.203
Cr2O7-2	8.64E-12	4.17E-12	-11.38
CrO3Cl-	1.01E-10	8.39E-11	-10.076
CrO3H2PO4-	1.36E-12	1.13E-12	-11.946
CrO3HPO4-2	2.02E-12	9.72E-13	-12.012
CrO3SO4-2	8.25E-10	3.98E-10	-9.4
CrO4-2	8.27E-11	3.99E-11	-10.399
Cu DOM1	8.17E-10	7.27E-10	-9.139
Cu(CO3)2-2	3.26E-26	1.57E-26	-25.803
Cu(N3)2 (aq)	4.48E-17	4.52E-17	-16.345
Cu(N3)3-	6.25E-22	5.21E-22	-21.284
Cu(N3)4-2	6.52E-28	3.15E-28	-27.502
Cu(NH3)2+2	1.08E-20	5.22E-21	-20.282
Cu(NH3)3+2	6.18E-28	2.98E-28	-27.525
Cu(NH3)4+2	7.3E-36	3.52E-36	-35.453
Cu(NO2)2 (aq)	3.1E-116	3.1E-116	-115.503

Species	Concentration	Activity	Log activity
Cu(NO3)2 (aq)	1.4E-154	1.4E-154	-153.84
Cu(OH)2 (aq)	6.84E-20	6.9E-20	-19.161
Cu(OH)3-	4.91E-27	4.09E-27	-26.388
Cu(OH)4-2	2.34E-38	1.13E-38	-37.947
Cu+2	5.24E-08	2.53E-08	-7.598
Cu2(OH)2+2	2.59E-21	1.25E-21	-20.903
Cu2OH+3	1.82E-19	3.52E-20	-19.453
Cu2S3-2	5.1E-71	2.46E-71	-70.609
Cu3(OH)4+2	3.59E-34	1.73E-34	-33.761
CuCl+	9.51E-10	7.93E-10	-9.101
CuCl2 (aq)	2.31E-12	2.34E-12	-11.632
CuCl3-	3.85E-16	3.21E-16	-15.494
CuCl4-2 1	8.32E-20	4.02E-20	-19.396
CuCO3 (aq)	9.24E-16	9.33E-16	-15.03
CuF+	5.5E-15	4.59E-15	-14.339
CuHCO3+	6.18E-13	5.15E-13	-12.288
CuHPO4 (aq)	6.88E-15	6.95E-15	-14.158
CuHSO4+	2.78E-11	2.31E-11	-10.636
CuN3+	5.05E-12	4.2E-12	-11.376
CuNH3+2	4.95E-14	2.39E-14	-13.622
CuNO2+	1.08E-61	9.01E-62	-61.045
CuNO3+	1.22E-80	1.01E-80	-79.994
CuOH+	2.42E-13	2.01E-13	-12.696
CuS(aq)	8.78E-29	8.87E-29	-28.052
CuSO4 (aq)	8.79E-09	8.87E-09	-8.052
DOC (Gaussian DOM)	0.000333	0.000336	-3.473
DOM1	7.76E-06	1.86E-06	-5.73
F-1	5.21E-09	4.34E-09	-8.362

Species	Concentration	Activity	Log activity
Fe DOM1	2.74E-12	2.72E-12	-11.566
Fe(N3)2+	3.6E-18	3E-18	-17.523
Fe(N3)3 (aq)	1.46E-22	1.48E-22	-21.831
Fe(NH3)2+2	1.93E-21	9.31E-22	-21.031
Fe(NH3)3+2	3.97E-31	1.91E-31	-30.718
Fe(NH3)4+2	3.48E-41	1.68E-41	-40.775
Fe(NO2)2+	1.1E-119	9.1E-120	-119.04
Fe(NO2)3 (aq)	3.5E-173	3.6E-173	-172.448
Fe(OH)2 (aq)	9.46E-20	9.56E-20	-19.02
Fe(OH)2+	3.22E-14	2.68E-14	-13.571
Fe(OH)3-	1.37E-27	1.14E-27	-26.942
Fe(OH)3 (aq)	3.65E-21	3.69E-21	-20.433
Fe(OH)4-	1.2E-26	9.99E-27	-26
Fe(SO4)2-	9.88E-14	8.24E-14	-13.084
Fe+2	0.001929	0.000931	-3.031
Fe+3	7.72E-13	1.5E-13	-12.825
Fe2(OH)2+4	4.1E-23	2.22E-24	-23.654
Fe3(OH)4+5	1.93E-33	2.03E-35	-34.693
FeCl+	1.25E-05	1.04E-05	-4.984
FeCl+2	1.2E-13	5.79E-14	-13.237
FeCrO4+	2.63E-16	2.19E-16	-15.659
FeF+	7.87E-11	6.56E-11	-10.183
FeF+2	1.29E-15	6.2E-16	-15.207
FeF2+	1.22E-19	1.02E-19	-18.992
FeF3 (aq)	4.06E-25	4.1E-25	-24.387
FeH2PO4+	4.4E-07	3.67E-07	-6.436
FeH2PO4+2	4.62E-15	2.23E-15	-14.652
FeHCO3+	4.54E-09	3.79E-09	-8.422

Species	Concentration	Activity	Log activity
FeHPO4 (aq)	7.57E-11	7.64E-11	-10.117
FeHPO4+	4.62E-14	3.85E-14	-13.415
FeHS+	2.49E-18	2.08E-18	-17.683
FeN3+2	1.11E-14	5.37E-15	-14.27
FeNH3+2	3.7E-12	1.78E-12	-11.749
FeNO2+2	1.68E-65	8.08E-66	-65.092
FeOH+	8.47E-11	7.06E-11	-10.151
FeOH+2	8.62E-13	4.16E-13	-12.381
FeSO4 (aq)	0.00035	0.000354	-3.451
FeSO4+	3.9E-12	3.25E-12	-11.488
H DOM1	1.17E-05	6.49E-06	-5.188
H+1	0.002899	0.002416	-2.617
H2AsO3-	1.13E-13	9.41E-14	-13.026
H2AsO4-	5.11E-14	4.26E-14	-13.371
H2CO3* (aq)	0.002552	0.002577	-2.589
H2CrO4 (aq)	2.73E-10	2.76E-10	-9.56
H2PO4-	1.21E-06	1.01E-06	-5.995
H2S (aq)	1.87E-16	1.88E-16	-15.725
H3AsO3	4.91E-07	4.95E-07	-6.305
H3AsO4	1.82E-14	1.84E-14	-13.736
H3PO4	3.06E-07	3.09E-07	-6.509
HAsO3-2	4.11E-25	1.98E-25	-24.703
HAsO4-2	3.58E-18	1.73E-18	-17.762
HCO3-	4.88E-07	4.06E-07	-6.391
HCrO4-	3.64E-07	3.03E-07	-6.518
HF (aq)	1.31E-08	1.32E-08	-7.88
HF2-	2.59E-16	2.15E-16	-15.667
Hg(CO3)2-2	7.61E-36	3.67E-36	-35.435

Species	Concentration	Activity	Log activity
Hg(HS)2 (aq)	1.83E-25	1.85E-25	-24.732
Hg(N3)2 (aq)	2.25E-15	2.27E-15	-14.644
Hg(NH3)2+2	1.08E-24	5.21E-25	-24.283
Hg(NH3)4+2	2.34E-43	1.13E-43	-42.948
Hg(NO2)2 (aq)	2.3E-124	2.3E-124	-123.635
Hg(NO2)3-	3.3E-178	2.7E-178	-177.563
Hg(NO2)4-2	5E-233	2.4E-233	-232.621
Hg(NO3)2 (aq)	5.8E-170	5.9E-170	-169.232
Hg(OH)2	2.88E-24	2.9E-24	-23.537
Hg(SO4)2-2	4.61E-25	2.23E-25	-24.653
Hg+2	8.96E-23	4.32E-23	-22.364
Hg2OH+3	1.65E-45	3.2E-46	-45.495
Hg3(OH)3+3	2.25E-66	4.37E-67	-66.359
HgCl+	2.6E-17	2.17E-17	-16.663
HgCl2 (aq)	2.91E-12	2.94E-12	-11.531
HgCl3-1	6.2E-13	5.17E-13	-12.286
HgCl4-2	8.48E-14	4.09E-14	-13.388
HgClOH (aq)	6.22E-18	6.28E-18	-17.202
HgCO3 (aq)	2.06E-25	2.08E-25	-24.683
HgF+	8.4E-30	7E-30	-29.155
HgHCO3+	1E-23	8.33E-24	-23.079
HgHS2-	2.98E-29	2.48E-29	-28.606
HgN3+	3.32E-11	2.77E-11	-10.558
HgNO2+	8.74E-73	7.29E-73	-72.138
HgNO3+	1.41E-96	1.18E-96	-95.93
HgOH+	6.42E-24	5.35E-24	-23.272

Species	Concentration	Activity	Log activity
HgOHCO3-	1.21E-29	1.01E-29	-28.996
HgS2-2	4.15E-35	2E-35	-34.699
HgSO4 (aq)	1.24E-23	1.26E-23	-22.901
HN3 (aq)	2.83E-05	2.86E-05	-4.544
HNO2 (aq)	1.15E-55	1.16E-55	-54.935
HPO4-2	5.27E-11	2.54E-11	-10.594
HS-1	6.42E-21	5.35E-21	-20.271
HSO4-	0.000374	0.000311	-3.507
K+1	0.000148	0.000124	-3.908
K2HPO4 (aq)	4.16E-18	4.2E-18	-17.377
K2PO4-	1.2E-26	1E-26	-26
KCl (aq)	1.15E-06	1.16E-06	-5.937
KCr2O7-	5.34E-15	4.45E-15	-14.352
KCrO4-	2.2E-14	1.83E-14	-13.737
KF (aq)	2.43E-13	2.45E-13	-12.61
KH2PO4 (aq)	1.92E-10	1.94E-10	-9.713
KHPO4-	2.32E-14	1.93E-14	-13.714
KNO3 (aq)	1.12E-77	1.13E-77	-76.947
KOH (aq)	4.05E-16	4.09E-16	-15.388
KPO4-2	2.01E-23	9.7E-24	-23.013
KSO4-	1.52E-06	1.26E-06	-5.898
Mg DOM1	3.98E-08	3.54E-08	-7.451
Mg(NH3)2+2	1.98E-23	9.54E-24	-23.021
Mg+2	0.002551	0.001231	-2.91
Mg2CO3+2	7.66E-17	3.69E-17	-16.432
MgCl+	9.82E-05	8.19E-05	-4.087
MgCO3 (aq)	5.45E-15	5.5E-15	-14.259
MgF+	4.25E-10	3.54E-10	-9.451

Species	Concentration	Activity	Log activity
MgHCO3+	5.83E-09	4.86E-09	-8.314
MgHPO4 (aq)	1.65E-11	1.67E-11	-10.777
MgOH+	9.5E-13	7.92E-13	-12.101
MgPO4-	2E-19	1.67E-19	-18.778
MgSO4 (aq)	0.000354	0.000358	-3.447
Mn+3	5.1E-06	9.89E-07	-6.005
N3-1	2.76E-07	2.3E-07	-6.639
Na+1	0.00684	0.0057	-2.244
Na2HPO4 (aq)	5.85E-15	5.9E-15	-14.229
Na2PO4-	5.46E-23	4.55E-23	-22.342
NaCl (aq)	5.59E-05	5.65E-05	-4.248
NaCO3-	1.06E-15	8.85E-16	-15.053
NaCrO4-	1.36E-12	1.13E-12	-11.947
NaF (aq)	2.17E-11	2.19E-11	-10.659
NaH2PO4 (aq)	8.86E-09	8.94E-09	-8.049
NaHCO3 (aq)	1.36E-09	1.37E-09	-8.862
NaHPO4-	1.66E-12	1.38E-12	-11.86
NaNO3 (aq)	1.91E-76	1.93E-76	-75.715
NaOH (aq)	1.28E-14	1.29E-14	-13.888
NaPO4-2	1.02E-21	4.94E-22	-21.306
NaSO4-	6.42E-05	5.35E-05	-4.272
NH3 (aq)	6.68E-11	6.74E-11	-10.171
NH4+1	0.000713	0.000594	-3.226
NH4Cr2O7-	2.98E-14	2.49E-14	-13.605
NH4SO4-	1.32E-05	1.1E-05	-4.958
Ni DOM1	1.27E-09	1.13E-09	-8.947
Ni(N3)2 (aq)	8.08E-18	8.16E-18	-17.088
Ni(NH3)2+2	1.71E-21	8.23E-22	-21.085

Species	Concentration	Activity	Log activity
Ni(NH3)3+2	6.66E-30	3.22E-30	-29.493
Ni(NH3)4+2	7.72E-39	3.72E-39	-38.429
Ni(NH3)5+2	2.89E-48	1.39E-48	-47.856
Ni(NH3)6+2	2.3E-58	1.11E-58	-57.955
Ni(NO2)2 (aq)	1.1E-115	1.1E-115	-114.951
Ni(OH)2 (aq)	2.68E-20	2.71E-20	-19.567
Ni(OH)3-	1.35E-28	1.13E-28	-27.948
Ni(SO4)2-2	6.43E-11	3.1E-11	-10.509
Ni+2	3.24E-06	1.56E-06	-5.806
NiCl+	1.2E-08	9.98E-09	-8.001
NiCl2 (aq)	6.23E-12	6.29E-12	-11.201
NiCO3 (aq)	3.61E-16	3.64E-16	-15.439
NiF+	1.47E-13	1.23E-13	-12.911
NiH2PO4+	1.25E-11	1.04E-11	-10.983
NiHCO3+	7.48E-11	6.23E-11	-10.205
NiHPO4 (aq)	2.88E-14	2.91E-14	-13.536
NiHS+	3.1E-21	2.59E-21	-20.587
NiN3+	8.12E-12	6.77E-12	-11.17
NiNH3+2	1.43E-13	6.92E-14	-13.16
NiNO2+	1.53E-60	1.28E-60	-59.894
NiNO3+	5.65E-79	4.71E-79	-78.327
NiOH+	4.76E-14	3.97E-14	-13.401
NiSO4 (aq)	4.94E-07	4.98E-07	-6.303
NO2-1	4.09E-56	3.41E-56	-55.468
NO3-1	1.44E-73	1.2E-73	-72.921
OH-	2.29E-12	1.91E-12	-11.72
Pb DOM1	1.01E-09	8.99E-10	-9.046
Pb(CO3)2-2	1.11E-26	5.36E-27	-26.271

Species	Concentration	Activity	Log activity
Pb(HS)2 (aq)	8.28E-34	8.36E-34	-33.078
Pb(HS)3-	1.07E-52	8.93E-53	-52.049
Pb(NO2)2 (aq)	2.3E-116	2.3E-116	-115.631
Pb(NO3)2 (aq)	6.1E-153	6.2E-153	-152.208
Pb(OH)2 (aq)	2.13E-20	2.16E-20	-19.667
Pb(OH)3-	1.08E-28	8.97E-29	-28.047
Pb(SO4)2-2	2.87E-10	1.39E-10	-9.858
Pb+2	3.25E-08	1.57E-08	-7.805
Pb2OH+3	2.09E-19	4.06E-20	-19.391
Pb3(OH)4+2	5.91E-38	2.85E-38	-37.545
Pb4(OH)4+4	1.27E-41	6.89E-43	-42.162
PbCl+	1.07E-08	8.89E-09	-8.051
PbCl2 (aq)	3.25E-10	3.28E-10	-9.484
PbCl3-	5.53E-12	4.61E-12	-11.336
PbCl4-2	6.17E-14	2.98E-14	-13.526
PbCO3 (aq)	3.29E-16	3.33E-16	-15.478
PbF+	1.15E-14	9.61E-15	-14.017
PbF2 (aq)	5.09E-22	5.14E-22	-21.289
PbH2PO4+	4.67E-13	3.89E-13	-12.41
PbHCO3+	4.83E-12	4.03E-12	-11.395
PbHPO4 (aq)	4.03E-16	4.07E-16	-15.391
PbNO2+	2.07E-61	1.73E-61	-60.763
PbNO3+	3.43E-80	2.85E-80	-79.544
PbOH+	1.41E-13	1.17E-13	-12.931
PbSO4 (aq)	1.32E-08	1.33E-08	-7.877
PO4-3	1.86E-20	3.6E-21	-20.444
S-2	9.16E-36	4.42E-36	-35.355

Species	Concentration	Activity	Log activity
SO4-2	0.00359	0.001732	-2.761
Zn DOM1	1.19E-08	1.06E-08	-7.976
Zn(CO3)2-2	1.5E-26	7.24E-27	-26.141
Zn(N3)2 (aq)	4.6E-17	4.65E-17	-16.333
Zn(N3)3-	7.33E-23	6.11E-23	-22.214
Zn(NH3)2+2	3.8E-21	1.84E-21	-20.736
Zn(NH3)3+2	7.55E-29	3.64E-29	-28.439
Zn(NH3)4+2	7.34E-37	3.54E-37	-36.451
Zn(NO2)2 (aq)	1.7E-115	1.7E-115	-114.771
Zn(NO3)2 (aq)	6.6E-152	6.6E-152	-151.178
Zn(OH)2 (aq)	1.99E-17	2.01E-17	-16.696
Zn(OH)3-	3.18E-26	2.65E-26	-25.577
Zn(OH)4-2	3.62E-36	1.75E-36	-35.758
Zn(SO4)2-2	1.09E-07	5.27E-08	-7.278
Zn+2	1.91E-05	9.22E-06	-5.035
Zn2OH+3	7.47E-17	1.45E-17	-16.839
Zn2S3-2	4.29E-63	2.07E-63	-62.684
Zn4S6-4	1.3E-123	7.3E-125	-124.137
ZnCl+	5.23E-07	4.36E-07	-6.361
ZnCl2 (aq)	4.89E-09	4.93E-09	-8.307
ZnCl3-	1.1E-10	9.2E-11	-10.036
ZnCl4-2	1.55E-12	7.5E-13	-12.125
ZnCO3 (aq)	3.3E-15	3.33E-15	-14.478
ZnF+	8.23E-13	6.86E-13	-12.164
ZnHCO3+	1.13E-10	9.43E-11	-10.026
ZnHPO4 (aq)	3.89E-13	3.93E-13	-12.406
ZnN3+	3.66E-11	3.05E-11	-10.516

Species	Concentration	Activity	Log activity
ZnNH3+2	2.44E-13	1.18E-13	-12.93
ZnNO2+	2.27E-60	1.89E-60	-59.723
ZnNO3+	3.55E-78	2.96E-78	-77.528
ZnOH+	2.11E-12	1.76E-12	-11.755
ZnS (aq)	7.52E-25	7.59E-25	-24.12
ZnSO4 (aq)	3.17E-06	3.2E-06	-5.494

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Species	Concentration	Activity	Log activity
Al DOM1	8.77E-06	8.71E-06	-5.06
Al(OH)2+	2.85E-10	2.37E-10	-9.625
Al(OH)3 (aq)	1.83E-14	1.85E-14	-13.733
Al(OH)4-	4.1E-18	3.42E-18	-17.466
Al(SO4)2-	0.000134	0.000112	-3.952
Al+3	0.000782	0.000152	-3.819
Al2(OH)2+4	5.17E-10	2.8E-11	-10.553
Al2(OH)2CO3+2	1.04E-12	5.04E-13	-12.298
Al2PO4+3	4.08E-09	7.92E-10	-9.101
Al3(OH)4+5	1.77E-14	1.86E-16	-15.732
AlCl+2	2.26E-06	1.09E-06	-5.962
AlF+2	1.31E-05	6.33E-06	-5.199
AlF2+	1.31E-08	1.09E-08	-7.963
AlF3 (aq)	5.47E-13	5.52E-13	-12.258
AlF4-	1.44E-18	1.2E-18	-17.92
AlHPO4+	1.62E-07	1.35E-07	-6.869
AlOH+2	6.71E-07	3.24E-07	-6.49
AlSO4+	0.001838	0.001532	-2.815
As3S4(HS)-	6.2E-124	5.1E-124	-123.288
AsO4-3	2.54E-25	4.93E-26	-25.307
AsS(OH)HS-	4.58E-46	3.81E-46	-45.419
Ca DOM1	3.9E-07	3.47E-07	-6.459
Ca(NH3)2+2	3.89E-23	1.88E-23	-22.727
Ca(NO3)2	5.3E-140	5.4E-140	-139.268
Ca+2	0.002503	0.001208	-2.918
CaCl+	6.08E-05	5.07E-05	-4.295

Species	Concentration	Activity	Log activity
CaCO3 (aq)	1.07E-14	1.08E-14	-13.966
CaCrO4 (aq)	2.81E-11	2.84E-11	-10.547
CaF+	7.14E-11	5.95E-11	-10.225
CaH2PO4+	2.77E-08	2.31E-08	-7.636
CaHCO3+	6.21E-09	5.18E-09	-8.286
CaHPO4 (aq)	1.18E-11	1.19E-11	-10.925
CaNH3+2	5.61E-13	2.71E-13	-12.567
CaNO3+	5.88E-69	4.9E-69	-68.31
CaOH+	4.91E-14	4.09E-14	-13.388
CaPO4-	1.25E-17	1.05E-17	-16.981
CaSO4 (aq)	0.00043	0.000434	-3.363
Cd DOM1	2.07E-12	1.84E-12	-11.734
Cd(CO3)2-2	3.53E-30	1.7E-30	-29.769
Cd(HS)2 (aq)	1.5E-48	1.52E-48	-47.819
Cd(HS)3-	6.2E-74	5.17E-74	-73.287
Cd(HS)4-2	9.2E-99	4.4E-99	-98.354
Cd(NH3)2+2	1.28E-24	6.16E-25	-24.21
Cd(NH3)3+2	2.23E-33	1.07E-33	-32.969
Cd(NH3)4+2	1.14E-42	5.52E-43	-42.258
Cd(NO2)2 (aq)	4E-106	4.1E-106	-105.391
Cd(NO3)2 (aq)	5.7E-141	5.7E-141	-140.243
Cd(OH)2 (aq)	2.19E-24	2.22E-24	-23.655
Cd(OH)3-	1.08E-34	9.03E-35	-34.044
Cd(OH)4-2	7.96E-46	3.84E-46	-45.416
Cd(SO4)2-2	5.02E-11	2.42E-11	-10.616
Cd+2	5.29E-09	2.55E-09	-8.593
Cd2OH+3	2.93E-24	5.68E-25	-24.246

Species	Concentration	Activity	Log activity
CdCl+	5.02E-09	4.19E-09	-8.378
CdCl2 (aq)	2.95E-10	2.97E-10	-9.527
CdCO3 (aq)	3.71E-19	3.75E-19	-18.426
CdF+	1.97E-16	1.64E-16	-15.786
CdHCO3+	3.14E-14	2.61E-14	-13.583
CdHPO4 (aq)	2.64E-16	2.67E-16	-15.574
CdHS+	1.69E-28	1.41E-28	-27.851
CdNH3+2	1.52E-16	7.31E-17	-16.136
CdNO2+	1.85E-57	1.55E-57	-56.811
CdNO3+	1.54E-74	1.29E-74	-73.891
CdOH+	4.7E-17	3.92E-17	-16.407
CdSO4 (aq)	9.08E-10	9.17E-10	-9.038
Cl-1	0.021205	0.017673	-1.753
CO3-2	1.3E-14	6.27E-15	-14.203
Cr2O7-2	8.64E-12	4.17E-12	-11.38
CrO3Cl-	1.01E-10	8.39E-11	-10.076
CrO3H2PO4-	1.36E-12	1.13E-12	-11.946
CrO3HPO4-2	2.02E-12	9.72E-13	-12.012
CrO3SO4-2	8.25E-10	3.98E-10	-9.4
CrO4-2	8.27E-11	3.99E-11	-10.399
Cu DOM1	8.17E-10	7.27E-10	-9.139
Cu(CO3)2-2	3.26E-26	1.57E-26	-25.803
Cu(N3)2 (aq)	4.48E-17	4.52E-17	-16.345
Cu(N3)3-	6.25E-22	5.21E-22	-21.284
Cu(N3)4-2	6.52E-28	3.15E-28	-27.502
Cu(NH3)2+2	1.08E-20	5.22E-21	-20.282
Cu(NH3)3+2	6.18E-28	2.98E-28	-27.525
Cu(NH3)4+2	7.3E-36	3.52E-36	-35.453

Species	Concentration	Activity	Log activity
Cu(NO2)2 (aq)	9.7E-106	9.8E-106	-105.008
Cu(NO3)2 (aq)	1.4E-140	1.4E-140	-139.847
Cu(OH)2 (aq)	6.84E-20	6.9E-20	-19.161
Cu(OH)3-	4.91E-27	4.09E-27	-26.388
Cu(OH)4-2	2.34E-38	1.13E-38	-37.947
Cu+2	5.24E-08	2.53E-08	-7.598
Cu2(OH)2+2	2.59E-21	1.25E-21	-20.903
Cu2OH+3	1.82E-19	3.52E-20	-19.453
Cu2S3-2	5.23E-92	2.52E-92	-91.598
Cu3(OH)4+2	3.59E-34	1.73E-34	-33.761
CuCl+	9.51E-10	7.93E-10	-9.101
CuCl2 (aq)	2.31E-12	2.34E-12	-11.632
CuCl3-	3.85E-16	3.21E-16	-15.494
CuCl4-2 1	8.32E-20	4.02E-20	-19.396
CuCO3 (aq)	9.24E-16	9.33E-16	-15.03
CuF+	5.5E-15	4.59E-15	-14.339
CuHCO3+	6.18E-13	5.15E-13	-12.288
CuHPO4 (aq)	6.88E-15	6.95E-15	-14.158
CuHSO4+	2.78E-11	2.31E-11	-10.636
CuN3+	5.05E-12	4.2E-12	-11.376
CuNH3+2	4.95E-14	2.39E-14	-13.622
CuNO2+	1.91E-56	1.59E-56	-55.798
CuNO3+	1.21E-73	1.01E-73	-72.998
CuOH+	2.42E-13	2.01E-13	-12.696
CuS(aq)	8.86E-36	8.94E-36	-35.049
CuSO4 (aq)	8.79E-09	8.87E-09	-8.052
DOC (Gaussian DOM)	0.000333	0.000336	-3.473

Species	Concentration	Activity	Log activity
DOM1	7.76E-06	1.86E-06	-5.73
F-1	5.21E-09	4.34E-09	-8.362
Fe DOM1	2.05E-11	2.04E-11	-10.691
Fe(N3)2+	2.7E-17	2.25E-17	-16.648
Fe(N3)3 (aq)	1.1E-21	1.11E-21	-20.956
Fe(NH3)2+2	1.93E-21	9.31E-22	-21.031
Fe(NH3)3+2	3.97E-31	1.91E-31	-30.718
Fe(NH3)4+2	3.48E-41	1.68E-41	-40.775
Fe(NO2)2+	2.6E-108	2.1E-108	-107.671
Fe(NO2)3 (aq)	1.5E-156	1.5E-156	-155.831
Fe(OH)2 (aq)	9.46E-20	9.56E-20	-19.02
Fe(OH)2+	2.41E-13	2.01E-13	-12.697
Fe(OH)3-	1.37E-27	1.14E-27	-26.942
Fe(OH)3 (aq)	2.74E-20	2.76E-20	-19.559
Fe(OH)4-	8.98E-26	7.49E-26	-25.126
Fe(SO4)2-	7.4E-13	6.17E-13	-12.21
Fe+2	0.001929	0.000931	-3.031
Fe+3	5.78E-12	1.12E-12	-11.95
Fe2(OH)2+4	2.3E-21	1.25E-22	-21.904
Fe3(OH)4+5	8.11E-31	8.52E-33	-32.069
FeCl+	1.25E-05	1.04E-05	-4.984
FeCl+2	8.99E-13	4.34E-13	-12.363
FeCrO4+	1.97E-15	1.64E-15	-14.784
FeF+	7.87E-11	6.56E-11	-10.183
FeF+2	9.63E-15	4.65E-15	-14.333
FeF2+	9.16E-19	7.63E-19	-18.117
FeF3 (aq)	3.04E-24	3.07E-24	-23.512

Species	Concentration	Activity	Log activity
FeH2PO4+	4.4E-07	3.67E-07	-6.436
FeH2PO4+2	3.46E-14	1.67E-14	-13.777
FeHCO3+	4.54E-09	3.79E-09	-8.422
FeHPO4 (aq)	7.57E-11	7.64E-11	-10.117
FeHPO4+	3.46E-13	2.88E-13	-12.54
FeHS+	2.51E-25	2.09E-25	-24.679
FeN3+2	8.33E-14	4.02E-14	-13.396
FeNH3+2	3.7E-12	1.78E-12	-11.749
FeNO2+2	2.22E-59	1.07E-59	-58.971
FeOH+	8.47E-11	7.06E-11	-10.151
FeOH+2	6.46E-12	3.12E-12	-11.506
FeSO4 (aq)	0.00035	0.000354	-3.451
FeSO4+	2.92E-11	2.44E-11	-10.614
H DOM1	1.17E-05	6.49E-06	-5.188
H+1	0.002899	0.002416	-2.617
H2AsO3-	1.13E-13	9.41E-14	-13.026
H2AsO4-	2.87E-12	2.39E-12	-11.622
H2CO3* (aq)	0.002552	0.002577	-2.589
H2CrO4 (aq)	2.73E-10	2.76E-10	-9.56
H2PO4-	1.21E-06	1.01E-06	-5.995
H2S (aq)	1.88E-23	1.9E-23	-22.722
H3AsO3	4.91E-07	4.95E-07	-6.305
H3AsO4	1.02E-12	1.03E-12	-11.987
H3PO4	3.06E-07	3.09E-07	-6.509
HAsO3-2	4.11E-25	1.98E-25	-24.703
HAsO4-2	2.01E-16	9.7E-17	-16.013
HCO3-	4.88E-07	4.06E-07	-6.391
HCrO4-	3.64E-07	3.03E-07	-6.518

Species	Concentration	Activity	Log activity
HF (aq)	1.31E-08	1.32E-08	-7.88
HF2-	2.59E-16	2.15E-16	-15.667
Hg(CO3)2-2	1.03E-34	4.97E-35	-34.303
Hg(HS)2 (aq)	2.53E-38	2.55E-38	-37.594
Hg(N3)2 (aq)	3.05E-14	3.08E-14	-13.512
Hg(NH3)2+2	1.46E-23	7.05E-24	-23.152
Hg(NH3)4+2	3.16E-42	1.53E-42	-41.816
Hg(NO2)2 (aq)	9.7E-113	9.8E-113	-112.009
Hg(NO2)3-	2.5E-161	2E-161	-160.689
Hg(NO2)4-2	6.6E-211	3.2E-211	-210.5
Hg(NO3)2 (aq)	7.7E-155	7.8E-155	-154.108
Hg(OH)2	3.9E-23	3.93E-23	-22.405
Hg(SO4)2-2	6.25E-24	3.01E-24	-23.521
Hg+2	1.21E-21	5.85E-22	-21.233
Hg2OH+3	3.03E-43	5.87E-44	-43.231
Hg3(OH)3+3	5.6E-63	1.09E-63	-62.964
HgCl+	3.53E-16	2.94E-16	-15.532
HgCl2 (aq)	3.95E-11	3.99E-11	-10.4
HgCl3-1	8.4E-12	7E-12	-11.155
HgCl4-2	1.15E-12	5.54E-13	-12.256
HgClOH (aq)	8.42E-17	8.5E-17	-16.071
HgCO3 (aq)	2.79E-24	2.81E-24	-23.551
HgF+	1.14E-28	9.49E-29	-28.023
HgHCO3+	1.35E-22	1.13E-22	-21.948
HgHS2-	4.1E-42	3.41E-42	-41.467
HgN3+	4.49E-10	3.75E-10	-9.426
HgNO2+	2.09E-66	1.74E-66	-65.758

Species	Concentration	Activity	Log activity
HgNO3+	1.89E-88	1.58E-88	-87.802
HgOH+	8.7E-23	7.25E-23	-22.14
HgOHCO3-	1.64E-28	1.37E-28	-27.864
HgS2-2	5.71E-48	2.76E-48	-47.56
HgSO4 (aq)	1.68E-22	1.7E-22	-21.769
HN3 (aq)	2.83E-05	2.86E-05	-4.544
HNO2 (aq)	2.03E-50	2.05E-50	-49.687
HPO4-2	5.27E-11	2.54E-11	-10.594
HS-1	6.48E-28	5.4E-28	-27.268
HSO4-	0.000374	0.000311	-3.507
K+1	0.000148	0.000124	-3.908
K2HPO4 (aq)	4.16E-18	4.2E-18	-17.377
K2PO4-	1.2E-26	1E-26	-26
KCl (aq)	1.15E-06	1.16E-06	-5.937
KCr2O7-	5.34E-15	4.45E-15	-14.352
KCrO4-	2.2E-14	1.83E-14	-13.737
KF (aq)	2.43E-13	2.45E-13	-12.61
KH2PO4 (aq)	1.92E-10	1.94E-10	-9.713
KHPO4-	2.32E-14	1.93E-14	-13.714
KNO3 (aq)	1.11E-70	1.12E-70	-69.95
KOH (aq)	4.05E-16	4.09E-16	-15.388
KPO4-2	2.01E-23	9.7E-24	-23.013
KSO4-	1.52E-06	1.26E-06	-5.898
Mg DOM1	3.98E-08	3.54E-08	-7.451
Mg(NH3)2+2	1.98E-23	9.54E-24	-23.021
Mg+2	0.002551	0.001231	-2.91
Mg2CO3+2	7.66E-17	3.69E-17	-16.432
MgCl+	9.82E-05	8.19E-05	-4.087

Species	Concentration	Activity	Log activity
MgCO3 (aq)	5.45E-15	5.5E-15	-14.259
MgF+	4.25E-10	3.54E-10	-9.451
MgHCO3+	5.83E-09	4.86E-09	-8.314
MgHPO4 (aq)	1.65E-11	1.67E-11	-10.777
MgOH+	9.5E-13	7.92E-13	-12.101
MgPO4-	2E-19	1.67E-19	-18.778
MgSO4 (aq)	0.000354	0.000358	-3.447
Mn+3	5.1E-06	9.89E-07	-6.005
N3-1	2.76E-07	2.3E-07	-6.639
Na+1	0.00684	0.0057	-2.244
Na2HPO4 (aq)	5.85E-15	5.9E-15	-14.229
Na2PO4-	5.46E-23	4.55E-23	-22.342
NaCl (aq)	5.59E-05	5.65E-05	-4.248
NaCO3-	1.06E-15	8.85E-16	-15.053
NaCrO4-	1.36E-12	1.13E-12	-11.947
NaF (aq)	2.17E-11	2.19E-11	-10.659
NaH2PO4 (aq)	8.86E-09	8.94E-09	-8.049
NaHCO3 (aq)	1.36E-09	1.37E-09	-8.862
NaHPO4-	1.66E-12	1.38E-12	-11.86
NaNO3 (aq)	1.89E-69	1.91E-69	-68.719
NaOH (aq)	1.28E-14	1.29E-14	-13.888
NaPO4-2	1.02E-21	4.94E-22	-21.306
NaSO4-	6.42E-05	5.35E-05	-4.272
NH3 (aq)	6.68E-11	6.74E-11	-10.171
NH4+1	0.000713	0.000594	-3.226
NH4Cr2O7-	2.98E-14	2.49E-14	-13.605
NH4SO4-	1.32E-05	1.1E-05	-4.958
Ni DOM1	1.27E-09	1.13E-09	-8.947

Species	Concentration	Activity	Log activity
Ni(N3)2 (aq)	8.08E-18	8.16E-18	-17.088
Ni(NH3)2+2	1.71E-21	8.23E-22	-21.085
Ni(NH3)3+2	6.66E-30	3.22E-30	-29.493
Ni(NH3)4+2	7.72E-39	3.72E-39	-38.429
Ni(NH3)5+2	2.89E-48	1.39E-48	-47.856
Ni(NH3)6+2	2.3E-58	1.11E-58	-57.955
Ni(NO2)2 (aq)	3.5E-105	3.5E-105	-104.457
Ni(OH)2 (aq)	2.68E-20	2.71E-20	-19.567
Ni(OH)3-	1.35E-28	1.13E-28	-27.948
Ni(SO4)2-2	6.43E-11	3.1E-11	-10.509
Ni+2	3.24E-06	1.56E-06	-5.806
NiCl+	1.2E-08	9.98E-09	-8.001
NiCl2 (aq)	6.23E-12	6.29E-12	-11.201
NiCO3 (aq)	3.61E-16	3.64E-16	-15.439
NiF+	1.47E-13	1.23E-13	-12.911
NiH2PO4+	1.25E-11	1.04E-11	-10.983
NiHCO3+	7.48E-11	6.23E-11	-10.205
NiHPO4 (aq)	2.88E-14	2.91E-14	-13.536
NiHS+	3.13E-28	2.61E-28	-27.584
NiN3+	8.12E-12	6.77E-12	-11.17
NiNH3+2	1.43E-13	6.92E-14	-13.16
NiNO2+	2.71E-55	2.26E-55	-54.646
NiNO3+	5.6E-72	4.67E-72	-71.331
NiOH+	4.76E-14	3.97E-14	-13.401
NiSO4 (aq)	4.94E-07	4.98E-07	-6.303
NO2-1	7.22E-51	6.02E-51	-50.22
NO3-1	1.43E-66	1.19E-66	-65.925
OH-	2.29E-12	1.91E-12	-11.72

Species	Concentration	Activity	Log activity
Pb DOM1	1.01E-09	8.99E-10	-9.046
Pb(CO3)2-2	1.11E-26	5.36E-27	-26.271
Pb(HS)2 (aq)	8.41E-48	8.5E-48	-47.071
Pb(HS)3-	1.1E-73	9.15E-74	-73.039
Pb(NO2)2 (aq)	7.2E-106	7.3E-106	-105.136
Pb(NO3)2 (aq)	6E-139	6.1E-139	-138.215
Pb(OH)2 (aq)	2.13E-20	2.16E-20	-19.667
Pb(OH)3-	1.08E-28	8.97E-29	-28.047
Pb(SO4)2-2	2.87E-10	1.39E-10	-9.858
Pb+2	3.25E-08	1.57E-08	-7.805
Pb2OH+3	2.09E-19	4.06E-20	-19.391
Pb3(OH)4+2	5.91E-38	2.85E-38	-37.545
Pb4(OH)4+4	1.27E-41	6.89E-43	-42.162
PbCl+	1.07E-08	8.89E-09	-8.051
PbCl2 (aq)	3.25E-10	3.28E-10	-9.484
PbCl3-	5.53E-12	4.61E-12	-11.336
PbCl4-2	6.17E-14	2.98E-14	-13.526
PbCO3 (aq)	3.29E-16	3.33E-16	-15.478
PbF+	1.15E-14	9.61E-15	-14.017
PbF2 (aq)	5.09E-22	5.14E-22	-21.289
PbH2PO4+	4.67E-13	3.89E-13	-12.41
PbHCO3+	4.83E-12	4.03E-12	-11.395
PbHPO4 (aq)	4.03E-16	4.07E-16	-15.391
PbNO2+	3.66E-56	3.05E-56	-55.516
PbNO3+	3.4E-73	2.83E-73	-72.548
PbOH+	1.41E-13	1.17E-13	-12.931
PbSO4 (aq)	1.32E-08	1.33E-08	-7.877

Species	Concentration	Activity	Log activity
PO4-3	1.86E-20	3.6E-21	-20.444
S-2	9.23E-43	4.45E-43	-42.351
SO4-2	0.00359	0.001732	-2.761
Zn DOM1	1.19E-08	1.06E-08	-7.976
Zn(CO3)2-2	1.5E-26	7.24E-27	-26.141
Zn(N3)2 (aq)	4.6E-17	4.65E-17	-16.333
Zn(N3)3-	7.33E-23	6.11E-23	-22.214
Zn(NH3)2+2	3.8E-21	1.84E-21	-20.736
Zn(NH3)3+2	7.55E-29	3.64E-29	-28.439
Zn(NH3)4+2	7.34E-37	3.54E-37	-36.451
Zn(NO2)2 (aq)	5.2E-105	5.3E-105	-104.276
Zn(NO3)2 (aq)	6.5E-138	6.5E-138	-137.185
Zn(OH)2 (aq)	1.99E-17	2.01E-17	-16.696
Zn(OH)3-	3.18E-26	2.65E-26	-25.577
Zn(OH)4-2	3.62E-36	1.75E-36	-35.758
Zn(SO4)2-2	1.09E-07	5.27E-08	-7.278
Zn+2	1.91E-05	9.22E-06	-5.035
Zn2OH+3	7.47E-17	1.45E-17	-16.839
Zn2S3-2	4.4E-84	2.12E-84	-83.673
Zn4S6-4	1.4E-165	7.7E-167	-166.116
ZnCl+	5.23E-07	4.36E-07	-6.361
ZnCl2 (aq)	4.89E-09	4.93E-09	-8.307
ZnCl3-	1.1E-10	9.2E-11	-10.036
ZnCl4-2	1.55E-12	7.5E-13	-12.125
ZnCO3 (aq)	3.3E-15	3.33E-15	-14.478
ZnF+	8.23E-13	6.86E-13	-12.164
ZnHCO3+	1.13E-10	9.43E-11	-10.026

Species	Concentration	Activity	Log activity
ZnHPO4 (aq)	3.89E-13	3.93E-13	-12.406
ZnN3+	3.66E-11	3.05E-11	-10.516
ZnNH3+2	2.44E-13	1.18E-13	-12.93
ZnNO2+	4.01E-55	3.35E-55	-54.476
ZnNO3+	3.53E-71	2.94E-71	-70.532
ZnOH+	2.11E-12	1.76E-12	-11.755
ZnS (aq)	7.58E-32	7.66E-32	-31.116
ZnSO4 (aq)	3.17E-06	3.2E-06	-5.494

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Species	Concentration	Activity	Log activity
Al DOM1	8.77E-06	8.71E-06	-5.06
Al(OH)2+	2.85E-10	2.37E-10	-9.625
Al(OH)3 (aq)	1.83E-14	1.85E-14	-13.733
Al(OH)4-	4.1E-18	3.42E-18	-17.466
Al(SO4)2-	0.000134	0.000112	-3.952
Al+3	0.000782	0.000152	-3.819
Al2(OH)2+4	5.17E-10	2.8E-11	-10.553
Al2(OH)2CO3+2	1.04E-12	5.04E-13	-12.298
Al2PO4+3	4.08E-09	7.92E-10	-9.101
Al3(OH)4+5	1.77E-14	1.86E-16	-15.732
AlCl+2	2.26E-06	1.09E-06	-5.962
AlF+2	1.31E-05	6.33E-06	-5.199
AlF2+	1.31E-08	1.09E-08	-7.963
AlF3 (aq)	5.47E-13	5.52E-13	-12.258
AlF4-	1.44E-18	1.2E-18	-17.92
AlHPO4+	1.62E-07	1.35E-07	-6.869
AlOH+2	6.71E-07	3.24E-07	-6.49
AlSO4+	0.001838	0.001532	-2.815
As3S4(HS)-	6.5E-166	5.4E-166	-165.268
AsO4-3	1.43E-23	2.77E-24	-23.558
AsS(OH)HS-	4.65E-60	3.88E-60	-59.412
Ca DOM1	3.9E-07	3.47E-07	-6.459
Ca(NH3)2+2	3.89E-23	1.88E-23	-22.727
Ca(NO3)2	5.3E-126	5.3E-126	-125.275
Ca+2	0.002503	0.001208	-2.918
CaCl+	6.08E-05	5.07E-05	-4.295

Species	Concentration	Activity	Log activity
CaCO3 (aq)	1.07E-14	1.08E-14	-13.966
CaCrO4 (aq)	2.81E-11	2.84E-11	-10.547
CaF+	7.14E-11	5.95E-11	-10.225
CaH2PO4+	2.77E-08	2.31E-08	-7.636
CaHCO3+	6.21E-09	5.18E-09	-8.286
CaHPO4 (aq)	1.18E-11	1.19E-11	-10.925
CaNH3+2	5.61E-13	2.71E-13	-12.567
CaNO3+	5.83E-62	4.86E-62	-61.314
CaOH+	4.91E-14	4.09E-14	-13.388
CaPO4-	1.25E-17	1.05E-17	-16.981
CaSO4 (aq)	0.00043	0.000434	-3.363
Cd DOM1	2.07E-12	1.84E-12	-11.734
Cd(CO3)2-2	3.53E-30	1.7E-30	-29.769
Cd(HS)2 (aq)	1.53E-62	1.54E-62	-61.812
Cd(HS)3-	6.36E-95	5.3E-95	-94.276
Cd(HS)4-2	9.5E-127	4.6E-127	-126.34
Cd(NH3)2+2	1.28E-24	6.16E-25	-24.21
Cd(NH3)3+2	2.23E-33	1.07E-33	-32.969
Cd(NH3)4+2	1.14E-42	5.52E-43	-42.258
Cd(NO2)2 (aq)	1.26E-95	1.27E-95	-94.896
Cd(NO3)2 (aq)	5.6E-127	5.6E-127	-126.25
Cd(OH)2 (aq)	2.19E-24	2.22E-24	-23.655
Cd(OH)3-	1.08E-34	9.03E-35	-34.044
Cd(OH)4-2	7.96E-46	3.84E-46	-45.416
Cd(SO4)2-2	5.02E-11	2.42E-11	-10.616
Cd+2	5.29E-09	2.55E-09	-8.593
Cd2OH+3	2.93E-24	5.68E-25	-24.246
CdCl+	5.02E-09	4.19E-09	-8.378

Species	Concentration	Activity	Log activity
CdCl2 (aq)	2.95E-10	2.97E-10	-9.527
CdCO3 (aq)	3.71E-19	3.75E-19	-18.426
CdF+	1.97E-16	1.64E-16	-15.786
CdHCO3+	3.14E-14	2.61E-14	-13.583
CdHPO4 (aq)	2.64E-16	2.67E-16	-15.574
CdHS+	1.7E-35	1.42E-35	-34.848
CdNH3+2	1.52E-16	7.31E-17	-16.136
CdNO2+	3.28E-52	2.73E-52	-51.564
CdNO3+	1.53E-67	1.28E-67	-66.894
CdOH+	4.7E-17	3.92E-17	-16.407
CdSO4 (aq)	9.08E-10	9.17E-10	-9.038
Cl-1	0.021205	0.017673	-1.753
CO3-2	1.3E-14	6.27E-15	-14.203
Cr2O7-2	8.64E-12	4.17E-12	-11.38
CrO3Cl-	1.01E-10	8.39E-11	-10.076
CrO3H2PO4-	1.36E-12	1.13E-12	-11.946
CrO3HPO4-2	2.02E-12	9.72E-13	-12.012
CrO3SO4-2	8.25E-10	3.98E-10	-9.4
CrO4-2	8.27E-11	3.99E-11	-10.399
Cu DOM1	8.16E-10	7.27E-10	-9.139
Cu(CO3)2-2	3.26E-26	1.57E-26	-25.803
Cu(N3)2 (aq)	4.48E-17	4.52E-17	-16.345
Cu(N3)3-	6.25E-22	5.21E-22	-21.284
Cu(N3)4-2	6.52E-28	3.15E-28	-27.502
Cu(NH3)2+2	1.08E-20	5.22E-21	-20.282
Cu(NH3)3+2	6.18E-28	2.98E-28	-27.525
Cu(NH3)4+2	7.3E-36	3.52E-36	-35.453
Cu(NO2)2 (aq)	3.03E-95	3.06E-95	-94.514

Species	Concentration	Activity	Log activity
Cu(NO3)2 (aq)	1.4E-126	1.4E-126	-125.854
Cu(OH)2 (aq)	6.84E-20	6.9E-20	-19.161
Cu(OH)3-	4.91E-27	4.09E-27	-26.388
Cu(OH)4-2	2.34E-38	1.13E-38	-37.947
Cu+2	5.24E-08	2.53E-08	-7.598
Cu2(OH)2+2	2.59E-21	1.25E-21	-20.903
Cu2OH+3	1.82E-19	3.52E-20	-19.453
Cu2S3-2	5.4E-113	2.6E-113	-112.587
Cu3(OH)4+2	3.59E-34	1.73E-34	-33.761
CuCl+	9.51E-10	7.93E-10	-9.101
CuCl2 (aq)	2.31E-12	2.34E-12	-11.632
CuCl3-	3.85E-16	3.21E-16	-15.494
CuCl4-2 1	8.32E-20	4.02E-20	-19.396
CuCO3 (aq)	9.24E-16	9.33E-16	-15.03
CuF+	5.5E-15	4.59E-15	-14.339
CuHCO3+	6.18E-13	5.15E-13	-12.288
CuHPO4 (aq)	6.88E-15	6.95E-15	-14.158
CuHSO4+	2.78E-11	2.31E-11	-10.636
CuN3+	5.05E-12	4.2E-12	-11.376
CuNH3+2	4.95E-14	2.39E-14	-13.622
CuNO2+	3.38E-51	2.81E-51	-50.551
CuNO3+	1.2E-66	9.97E-67	-66.001
CuOH+	2.42E-13	2.01E-13	-12.696
CuS(aq)	8.93E-43	9.02E-43	-42.045
CuSO4 (aq)	8.79E-09	8.87E-09	-8.052
DOC (Gaussian DOM)	0.000333	0.000336	-3.473
DOM1	7.76E-06	1.86E-06	-5.73

Species	Concentration	Activity	Log activity
F-1	5.21E-09	4.34E-09	-8.362
Fe DOM1	1.54E-10	1.53E-10	-9.817
Fe(N3)2+	2.02E-16	1.68E-16	-15.774
Fe(N3)3 (aq)	8.21E-21	8.29E-21	-20.082
Fe(NH3)2+2	1.93E-21	9.31E-22	-21.031
Fe(NH3)3+2	3.97E-31	1.91E-31	-30.718
Fe(NH3)4+2	3.48E-41	1.68E-41	-40.775
Fe(NO2)2+	5.99E-97	4.99E-97	-96.302
Fe(NO2)3 (aq)	6E-140	6.1E-140	-139.215
Fe(OH)2 (aq)	9.46E-20	9.56E-20	-19.02
Fe(OH)2+	1.81E-12	1.51E-12	-11.822
Fe(OH)3-	1.37E-27	1.14E-27	-26.942
Fe(OH)3 (aq)	2.05E-19	2.07E-19	-18.684
Fe(OH)4-	6.73E-25	5.61E-25	-24.251
Fe(SO4)2-	5.55E-12	4.62E-12	-11.335
Fe+2	0.001929	0.000931	-3.031
Fe+3	4.33E-11	8.4E-12	-11.076
Fe2(OH)2+4	1.29E-19	6.99E-21	-20.155
Fe3(OH)4+5	3.41E-28	3.58E-30	-29.446
FeCl+	1.25E-05	1.04E-05	-4.984
FeCl+2	6.74E-12	3.25E-12	-11.488
FeCrO4+	1.48E-14	1.23E-14	-13.91
FeF+	7.87E-11	6.56E-11	-10.183
FeF+2	7.21E-14	3.48E-14	-13.458
FeF2+	6.86E-18	5.72E-18	-17.243
FeF3 (aq)	2.28E-23	2.3E-23	-22.638
FeH2PO4+	4.4E-07	3.67E-07	-6.436
FeH2PO4+2	2.59E-13	1.25E-13	-12.903

Species	Concentration	Activity	Log activity
FeHCO3+	4.54E-09	3.79E-09	-8.422
FeHPO4 (aq)	7.57E-11	7.64E-11	-10.117
FeHPO4+	2.59E-12	2.16E-12	-11.665
FeHS+	2.53E-32	2.11E-32	-31.675
FeN3+2	6.24E-13	3.01E-13	-12.521
FeNH3+2	3.7E-12	1.78E-12	-11.749
FeNO2+2	2.94E-53	1.42E-53	-52.849
FeOH+	8.47E-11	7.06E-11	-10.151
FeOH+2	4.84E-11	2.33E-11	-10.632
FeSO4 (aq)	0.00035	0.000354	-3.451
FeSO4+	2.19E-10	1.82E-10	-9.739
H DOM1	1.17E-05	6.49E-06	-5.188
H+1	0.002899	0.002416	-2.617
H2AsO3-	1.13E-13	9.41E-14	-13.026
H2AsO4-	1.61E-10	1.34E-10	-9.873
H2CO3* (aq)	0.002552	0.002577	-2.589
H2CrO4 (aq)	2.73E-10	2.76E-10	-9.56
H2PO4-	1.21E-06	1.01E-06	-5.995
H2S (aq)	1.9E-30	1.91E-30	-29.718
H3AsO3	4.9E-07	4.95E-07	-6.305
H3AsO4	5.72E-11	5.78E-11	-10.238
H3PO4	3.06E-07	3.09E-07	-6.509
HAsO3-2	4.11E-25	1.98E-25	-24.703
HAsO4-2	1.13E-14	5.44E-15	-14.264
HCO3-	4.88E-07	4.06E-07	-6.391
HCrO4-	3.64E-07	3.03E-07	-6.518
HF (aq)	1.31E-08	1.32E-08	-7.88
HF2-	2.59E-16	2.15E-16	-15.667

Species	Concentration	Activity	Log activity
Hg(CO3)2-2	1.03E-34	4.97E-35	-34.303
Hg(HS)2 (aq)	2.57E-52	2.59E-52	-51.586
Hg(N3)2 (aq)	3.05E-14	3.08E-14	-13.512
Hg(NH3)2+2	1.46E-23	7.05E-24	-23.152
Hg(NH3)4+2	3.16E-42	1.53E-42	-41.816
Hg(NO2)2 (aq)	3E-102	3.1E-102	-101.514
Hg(NO2)3-	1.4E-145	1.1E-145	-144.947
Hg(NO2)4-2	6.4E-190	3.1E-190	-189.51
Hg(NO3)2 (aq)	7.6E-141	7.7E-141	-140.115
Hg(OH)2	3.9E-23	3.93E-23	-22.405
Hg(SO4)2-2	6.25E-24	3.01E-24	-23.521
Hg+2	1.21E-21	5.85E-22	-21.233
Hg2OH+3	3.03E-43	5.87E-44	-43.231
Hg3(OH)3+3	5.6E-63	1.09E-63	-62.964
HgCl+	3.53E-16	2.94E-16	-15.532
HgCl2 (aq)	3.95E-11	3.99E-11	-10.4
HgCl3-1	8.4E-12	7E-12	-11.155
HgCl4-2	1.15E-12	5.54E-13	-12.256
HgClOH (aq)	8.42E-17	8.5E-17	-16.071
HgCO3 (aq)	2.79E-24	2.81E-24	-23.551
HgF+	1.14E-28	9.49E-29	-28.023
HgHCO3+	1.35E-22	1.13E-22	-21.948
HgHS2-	4.16E-56	3.47E-56	-55.46
HgN3+	4.49E-10	3.75E-10	-9.426
HgNO2+	3.7E-61	3.08E-61	-60.511
HgNO3+	1.88E-81	1.57E-81	-80.805
HgOH+	8.7E-23	7.25E-23	-22.14

Species	Concentration	Activity	Log activity
HgOHCO3-	1.64E-28	1.37E-28	-27.864
HgS2-2	5.8E-62	2.8E-62	-61.553
HgSO4 (aq)	1.68E-22	1.7E-22	-21.769
HN3 (aq)	2.83E-05	2.86E-05	-4.544
HNO2 (aq)	3.6E-45	3.63E-45	-44.44
HPO4-2	5.27E-11	2.54E-11	-10.594
HS-1	6.53E-35	5.44E-35	-34.264
HSO4-	0.000374	0.000311	-3.507
K+1	0.000148	0.000124	-3.908
K2HPO4 (aq)	4.16E-18	4.2E-18	-17.377
K2PO4-	1.2E-26	1E-26	-26
KCl (aq)	1.15E-06	1.16E-06	-5.937
KCr2O7-	5.34E-15	4.45E-15	-14.352
KCrO4-	2.2E-14	1.83E-14	-13.737
KF (aq)	2.43E-13	2.45E-13	-12.61
KH2PO4 (aq)	1.92E-10	1.94E-10	-9.713
KHPO4-	2.32E-14	1.93E-14	-13.714
KNO3 (aq)	1.1E-63	1.11E-63	-62.954
KOH (aq)	4.05E-16	4.09E-16	-15.388
KPO4-2	2.01E-23	9.7E-24	-23.013
KSO4-	1.52E-06	1.26E-06	-5.898
Mg DOM1	3.98E-08	3.54E-08	-7.451
Mg(NH3)2+2	1.98E-23	9.54E-24	-23.021
Mg+2	0.002551	0.001231	-2.91
Mg2CO3+2	7.66E-17	3.69E-17	-16.432
MgCl+	9.82E-05	8.19E-05	-4.087
MgCO3 (aq)	5.45E-15	5.5E-15	-14.259
MgF+	4.25E-10	3.54E-10	-9.451

Species	Concentration	Activity	Log activity
MgHCO3+	5.83E-09	4.86E-09	-8.314
MgHPO4 (aq)	1.65E-11	1.67E-11	-10.777
MgOH+	9.5E-13	7.92E-13	-12.101
MgPO4-	2E-19	1.67E-19	-18.778
MgSO4 (aq)	0.000354	0.000358	-3.447
Mn+3	5.1E-06	9.89E-07	-6.005
N3-1	2.76E-07	2.3E-07	-6.639
Na+1	0.00684	0.0057	-2.244
Na2HPO4 (aq)	5.85E-15	5.9E-15	-14.229
Na2PO4-	5.46E-23	4.55E-23	-22.342
NaCl (aq)	5.59E-05	5.65E-05	-4.248
NaCO3-	1.06E-15	8.85E-16	-15.053
NaCrO4-	1.36E-12	1.13E-12	-11.947
NaF (aq)	2.17E-11	2.19E-11	-10.659
NaH2PO4 (aq)	8.86E-09	8.94E-09	-8.049
NaHCO3 (aq)	1.36E-09	1.37E-09	-8.862
NaHPO4-	1.66E-12	1.38E-12	-11.86
NaNO3 (aq)	1.88E-62	1.89E-62	-61.723
NaOH (aq)	1.28E-14	1.29E-14	-13.888
NaPO4-2	1.02E-21	4.94E-22	-21.306
NaSO4-	6.42E-05	5.35E-05	-4.272
NH3 (aq)	6.68E-11	6.74E-11	-10.171
NH4+1	0.000713	0.000594	-3.226
NH4Cr2O7-	2.98E-14	2.49E-14	-13.605
NH4SO4-	1.32E-05	1.1E-05	-4.958
Ni DOM1	1.27E-09	1.13E-09	-8.947
Ni(N3)2 (aq)	8.08E-18	8.16E-18	-17.088
Ni(NH3)2+2	1.71E-21	8.23E-22	-21.085

Species	Concentration	Activity	Log activity
Ni(NH3)3+2	6.66E-30	3.22E-30	-29.493
Ni(NH3)4+2	7.72E-39	3.72E-39	-38.429
Ni(NH3)5+2	2.89E-48	1.39E-48	-47.856
Ni(NH3)6+2	2.3E-58	1.11E-58	-57.955
Ni(NO2)2 (aq)	1.08E-94	1.09E-94	-93.962
Ni(OH)2 (aq)	2.68E-20	2.71E-20	-19.567
Ni(OH)3-	1.35E-28	1.13E-28	-27.948
Ni(SO4)2-2	6.43E-11	3.1E-11	-10.509
Ni+2	3.24E-06	1.56E-06	-5.806
NiCl+	1.2E-08	9.98E-09	-8.001
NiCl2 (aq)	6.23E-12	6.29E-12	-11.201
NiCO3 (aq)	3.61E-16	3.64E-16	-15.439
NiF+	1.47E-13	1.23E-13	-12.911
NiH2PO4+	1.25E-11	1.04E-11	-10.983
NiHCO3+	7.48E-11	6.23E-11	-10.205
NiHPO4 (aq)	2.88E-14	2.91E-14	-13.536
NiHS+	3.16E-35	2.63E-35	-34.58
NiN3+	8.12E-12	6.77E-12	-11.17
NiNH3+2	1.43E-13	6.92E-14	-13.16
NiNO2+	4.79E-50	3.99E-50	-49.399
NiNO3+	5.56E-65	4.63E-65	-64.334
NiOH+	4.76E-14	3.97E-14	-13.401
NiSO4 (aq)	4.94E-07	4.98E-07	-6.303
NO2-1	1.28E-45	1.06E-45	-44.973
NO3-1	1.41E-59	1.18E-59	-58.928
OH-	2.29E-12	1.91E-12	-11.72
Pb DOM1	1.01E-09	8.99E-10	-9.046
Pb(CO3)2-2	1.11E-26	5.36E-27	-26.271

Species	Concentration	Activity	Log activity
Pb(HS)2 (aq)	8.55E-62	8.64E-62	-61.064
Pb(HS)3-	1.13E-94	9.38E-95	-94.028
Pb(NO2)2 (aq)	2.26E-95	2.28E-95	-94.642
Pb(NO3)2 (aq)	5.9E-125	6E-125	-124.222
Pb(OH)2 (aq)	2.13E-20	2.16E-20	-19.667
Pb(OH)3-	1.08E-28	8.97E-29	-28.047
Pb(SO4)2-2	2.87E-10	1.39E-10	-9.858
Pb+2	3.25E-08	1.57E-08	-7.805
Pb2OH+3	2.09E-19	4.06E-20	-19.391
Pb3(OH)4+2	5.91E-38	2.85E-38	-37.545
Pb4(OH)4+4	1.27E-41	6.89E-43	-42.162
PbCl+	1.07E-08	8.89E-09	-8.051
PbCl2 (aq)	3.25E-10	3.28E-10	-9.484
PbCl3-	5.53E-12	4.61E-12	-11.336
PbCl4-2	6.17E-14	2.98E-14	-13.526
PbCO3 (aq)	3.29E-16	3.33E-16	-15.478
PbF+	1.15E-14	9.61E-15	-14.017
PbF2 (aq)	5.09E-22	5.14E-22	-21.289
PbH2PO4+	4.67E-13	3.89E-13	-12.41
PbHCO3+	4.83E-12	4.03E-12	-11.395
PbHPO4 (aq)	4.03E-16	4.07E-16	-15.391
PbNO2+	6.47E-51	5.39E-51	-50.268
PbNO3+	3.37E-66	2.81E-66	-65.552
PbOH+	1.41E-13	1.17E-13	-12.931
PbSO4 (aq)	1.32E-08	1.33E-08	-7.877
PO4-3	1.86E-20	3.6E-21	-20.444
S-2	9.31E-50	4.49E-50	-49.348
SO4-2	0.00359	0.001732	-2.761

Species	Concentration	Activity	Log activity
Zn DOM1	1.19E-08	1.06E-08	-7.976
Zn(CO3)2-2	1.5E-26	7.24E-27	-26.141
Zn(N3)2 (aq)	4.6E-17	4.65E-17	-16.333
Zn(N3)3-	7.33E-23	6.11E-23	-22.214
Zn(NH3)2+2	3.8E-21	1.84E-21	-20.736
Zn(NH3)3+2	7.55E-29	3.64E-29	-28.439
Zn(NH3)4+2	7.34E-37	3.54E-37	-36.451
Zn(NO2)2 (aq)	1.64E-94	1.65E-94	-93.781
Zn(NO3)2 (aq)	6.4E-124	6.4E-124	-123.192
Zn(OH)2 (aq)	1.99E-17	2.01E-17	-16.696
Zn(OH)3-	3.18E-26	2.65E-26	-25.577
Zn(OH)4-2	3.62E-36	1.75E-36	-35.758
Zn(SO4)2-2	1.09E-07	5.27E-08	-7.278
Zn+2	1.91E-05	9.22E-06	-5.035
Zn2OH+3	7.47E-17	1.45E-17	-16.839
Zn2S3-2	4.5E-105	2.2E-105	-104.662
Zn4S6-4	1.5E-207	8E-209	-208.095
ZnCl+	5.23E-07	4.36E-07	-6.361
ZnCl2 (aq)	4.89E-09	4.93E-09	-8.307
ZnCl3-	1.1E-10	9.2E-11	-10.036
ZnCl4-2	1.55E-12	7.5E-13	-12.125
ZnCO3 (aq)	3.3E-15	3.33E-15	-14.478
ZnF+	8.23E-13	6.86E-13	-12.164
ZnHCO3+	1.13E-10	9.43E-11	-10.026
ZnHPO4 (aq)	3.89E-13	3.93E-13	-12.406
ZnN3+	3.66E-11	3.05E-11	-10.516
ZnNH3+2	2.44E-13	1.18E-13	-12.93

Species	Concentration	Activity	Log activity
ZnNO2+	7.1E-50	5.91E-50	-49.228
ZnNO3+	3.5E-64	2.91E-64	-63.536
ZnOH+	2.11E-12	1.76E-12	-11.755
ZnS (aq)	7.64E-39	7.72E-39	-38.112
ZnSO4 (aq)	3.17E-06	3.2E-06	-5.494

D2 Species distribution

D2.1: Eh 150

Component	% of total concentration	Species name
Pb+2	56.037	Pb+2
	1.744	Pb DOM1
	18.428	PbCl+
	0.562	PbCl2 (aq)
	22.714	PbSO4 (aq)
	0.496	Pb(SO4)2-2
NH4+1	98.178	NH4+1
	1.822	NH4SO4-
Cl-1	98.92	Cl-1
	0.011	AlCl+2
	0.284	CaCl+
	0.058	FeCl+
	0.458	MgCl+
	0.261	NaCl (aq)
Fe+2	84.153	Fe+2
	0.543	FeCl+
	15.284	FeSO4 (aq)
	0.019	FeH2PO4+
Zn+2	83.335	Zn+2
	0.052	Zn DOM1
	2.28	ZnCl+
	0.021	ZnCl2 (aq)
	13.834	ZnSO4 (aq)
	0.476	Zn(SO4)2-2
F-1	0.04	F-1
	0.099	HF (aq)

Component	% of total concentration	Species name
	99.658	AlF+2
	0.198	AlF2+
Cu+2	83.173	Cu+2
	1.297	Cu DOM1
	1.512	CuCl+
	13.961	CuSO4 (aq)
	0.044	CuHSO4+
Ni+2	86.476	Ni+2
	0.034	Ni DOM1
	0.32	NiCl+
	13.166	NiSO4 (aq)
N3-1	0.966	N3-1
	99.034	HN3 (aq)
PO4-3	56.106	H2PO4-
	14.166	H3PO4
	20.339	FeH2PO4+
	1.282	CaH2PO4+
	7.492	AlHPO4+
	0.189	Al2PO4+3
	0.409	NaH2PO4 (aq)
AsO4-3	26.248	H3AsO4
	73.746	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	27.058	DOM1
	40.807	H DOM1
	30.586	Al DOM1
	1.361	Ca DOM1

Component	% of total concentration	Species name
	0.139	Mg DOM1
	0.041	Zn DOM1
Ca+2	83.604	Ca+2
	0.013	Ca DOM1
	2.031	CaCl+
	14.351	CaSO4 (aq)
Mg+2	84.934	Mg+2
	3.271	MgCl+
	11.793	MgSO4 (aq)
K+1	98.235	K+1
	0.76	KCl (aq)
	1.006	KSO4-
Na+1	98.274	Na+1
	0.804	NaCl (aq)
	0.922	NaSO4-
CO3-2	0.019	HCO3-
	99.98	H2CO3* (aq)
Al+3	28.146	Al+3
	0.316	Al DOM1
	0.024	AlOH+2
	0.472	AlF+2
	0.081	AlCl+2
	66.134	AlSO4+
	4.82	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.717	Cd+2
	0.018	Cd DOM1
	43.432	CdCl+

Component	% of total concentration	Species name
	2.547	CdCl2 (aq)
	7.852	CdSO4 (aq)
	0.434	Cd(SO4)2-2
CrO4-2	0.023	CrO4-2
	99.636	HCrO4-
	0.075	H2CrO4 (aq)
	0.028	CrO3Cl-
	0.226	CrO3SO4-2
Fe+3	8.99	Fe+3
	31.886	Fe DOM1
	10.043	FeOH+2
	0.375	Fe(OH)2+
	0.015	FeF+2
	1.398	FeCl+2
	45.417	FeSO4+
	1.151	Fe(SO4)2-
	0.13	FeN3+2
	0.054	FeH2PO4+2
	0.538	FeHPO4+
NO2-1	26.197	NO2-1
	73.801	HNO2 (aq)
NO3-1	99.448	NO3-1
	0.41	CaNO3+
	0.132	NaNO3 (aq)
SO4-2	49.268	SO4-2
	5.126	HSO4-
	25.227	AlSO4+
	3.678	Al(SO4)2-

Component	% of total concentration	Species name
	0.044	ZnSO4 (aq)
	4.808	FeSO4 (aq)
	4.861	MgSO4 (aq)
	5.897	CaSO4 (aq)
	0.881	NaSO4-
	0.021	KSO4-
	0.182	NH4SO4-
H3AsO3	100	H3AsO3
Hg(OH)2	5.313	HgCl2 (aq)
	1.131	HgCl3-1
	0.155	HgCl4-2
	32.88	Hg(HS)2 (aq)
	60.512	HgN3+
HS-1	98.676	H2S (aq)
	1.319	FeHS+

D2.2: Eh 200

Component	% of total concentration	Species name
Pb+2	56.037	Pb+2
	1.744	Pb DOM1
	18.428	PbCl+
	0.562	PbCl2 (aq)
	22.714	PbSO4 (aq)
	0.496	Pb(SO4)2-2
NH4+1	98.178	NH4+1
	1.822	NH4SO4-
Cl-1	98.92	Cl-1
	0.011	AlCl+2
	0.284	CaCl+
	0.058	FeCl+
	0.458	MgCl+
	0.261	NaCl (aq)
Fe+2	84.153	Fe+2
	0.543	FeCl+
	15.285	FeSO4 (aq)
	0.019	FeH2PO4+
Zn+2	83.335	Zn+2
	0.052	Zn DOM1
	2.28	ZnCl+
	0.021	ZnCl2 (aq)
	13.834	ZnSO4 (aq)
	0.476	Zn(SO4)2-2
F-1	0.04	F-1
	0.099	HF (aq)
	99.658	AlF+2

Component	% of total concentration	Species name
	0.198	AlF2+
SO4-2	49.268	SO4-2
	5.126	HSO4-
	25.227	AlSO4+
	3.678	Al(SO4)2-
	0.044	ZnSO4 (aq)
	4.808	FeSO4 (aq)
	4.861	MgSO4 (aq)
	5.897	CaSO4 (aq)
	0.881	NaSO4-
	0.021	KSO4-
	0.182	NH4SO4-
Ni+2	86.476	Ni+2
	0.034	Ni DOM1
	0.32	NiCl+
	13.166	NiSO4 (aq)
N3-1	0.966	N3-1
	99.034	HN3 (aq)
PO4-3	56.106	H2PO4-
	14.166	H3PO4
	20.339	FeH2PO4+
	1.282	CaH2PO4+
	7.492	AlHPO4+
	0.189	Al2PO4+3
	0.409	NaH2PO4 (aq)
AsO4-3	26.249	H3AsO4
	73.746	H2AsO4-

Component	% of total concentration	Species name
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	27.057	DOM1
	40.806	H DOM1
	30.585	Al DOM1
	1.361	Ca DOM1
	0.139	Mg DOM1
	0.041	Zn DOM1
Ca+2	83.603	Ca+2
	0.013	Ca DOM1
	2.031	CaCl+
	14.351	CaSO4 (aq)
Mg+2	84.934	Mg+2
	3.271	MgCl+
	11.794	MgSO4 (aq)
K+1	98.235	K+1
	0.76	KCl (aq)
	1.006	KSO4-
Na+1	98.274	Na+1
	0.804	NaCl (aq)
	0.922	NaSO4-
CO3-2	0.019	HCO3-
	99.98	H2CO3* (aq)
Al+3	28.146	Al+3
	0.316	Al DOM1
	0.024	AlOH+2
	0.472	AlF+2
	0.081	AlCl+2

Component	% of total concentration	Species name
	66.134	AlSO4+
	4.82	Al(SO4)2-
Mn+3	100	Mn+3
Cd+2	45.717	Cd+2
	0.018	Cd DOM1
	43.432	CdCl+
	2.547	CdCl2 (aq)
	7.852	CdSO4 (aq)
	0.434	Cd(SO4)2-2
CrO4-2	0.023	CrO4-2
	99.636	HCrO4-
	0.075	H2CrO4 (aq)
	0.028	CrO3Cl-
	0.226	CrO3SO4-2
Cu+2	83.173	Cu+2
	1.297	Cu DOM1
	1.512	CuCl+
	13.961	CuSO4 (aq)
	0.044	CuHSO4+
Fe+3	8.99	Fe+3
	31.885	Fe DOM1
	10.043	FeOH+2
	0.375	Fe(OH)2+
	0.015	FeF+2
	1.398	FeCl+2
	45.419	FeSO4+
	1.151	Fe(SO4)2-
	0.13	FeN3+2

Component	% of total concentration	Species name
	0.054	FeH2PO4+2
	0.538	FeHPO4+
NO2-1	26.196	NO2-1
	73.801	HNO2 (aq)
NO3-1	99.448	NO3-1
	0.41	CaNO3+
	0.132	NaNO3 (aq)
HS-1	98.676	H2S (aq)
	1.319	FeHS+
H3AsO3	100	H3AsO3
Hg(OH)2	7.918	HgCl2 (aq)
	1.686	HgCl3-1
	0.23	HgCl4-2
	90.16	HgN3+

D2.3: Eh 250

Component	% of total concentration	Species name
Hg(OH)2	7.918	HgCl2 (aq)
	1.686	HgCl3-1
	0.23	HgCl4-2
	90.16	HgN3+
NH4+1	98.178	NH4+1
	1.822	NH4SO4-
Cl-1	98.92	Cl-1
	0.011	AlCl+2
	0.284	CaCl+
	0.058	FeCl+
	0.458	MgCl+
	0.261	NaCl (aq)
Fe+2	84.153	Fe+2
	0.543	FeCl+
	15.285	FeSO4 (aq)
	0.019	FeH2PO4+
Zn+2	83.335	Zn+2
	0.052	Zn DOM1
	2.28	ZnCl+
	0.021	ZnCl2 (aq)
	13.834	ZnSO4 (aq)
	0.476	Zn(SO4)2-2
F-1	0.04	F-1
	0.099	HF (aq)
	99.658	AlF+2
	0.198	AlF2+
SO4-2	49.268	SO4-2

Component	% of total concentration	Species name
	5.126	HSO4-
	25.227	AlSO4+
	3.678	Al(SO4)2-
	0.044	ZnSO4 (aq)
	4.808	FeSO4 (aq)
	4.861	MgSO4 (aq)
	5.897	CaSO4 (aq)
	0.881	NaSO4-
	0.021	KSO4-
	0.182	NH4SO4-
Ni+2	86.476	Ni+2
	0.034	Ni DOM1
	0.32	NiCl+
	13.166	NiSO4 (aq)
N3-1	0.966	N3-1
	99.033	HN3 (aq)
PO4-3	56.106	H2PO4-
	14.166	H3PO4
	20.339	FeH2PO4+
	1.282	CaH2PO4+
	7.492	AlHPO4+
	0.189	Al2PO4+3
	0.409	NaH2PO4 (aq)
AsO4-3	26.249	H3AsO4
	73.746	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	27.057	DOM1

Component	% of total concentration	Species name
	40.806	H DOM1
	30.585	Al DOM1
	1.361	Ca DOM1
	0.139	Mg DOM1
	0.041	Zn DOM1
Ca+2	83.603	Ca+2
	0.013	Ca DOM1
	2.031	CaCl+
	14.351	CaSO4 (aq)
Mg+2	84.934	Mg+2
	3.271	MgCl+
	11.794	MgSO4 (aq)
K+1	98.235	K+1
	0.76	KCl (aq)
	1.006	KSO4-
Na+1	98.274	Na+1
	0.804	NaCl (aq)
	0.922	NaSO4-
CO3-2	0.019	HCO3-
	99.98	H2CO3* (aq)
Al+3	28.146	Al+3
	0.316	Al DOM1
	0.024	AlOH+2
	0.472	AlF+2
	0.081	AlCl+2
	66.134	AlSO4+
	4.82	Al(SO4)2-
Mn+3	100	Mn+3

Component	% of total concentration	Species name
Cd+2	45.717	Cd+2
	0.018	Cd DOM1
	43.432	CdCl+
	2.547	CdCl2 (aq)
	7.852	CdSO4 (aq)
	0.434	Cd(SO4)2-2
CrO4-2	0.023	CrO4-2
	99.636	HCrO4-
	0.075	H2CrO4 (aq)
	0.028	CrO3Cl-
	0.226	CrO3SO4-2
Cu+2	83.173	Cu+2
	1.297	Cu DOM1
	1.512	CuCl+
	13.961	CuSO4 (aq)
	0.044	CuHSO4+
Pb+2	56.037	Pb+2
	1.744	Pb DOM1
	18.428	PbCl+
	0.562	PbCl2 (aq)
	22.714	PbSO4 (aq)
	0.496	Pb(SO4)2-2
Fe+3	8.99	Fe+3
	31.885	Fe DOM1
	10.043	FeOH+2
	0.375	Fe(OH)2+
	0.015	FeF+2
	1.398	FeCl+2

Component	% of total concentration	Species name
	45.419	FeSO4+
	1.151	Fe(SO4)2-
	0.13	FeN3+2
	0.054	FeH2PO4+2
	0.538	FeHPO4+
NO2-1	26.196	NO2-1
	73.801	HNO2 (aq)
NO3-1	99.448	NO3-1
	0.41	CaNO3+
	0.132	NaNO3 (aq)
HS-1	98.676	H2S (aq)
	1.319	FeHS+
H3AsO3	100	H3AsO3

D2.4: Eh 300

Component	% of total concentration	Species name
Hg(OH)2	7.918	HgCl2 (aq)
	1.686	HgCl3-1
	0.23	HgCl4-2
	90.16	HgN3+
NH4+1	98.178	NH4+1
	1.822	NH4SO4-
Cl-1	98.92	Cl-1
	0.011	AlCl+2
	0.284	CaCl+
	0.058	FeCl+
	0.458	MgCl+
	0.261	NaCl (aq)
Fe+2	84.153	Fe+2
	0.543	FeCl+
	15.285	FeSO4 (aq)
	0.019	FeH2PO4+
Zn+2	83.335	Zn+2
	0.052	Zn DOM1
	2.28	ZnCl+
	0.021	ZnCl2 (aq)
	13.834	ZnSO4 (aq)
	0.476	Zn(SO4)2-2
F-1	0.04	F-1
	0.099	HF (aq)
	99.658	AlF+2
	0.198	AlF2+
SO4-2	49.268	SO4-2

Component	% of total concentration	Species name
	5.126	HSO4-
	25.227	AlSO4+
	3.678	Al(SO4)2-
	0.044	ZnSO4 (aq)
	4.808	FeSO4 (aq)
	4.861	MgSO4 (aq)
	5.897	CaSO4 (aq)
	0.881	NaSO4-
	0.021	KSO4-
	0.182	NH4SO4-
Ni+2	86.476	Ni+2
	0.034	Ni DOM1
	0.32	NiCl+
	13.166	NiSO4 (aq)
N3-1	0.966	N3-1
	99.033	HN3 (aq)
PO4-3	56.106	H2PO4-
	14.166	H3PO4
	20.339	FeH2PO4+
	1.282	CaH2PO4+
	7.492	AlHPO4+
	0.189	Al2PO4+3
	0.409	NaH2PO4 (aq)
AsO4-3	26.249	H3AsO4
	73.746	H2AsO4-
DOC (Gaussian DOM)	100	DOC (Gaussian DOM)
DOM1	27.057	DOM1

Component	% of total concentration	Species name
	40.806	H DOM1
	30.584	Al DOM1
	1.361	Ca DOM1
	0.139	Mg DOM1
	0.041	Zn DOM1
Ca+2	83.603	Ca+2
	0.013	Ca DOM1
	2.031	CaCl+
	14.351	CaSO4 (aq)
Mg+2	84.934	Mg+2
	3.271	MgCl+
	11.794	MgSO4 (aq)
K+1	98.235	K+1
	0.76	KCl (aq)
	1.006	KSO4-
Na+1	98.274	Na+1
	0.804	NaCl (aq)
	0.922	NaSO4-
CO3-2	0.019	HCO3-
	99.98	H2CO3* (aq)
Al+3	28.146	Al+3
	0.316	Al DOM1
	0.024	AlOH+2
	0.472	AlF+2
	0.081	AlCl+2
	66.134	AlSO4+
	4.82	Al(SO4)2-
Mn+3	100	Mn+3

Component	% of total concentration	Species name
Cd+2	45.717	Cd+2
	0.018	Cd DOM1
	43.432	CdCl+
	2.547	CdCl2 (aq)
	7.852	CdSO4 (aq)
	0.434	Cd(SO4)2-2
CrO4-2	0.023	CrO4-2
	99.636	HCrO4-
	0.075	H2CrO4 (aq)
	0.028	CrO3Cl-
	0.226	CrO3SO4-2
Cu+2	83.173	Cu+2
	1.297	Cu DOM1
	1.512	CuCl+
	13.961	CuSO4 (aq)
	0.044	CuHSO4+
Pb+2	56.037	Pb+2
	1.744	Pb DOM1
	18.428	PbCl+
	0.562	PbCl2 (aq)
	22.714	PbSO4 (aq)
	0.496	Pb(SO4)2-2
Fe+3	8.99	Fe+3
	31.885	Fe DOM1
	10.043	FeOH+2
	0.375	Fe(OH)2+
	0.015	FeF+2
	1.398	FeCl+2

Component	% of total concentration	Species name
	45.419	FeSO4+
	1.151	Fe(SO4)2-
	0.13	FeN3+2
	0.054	FeH2PO4+2
	0.538	FeHPO4+
NO2-1	26.196	NO2-1
	73.801	HNO2 (aq)
NO3-1	99.448	NO3-1
	0.41	CaNO3+
	0.132	NaNO3 (aq)
HS-1	98.676	H2S (aq)
	1.319	FeHS+
H3AsO3	100	H3AsO3

D3 Saturation indicies

D3.1: Eh 150

Mineral	log IAP	Sat. index
Al(OH)3 (am)	4.03	-7.444
Al(OH)3 (Soil)	4.03	-4.898
Al2O3(s)	8.062	-13.162
Al4(OH)10SO4(s)	8.127	-14.573
AlAsO4:2H2O(s)	-32.625	-16.825
AlOHF2(s)	-17.926	-18.333
AlOHSO4(s)	-3.964	-0.734
Alunite	-5.189	-5.066
Anglesite	-10.567	-2.704
Anhydrite	-5.679	-1.363
Antlerite	-28.751	-37.539
Aragonite	-17.121	-8.842
Arsenolite	-12.609	-11.046
Artinite	-14.791	-25.122
As2O5(s)	-73.31	-38.601
As2S3(am)	-60.283	-13.898
Atacamite	-18.207	-26.166
Azurite	-59.627	-42.474
Bianchite	-7.799	-6.038
Birnessite	7.085	-11.006
Bixbyite	3.69	3.577
Boehmite	4.031	-5.263
Brochantite	-35.669	-52.125
Brucite	2.323	-15.47
Ca3(AsO4)2:4H2O(s)	-66.366	-47.466
Ca3(PO4)2 (am1)	-49.642	-24.713

Mineral	log IAP	Sat. index
Ca3(PO4)2 (am2)	-49.642	-21.921
Ca3(PO4)2 (beta)	-49.642	-20.393
Ca4H(PO4)3:3H2O(s)	-75.622	-28.31
CaCO3xH2O(s)	-17.121	-10.034
CaCrO4(s)	-13.317	-11.215
CaHPO4(s)	-25.979	-6.515
CaHPO4:2H2O(s)	-25.98	-6.845
Calcite	-17.121	-8.691
CaS(s)	-13.576	-24.756
Cd metal (alpha)	-13.841	-27.813
Cd metal (gamma)	-13.841	-27.92
Cd(OH)2(s)	-3.361	-17.58
Cd3(OH)4SO4(s)	-18.076	-40.636
Cd3(PO4)2(s)	-66.667	-34.067
Cd3OH2(SO4)2(s)	-26.07	-32.78
Cd4(OH)6SO4(s)	-21.436	-49.836
CdCl2(s)	-12.099	-11.553
CdCl2:1H2O(s)	-12.099	-10.451
CdCl2:2.5H2O(s)	-12.1	-10.143
CdF2(s)	-25.317	-24.386
CdOHCl(s)	-7.73	-11.455
CdSO4(s)	-11.355	-11.499
CdSO4:1H2O(s)	-11.355	-9.821
CdSO4:2.67H2O(s)	-11.356	-9.592
Cerrusite	-22.008	-8.657
Chalcanthite	-14.915	-12.239
Chalcopyrite	-36.499	-0.327
Chloropyromorphite(c)	-102.11	-17.68

Mineral	log IAP	Sat. index
Chloropyromorphite(soil)	-102.11	-21.71
Cinnabar	-46.424	0.399
Claudetite	-12.609	-11.096
Cotunnite	-11.311	-6.372
Covellite	-22.81	0
Cr(VI)-Ettringite	-24.958	-88.359
Cr(VI)-Jarosite	-50.105	-31.589
CrO3(s)	-15.632	-12.453
Cryolite	-60.723	-26.652
Cu azide	-25.429	-17.588
Cu(OH)2(s)	-6.919	-16.532
Cu2(OH)3NO3(s)	-96.372	-106.064
Cu3(AsO4)2:2H2O(s)	-94.066	-58.966
Cu3(PO4)2(s)	-77.342	-40.492
Cu3(PO4)2:3H2O(s)	-77.344	-42.224
CuCO3(s)	-26.354	-14.854
CuCrO4(s)	-22.551	-17.111
CuF2(s)	-28.876	-30.397
CuF2:2H2O(s)	-28.877	-24.419
CuOCuSO4(s)	-21.831	-32.972
Cupric Ferrite	-18.617	-25.883
CuSO4(s)	-14.913	-18.297
Diaspore	4.031	-3.469
Dolomite (disordered)	-34.233	-17.975
Dolomite (ordered)	-34.233	-17.383
Epsomite	-5.674	-3.478
Ettringite	-2.045	-61.233

Mineral	log IAP	Sat. index
FCO3-Apatite	-164.322	-48.92
Fe(OH)2 (am)	2.202	-11.845
Fe(OH)2 (c)	2.202	-10.688
Fe(OH)2.7Cl.3(s)	-7.161	-4.121
Fe2(SO4)3(s)	-35.683	-33.42
Fe3(OH)8(s)	-9.498	-29.72
FeAsO4:2H2O(s)	-42.505	-22.305
Ferrihydrite	-5.85	-9.66
Ferrihydrite (aged)	-5.85	-9.15
FeS (ppt)	-13.689	-10.806
Fluorite	-19.642	-9.069
Galena	-18.463	-3.057
Gibbsite (C)	4.03	-4.348
Goethite	-5.85	-6.709
Goslarite	-7.8	-5.702
Greenockite	-19.251	-4.897
Greigite	-73.062	-28.027
Gypsum	-5.68	-1.064
Halite	-3.997	-5.524
Hematite	-11.699	-11.065
Hercynite	10.264	-14.537
Hg(OH)2(s)	-30.533	-27.037
Hg3O2CO3(s)	-111.035	-81.455
HgCl2(s)	-39.272	-17.354
HgSO4(s)	-38.528	-29.019
Hinsdalite	-26.768	-24.268
H-Jarosite	-33.539	-29.507

Mineral	log IAP	Sat. index
Huntite	-68.458	-39.146
Hydrocerrusite	-46.588	-27.828
Hydromagnesite	-66.129	-58.691
Hydroxyapatite	-73.305	-28.972
Hydroxylpyromorphite	-97.741	-34.951
Hydrozincite	-37.882	-48.02
K2Cr2O7(s)	-33.847	-16.114
K2CrO4(s)	-18.215	-17.591
K-Alum	-13.255	-7.902
KCl(s)	-5.661	-6.561
K-Jarosite	-34.83	-24.449
Langite	-35.67	-54.165
Larnakite	-13.139	-12.837
Laurionite	-6.942	-7.565
Lepidocrocite	-5.85	-7.221
Lime	2.315	-31.563
Litharge	-2.572	-15.66
Mackinawite	-13.689	-10.089
Maghemite	-11.699	-18.085
Magnesioferrite	-9.375	-27.931
Magnesite	-17.113	-9.531
Magnetite	-9.497	-14.167
Malachite	-33.273	-28.073
Massicot	-2.572	-15.868
Matlockite	-17.92	-8.745
Melanothallite	-15.657	-22.3
Melanterite	-5.796	-3.462
Metacinnabar	-46.424	0

Mineral	log IAP	Sat. index
Mg(OH)2 (active)	2.323	-16.471
Mg2(OH)3Cl:4H2O(s)	0.275	-25.725
Mg3(PO4)2(s)	-49.617	-26.337
MgCO3:5H2O(s)	-17.115	-12.575
MgCrO4(s)	-13.309	-19.23
MgF2(s)	-19.634	-11.573
MgHPO4:3H2O(s)	-25.972	-7.797
MgS(s)	-13.568	-31.248
Minium	2.764	-73.322
Mirabilite	-7.254	-5.657
Mn2(SO4)3(s)	-20.294	-15.577
Montroydite	-30.533	-26.816
Morenosite	-8.57	-6.351
Na2Cr2O7(s)	-30.519	-20.489
Na2CrO4(s)	-14.887	-17.937
NaF(s)	-10.606	-10.111
Na-Jarosite	-33.166	-28.671
Natron	-18.695	-16.984
Nesquehonite	-17.114	-12.591
Ni(OH)2 (am)	-0.573	-14.046
Ni(OH)2 (c)	-0.573	-11.363
Ni3(AsO4)2:8H2O(s)	-75.031	-49.531
Ni3(PO4)2(s)	-58.305	-27.005
Ni4(OH)6SO4(s)	-10.286	-42.286
NiCO3(s)	-20.009	-9.061
NiS (alpha)	-16.464	-10.944
NiS (beta)	-16.464	-5.444
NiS (gamma)	-16.464	-3.744

Mineral	log IAP	Sat. index
Nsutite	7.085	-10.419
Orpiment	-60.283	-12.384
Otavite	-22.796	-10.745
Pb azide (alpha)	-21.083	-12.108
Pb metal	-13.053	-17.293
Pb(OH)2(s)	-2.572	-11.078
Pb10(OH)6O(CO3)6(s)	-142.337	-133.577
Pb2(OH)3Cl(s)	-9.514	-18.307
Pb2O(OH)2(s)	-5.145	-31.335
Pb2O3(s)	5.337	-55.703
Pb2OCO3(s)	-24.58	-24.27
Pb3(AsO4)2(s)	-81.026	-45.526
Pb3(PO4)2(s)	-64.303	-20.773
Pb3O2CO3(s)	-27.152	-38.844
Pb3O2SO4(s)	-15.711	-26.878
Pb4(OH)6SO4(s)	-18.284	-39.384
Pb4O3SO4(s)	-18.283	-40.99
PbCrO4(s)	-18.204	-5.336
PbF2(s)	-24.529	-16.968
PbHPO4(s)	-30.866	-7.061
PbO:0.3H2O(s)	-2.572	-15.552
Periclase	2.323	-20.18
Phosgenite	-33.319	-13.509
Plattnerite	7.909	-43.493
Plumbgummite	-47.068	-14.278
Portlandite	2.315	-21.171
Pyrite	-19.1	-0.289
Realgar	-27.436	-6.706

Mineral	log IAP	Sat. index
Retgersite	-8.57	-6.502
Siderite	-17.234	-6.688
Smithsonite	-19.238	-8.361
Spharelite	-15.693	-4.691
Spinel	10.386	-28.821
Strengite	-34.144	-7.801
Struvite	-26.58	-13.32
Sulfur	-5.411	-3.365
Tenorite(am)	-6.918	-15.803
Tenorite(c)	-6.918	-14.953
Thenardite	-7.25	-7.627
Thermonatrite	-18.691	-19.392
Tsumebite	-40.358	-30.568
Vaterite	-17.121	-9.284
Vivianite	-49.985	-12.194
Wurtzite	-15.693	-6.944
Zincite	0.198	-11.577
Zincosite	-7.797	-12.228
Zn metal	-10.282	-37.004
Zn(NO3)2:6H2O(s)	-164.873	-168.039
Zn(OH)2 (am)	0.198	-12.797
Zn(OH)2 (beta)	0.198	-12.062
Zn(OH)2 (delta)	0.198	-11.646
Zn(OH)2 (epsilon)	0.198	-11.814
Zn(OH)2 (gamma)	0.198	-12.034
Zn2(OH)2SO4(s)	-7.599	-15.099
Zn2(OH)3Cl(s)	-3.974	-19.165
Zn3(PO4)2:4H2O(s)	-55.994	-20.574

Mineral	log IAP	Sat. index
Zn3AsO42:2.5H2O(s)	-72.717	-45.217
Zn3O(SO4)2(s)	-15.395	-35.877
Zn4(OH)6SO4(s)	-7.203	-35.603
Zn5(OH)8Cl2(s)	-7.75	-46.25
Zn-Al LDH(s)	-5.292	-25.122
ZnCl2(s)	-8.54	-16.031
ZnCO3(s)	-19.238	-8.438
ZnCO3:1H2O(s)	-19.238	-8.978
ZnF2(s)	-21.759	-21.588
ZnSO4:1H2O(s)	-7.797	-7.427

D3.2: Eh 200

Mineral	log IAP	Sat. index
Al(OH)3 (am)	4.03	-7.445
Al(OH)3 (Soil)	4.03	-4.898
Al2O3(s)	8.062	-13.163
Al4(OH)10SO4(s)	8.127	-14.573
AlAsO4:2H2O(s)	-30.876	-15.076
AlOHF2(s)	-17.926	-18.333
AlOHSO4(s)	-3.964	-0.734
Alunite	-5.189	-5.066
Anglesite	-10.567	-2.704
Anhydrite	-5.679	-1.363
Antlerite	-15.089	-23.877
Aragonite	-17.121	-8.842
Arsenolite	-12.609	-11.046
Artinite	-14.791	-25.122
As2O5(s)	-69.812	-35.103
As2S3(am)	-81.272	-34.887
Atacamite	-9.099	-17.058
Azurite	-45.965	-28.812
Bianchite	-7.799	-6.038
Birnessite	7.96	-10.131
Bixbyite	3.69	3.577
Boehmite	4.031	-5.263
Brochantite	-17.453	-33.909
Brucite	2.323	-15.47
Ca3(AsO4)2:4H2O(s)	-62.868	-43.968
Ca3(PO4)2 (am1)	-49.642	-24.713
Ca3(PO4)2 (am2)	-49.642	-21.921

Mineral	log IAP	Sat. index
Ca3(PO4)2 (beta)	-49.642	-20.393
Ca4H(PO4)3:3H2O(s)	-75.622	-28.31
CaCO3xH2O(s)	-17.121	-10.034
CaCrO4(s)	-13.317	-11.215
CaHPO4(s)	-25.979	-6.515
CaHPO4:2H2O(s)	-25.98	-6.845
Calcite	-17.121	-8.691
CaS(s)	-20.573	-31.753
Cd metal (alpha)	-15.59	-29.562
Cd metal (gamma)	-15.59	-29.669
Cd(OH)2(s)	-3.361	-17.58
Cd3(OH)4SO4(s)	-18.076	-40.636
Cd3(PO4)2(s)	-66.667	-34.067
Cd3OH2(SO4)2(s)	-26.07	-32.78
Cd4(OH)6SO4(s)	-21.436	-49.836
CdCl2(s)	-12.099	-11.553
CdCl2:1H2O(s)	-12.099	-10.451
CdCl2:2.5H2O(s)	-12.1	-10.143
CdF2(s)	-25.317	-24.386
CdOHCl(s)	-7.73	-11.455
CdSO4(s)	-11.355	-11.499
CdSO4:1H2O(s)	-11.355	-9.821
CdSO4:2.67H2O(s)	-11.356	-9.592
Cerrusite	-22.008	-8.657
Chalcanthite	-10.361	-7.685
Chalcopyrite	-45.938	-9.765
Chloropyromorphite(c)	-102.11	-17.68
Chloropyromorphite(soil)	-102.11	-21.71

Mineral	log IAP	Sat. index
Cinnabar	-46.424	0.399
Claudetite	-12.609	-11.096
Cotunnite	-11.311	-6.372
Covellite	-25.252	-2.442
Cr(VI)-Ettringite	-24.958	-88.359
Cr(VI)-Jarosite	-47.482	-28.966
CrO3(s)	-15.632	-12.453
Cryolite	-60.723	-26.652
Cu azide	-20.875	-13.034
Cu(OH)2(s)	-2.365	-11.978
Cu2(OH)3NO3(s)	-80.267	-89.96
Cu3(AsO4)2:2H2O(s)	-76.906	-41.806
Cu3(PO4)2(s)	-63.68	-26.83
Cu3(PO4)2:3H2O(s)	-63.682	-28.562
CuCO3(s)	-21.8	-10.3
CuCrO4(s)	-17.997	-12.557
CuF2(s)	-24.322	-25.843
CuF2:2H2O(s)	-24.323	-19.865
CuOCuSO4(s)	-12.723	-23.864
Cupric Ferrite	-12.314	-19.58
CuSO4(s)	-10.359	-13.743
Diaspore	4.031	-3.469
Dolomite (disordered)	-34.233	-17.975
Dolomite (ordered)	-34.233	-17.383
Epsomite	-5.674	-3.478
Ettringite	-2.045	-61.233
FCO3-Apatite	-164.322	-48.92
Fe(OH)2 (am)	2.202	-11.846

Mineral	log IAP	Sat. index
Fe(OH)2 (c)	2.202	-10.688
Fe(OH)2.7Cl.3(s)	-6.286	-3.246
Fe2(SO4)3(s)	-33.934	-31.671
Fe3(OH)8(s)	-7.749	-27.971
FeAsO4:2H2O(s)	-39.882	-19.682
Ferrihydrite	-4.975	-8.786
Ferrihydrite (aged)	-4.975	-8.276
FeS (ppt)	-20.686	-17.803
Fluorite	-19.642	-9.069
Galena	-25.46	-10.053
Gibbsite (C)	4.03	-4.348
Goethite	-4.975	-5.834
Goslarite	-7.8	-5.702
Greenockite	-26.248	-11.893
Greigite	-99.298	-54.263
Gypsum	-5.68	-1.064
Halite	-3.997	-5.524
Hematite	-9.95	-9.316
Hercynite	10.264	-14.538
Hg(OH)2(s)	-23.537	-20.041
Hg3O2CO3(s)	-90.046	-60.466
HgCl2(s)	-32.275	-10.358
HgSO4(s)	-31.531	-22.023
Hinsdalite	-26.769	-24.269
H-Jarosite	-30.916	-26.883
Huntite	-68.458	-39.146
Hydrocerrusite	-46.589	-27.829
Hydromagnesite	-66.129	-58.691

Mineral	log IAP	Sat. index
Hydroxyapatite	-73.305	-28.972
Hydroxylpyromorphite	-97.741	-34.951
Hydrozincite	-37.882	-48.02
K2Cr2O7(s)	-33.847	-16.114
K2CrO4(s)	-18.215	-17.591
K-Alum	-13.255	-7.902
KCl(s)	-5.661	-6.561
K-Jarosite	-32.207	-21.826
Langite	-17.454	-35.949
Larnakite	-13.139	-12.837
Laurionite	-6.942	-7.565
Lepidocrocite	-4.975	-6.346
Lime	2.315	-31.563
Litharge	-2.572	-15.66
Mackinawite	-20.686	-17.086
Maghemite	-9.95	-16.336
Magnesioferrite	-7.626	-26.182
Magnesite	-17.113	-9.531
Magnetite	-7.748	-12.418
Malachite	-24.165	-18.965
Massicot	-2.572	-15.868
Matlockite	-17.92	-8.745
Melanothallite	-11.103	-17.746
Melanterite	-5.796	-3.462
Metacinnabar	-46.424	0
Mg(OH)2 (active)	2.323	-16.471
Mg2(OH)3Cl:4H2O(s)	0.275	-25.725
Mg3(PO4)2(s)	-49.617	-26.337

Mineral	log IAP	Sat. index
MgCO3:5H2O(s)	-17.115	-12.575
MgCrO4(s)	-13.309	-19.23
MgF2(s)	-19.634	-11.573
MgHPO4:3H2O(s)	-25.972	-7.797
MgS(s)	-20.564	-38.244
Minium	4.514	-71.573
Mirabilite	-7.254	-5.657
Mn2(SO4)3(s)	-20.294	-15.577
Montroydite	-23.537	-19.82
Morenosite	-8.57	-6.351
Na2Cr2O7(s)	-30.519	-20.489
Na2CrO4(s)	-14.887	-17.937
NaF(s)	-10.606	-10.111
Na-Jarosite	-30.543	-26.048
Natron	-18.695	-16.984
Nesquehonite	-17.114	-12.591
Ni(OH)2 (am)	-0.573	-14.046
Ni(OH)2 (c)	-0.573	-11.363
Ni3(AsO4)2:8H2O(s)	-71.533	-46.033
Ni3(PO4)2(s)	-58.305	-27.005
Ni4(OH)6SO4(s)	-10.286	-42.286
NiCO3(s)	-20.009	-9.061
NiS (alpha)	-23.46	-17.94
NiS (beta)	-23.46	-12.44
NiS (gamma)	-23.46	-10.74
Nsutite	7.96	-9.544
Orpiment	-81.272	-33.373
Otavite	-22.796	-10.745

Mineral	log IAP	Sat. index
Pb azide (alpha)	-21.083	-12.108
Pb metal	-14.802	-19.042
Pb(OH)2(s)	-2.573	-11.078
Pb10(OH)6O(CO3)6(s)	-142.338	-133.578
Pb2(OH)3Cl(s)	-9.514	-18.307
Pb2O(OH)2(s)	-5.145	-31.335
Pb2O3(s)	7.086	-53.954
Pb2OCO3(s)	-24.58	-24.27
Pb3(AsO4)2(s)	-77.528	-42.028
Pb3(PO4)2(s)	-64.303	-20.773
Pb3O2CO3(s)	-27.152	-38.844
Pb3O2SO4(s)	-15.711	-26.878
Pb4(OH)6SO4(s)	-18.284	-39.384
Pb4O3SO4(s)	-18.283	-40.99
PbCrO4(s)	-18.204	-5.336
PbF2(s)	-24.529	-16.968
PbHPO4(s)	-30.866	-7.061
PbO:0.3H2O(s)	-2.572	-15.552
Periclase	2.323	-20.18
Phosgenite	-33.319	-13.509
Plattnerite	9.658	-41.744
Plumbgummite	-47.068	-14.278
Portlandite	2.315	-21.171
Pyrite	-31.344	-12.533
Realgar	-35.307	-14.577
Retgersite	-8.57	-6.502
Siderite	-17.234	-6.688
Smithsonite	-19.238	-8.361

Mineral	log IAP	Sat. index
Spharelite	-22.69	-11.687
Spinel	10.385	-28.821
Strengite	-33.269	-6.926
Struvite	-26.58	-13.32
Sulfur	-10.658	-8.612
Tenorite(am)	-2.364	-11.249
Tenorite(c)	-2.364	-10.399
Thenardite	-7.25	-7.627
Thermonatrite	-18.691	-19.392
Tsumebite	-35.804	-26.014
Vaterite	-17.121	-9.284
Vivianite	-49.985	-12.194
Wurtzite	-22.69	-13.941
Zincite	0.198	-11.577
Zincosite	-7.797	-12.228
Zn metal	-12.032	-38.753
Zn(NO3)2:6H2O(s)	-150.88	-154.046
Zn(OH)2 (am)	0.198	-12.797
Zn(OH)2 (beta)	0.198	-12.062
Zn(OH)2 (delta)	0.198	-11.646
Zn(OH)2 (epsilon)	0.198	-11.814
Zn(OH)2 (gamma)	0.198	-12.034
Zn2(OH)2SO4(s)	-7.599	-15.099
Zn2(OH)3Cl(s)	-3.974	-19.165
Zn3(PO4)2:4H2O(s)	-55.994	-20.574
Zn3AsO42:2.5H2O(s)	-69.219	-41.719
Zn3O(SO4)2(s)	-15.395	-35.877
Zn4(OH)6SO4(s)	-7.203	-35.603

Mineral	log IAP	Sat. index
Zn5(OH)8Cl2(s)	-7.75	-46.25
Zn-Al LDH(s)	-5.292	-25.122
ZnCl2(s)	-8.54	-16.031
ZnCO3(s)	-19.238	-8.438
ZnCO3:1H2O(s)	-19.238	-8.978
ZnF2(s)	-21.759	-21.588
ZnSO4:1H2O(s)	-7.797	-7.427

D3.3: Eh 250

Mineral	log IAP	Sat. index
Al(OH)3 (am)	4.03	-7.445
Al(OH)3 (Soil)	4.03	-4.898
Al2O3(s)	8.062	-13.163
Al4(OH)10SO4(s)	8.127	-14.573
AlAsO4:2H2O(s)	-29.127	-13.327
AlOHF2(s)	-17.926	-18.333
AlOHSO4(s)	-3.964	-0.734
Alunite	-5.189	-5.066
Anglesite	-10.567	-2.704
Anhydrite	-5.679	-1.363
Antlerite	-15.089	-23.877
Aragonite	-17.121	-8.842
Arsenolite	-12.609	-11.046
Artinite	-14.791	-25.122
As2O5(s)	-66.314	-31.605
As2S3(am)	-102.261	-55.877
Atacamite	-9.099	-17.058
Azurite	-45.965	-28.812
Bianchite	-7.799	-6.038
Birnessite	8.834	-9.257
Bixbyite	3.69	3.577
Boehmite	4.031	-5.263
Brochantite	-17.453	-33.909
Brucite	2.323	-15.47
Ca3(AsO4)2:4H2O(s)	-59.37	-40.47
Ca3(PO4)2 (am1)	-49.642	-24.713
Ca3(PO4)2 (am2)	-49.642	-21.921

Mineral	log IAP	Sat. index
Ca3(PO4)2 (beta)	-49.642	-20.393
Ca4H(PO4)3:3H2O(s)	-75.622	-28.31
CaCO3xH2O(s)	-17.121	-10.034
CaCrO4(s)	-13.317	-11.215
CaHPO4(s)	-25.979	-6.515
CaHPO4:2H2O(s)	-25.98	-6.845
Calcite	-17.121	-8.691
CaS(s)	-27.569	-38.749
Cd metal (alpha)	-17.339	-31.312
Cd metal (gamma)	-17.339	-31.418
Cd(OH)2(s)	-3.361	-17.58
Cd3(OH)4SO4(s)	-18.076	-40.636
Cd3(PO4)2(s)	-66.667	-34.067
Cd3OH2(SO4)2(s)	-26.07	-32.78
Cd4(OH)6SO4(s)	-21.436	-49.836
CdCl2(s)	-12.099	-11.553
CdCl2:1H2O(s)	-12.099	-10.451
CdCl2:2.5H2O(s)	-12.1	-10.143
CdF2(s)	-25.317	-24.386
CdOHCl(s)	-7.73	-11.455
CdSO4(s)	-11.355	-11.499
CdSO4:1H2O(s)	-11.355	-9.821
CdSO4:2.67H2O(s)	-11.356	-9.592
Cerrusite	-22.008	-8.657
Chalcanthite	-10.361	-7.685
Chalcopyrite	-59.931	-23.758
Chloropyromorphite(c)	-102.11	-17.68
Chloropyromorphite(soil)	-102.11	-21.71

Mineral	log IAP	Sat. index
Cinnabar	-52.289	-5.466
Claudetite	-12.609	-11.096
Cotunnite	-11.311	-6.372
Covellite	-32.249	-9.439
Cr(VI)-Ettringite	-24.958	-88.359
Cr(VI)-Jarosite	-44.858	-26.342
CrO3(s)	-15.632	-12.453
Cryolite	-60.723	-26.652
Cu azide	-20.875	-13.034
Cu(OH)2(s)	-2.365	-11.978
Cu2(OH)3NO3(s)	-73.271	-82.963
Cu3(AsO4)2:2H2O(s)	-73.408	-38.308
Cu3(PO4)2(s)	-63.68	-26.83
Cu3(PO4)2:3H2O(s)	-63.682	-28.562
CuCO3(s)	-21.8	-10.3
CuCrO4(s)	-17.997	-12.557
CuF2(s)	-24.322	-25.843
CuF2:2H2O(s)	-24.323	-19.865
CuOCuSO4(s)	-12.723	-23.864
Cupric Ferrite	-10.565	-17.831
CuSO4(s)	-10.359	-13.743
Diaspore	4.031	-3.469
Dolomite (disordered)	-34.233	-17.975
Dolomite (ordered)	-34.233	-17.383
Epsomite	-5.674	-3.478
Ettringite	-2.045	-61.233
FCO3-Apatite	-164.322	-48.92
Fe(OH)2 (am)	2.202	-11.846

Mineral	log IAP	Sat. index
Fe(OH)2 (c)	2.202	-10.688
Fe(OH)2.7Cl.3(s)	-5.412	-2.372
Fe2(SO4)3(s)	-32.184	-29.922
Fe3(OH)8(s)	-6	-26.222
FeAsO4:2H2O(s)	-37.258	-17.058
Ferrihydrite	-4.101	-7.911
Ferrihydrite (aged)	-4.101	-7.401
FeS (ppt)	-27.682	-24.799
Fluorite	-19.642	-9.069
Galena	-32.456	-17.05
Gibbsite (C)	4.03	-4.348
Goethite	-4.1	-4.96
Goslarite	-7.8	-5.702
Greenockite	-33.244	-18.89
Greigite	-125.535	-80.5
Gypsum	-5.68	-1.064
Halite	-3.997	-5.524
Hematite	-8.2	-7.567
Hercynite	10.264	-14.538
Hg(OH)2(s)	-22.405	-18.909
Hg3O2CO3(s)	-86.65	-57.07
HgCl2(s)	-31.143	-9.226
HgSO4(s)	-30.399	-20.891
Hinsdalite	-26.769	-24.269
H-Jarosite	-28.292	-24.259
Huntite	-68.458	-39.146
Hydrocerrusite	-46.589	-27.829
Hydromagnesite	-66.129	-58.691

Mineral	log IAP	Sat. index
Hydroxyapatite	-73.305	-28.972
Hydroxylpyromorphite	-97.741	-34.951
Hydrozincite	-37.882	-48.02
K2Cr2O7(s)	-33.847	-16.114
K2CrO4(s)	-18.215	-17.591
K-Alum	-13.255	-7.902
KCl(s)	-5.661	-6.561
K-Jarosite	-29.583	-19.202
Langite	-17.454	-35.949
Larnakite	-13.139	-12.837
Laurionite	-6.942	-7.565
Lepidocrocite	-4.1	-5.471
Lime	2.315	-31.563
Litharge	-2.572	-15.66
Mackinawite	-27.682	-24.082
Maghemite	-8.2	-14.586
Magnesioferrite	-5.877	-24.433
Magnesite	-17.113	-9.531
Magnetite	-5.999	-10.669
Malachite	-24.165	-18.965
Massicot	-2.572	-15.868
Matlockite	-17.92	-8.745
Melanothallite	-11.103	-17.746
Melanterite	-5.796	-3.462
Metacinnabar	-52.289	-5.865
Mg(OH)2 (active)	2.323	-16.471
Mg2(OH)3Cl:4H2O(s)	0.275	-25.725
Mg3(PO4)2(s)	-49.617	-26.337

Mineral	log IAP	Sat. index
MgCO3:5H2O(s)	-17.115	-12.575
MgCrO4(s)	-13.309	-19.23
MgF2(s)	-19.634	-11.573
MgHPO4:3H2O(s)	-25.972	-7.797
MgS(s)	-27.561	-45.241
Minium	6.263	-69.824
Mirabilite	-7.254	-5.657
Mn2(SO4)3(s)	-20.294	-15.577
Montroydite	-22.405	-18.688
Morenosite	-8.57	-6.351
Na2Cr2O7(s)	-30.519	-20.489
Na2CrO4(s)	-14.887	-17.937
NaF(s)	-10.606	-10.111
Na-Jarosite	-27.919	-23.424
Natron	-18.695	-16.984
Nesquehonite	-17.114	-12.591
Ni(OH)2 (am)	-0.573	-14.046
Ni(OH)2 (c)	-0.573	-11.363
Ni3(AsO4)2:8H2O(s)	-68.035	-42.535
Ni3(PO4)2(s)	-58.305	-27.005
Ni4(OH)6SO4(s)	-10.286	-42.286
NiCO3(s)	-20.009	-9.061
NiS (alpha)	-30.457	-24.937
NiS (beta)	-30.457	-19.437
NiS (gamma)	-30.457	-17.737
Nsutite	8.834	-8.67
Orpiment	-102.261	-54.362
Otavite	-22.796	-10.745

Mineral	log IAP	Sat. index
Pb azide (alpha)	-21.083	-12.108
Pb metal	-16.551	-20.791
Pb(OH)2(s)	-2.573	-11.078
Pb10(OH)6O(CO3)6(s)	-142.338	-133.578
Pb2(OH)3Cl(s)	-9.514	-18.307
Pb2O(OH)2(s)	-5.145	-31.335
Pb2O3(s)	8.835	-52.205
Pb2OCO3(s)	-24.58	-24.27
Pb3(AsO4)2(s)	-74.03	-38.53
Pb3(PO4)2(s)	-64.303	-20.773
Pb3O2CO3(s)	-27.152	-38.844
Pb3O2SO4(s)	-15.711	-26.878
Pb4(OH)6SO4(s)	-18.284	-39.384
Pb4O3SO4(s)	-18.283	-40.99
PbCrO4(s)	-18.204	-5.336
PbF2(s)	-24.529	-16.968
PbHPO4(s)	-30.866	-7.061
PbO:0.3H2O(s)	-2.572	-15.552
Periclase	2.323	-20.18
Phosgenite	-33.319	-13.509
Plattnerite	11.407	-39.995
Plumbgummite	-47.068	-14.278
Portlandite	2.315	-21.171
Pyrite	-43.588	-24.776
Realgar	-43.178	-22.448
Retgersite	-8.57	-6.502
Siderite	-17.234	-6.688
Smithsonite	-19.238	-8.361

Mineral	log IAP	Sat. index
Spharelite	-29.686	-18.684
Spinel	10.385	-28.821
Strengite	-32.395	-6.052
Struvite	-26.58	-13.32
Sulfur	-15.905	-13.86
Tenorite(am)	-2.364	-11.249
Tenorite(c)	-2.364	-10.399
Thenardite	-7.25	-7.627
Thermonatrite	-18.691	-19.392
Tsumebite	-35.804	-26.014
Vaterite	-17.121	-9.284
Vivianite	-49.985	-12.194
Wurtzite	-29.686	-20.937
Zincite	0.198	-11.577
Zincosite	-7.797	-12.228
Zn metal	-13.781	-40.502
Zn(NO3)2:6H2O(s)	-136.888	-140.053
Zn(OH)2 (am)	0.198	-12.797
Zn(OH)2 (beta)	0.198	-12.062
Zn(OH)2 (delta)	0.198	-11.646
Zn(OH)2 (epsilon)	0.198	-11.814
Zn(OH)2 (gamma)	0.198	-12.034
Zn2(OH)2SO4(s)	-7.599	-15.099
Zn2(OH)3Cl(s)	-3.974	-19.165
Zn3(PO4)2:4H2O(s)	-55.994	-20.574
Zn3AsO42:2.5H2O(s)	-65.72	-38.22
Zn3O(SO4)2(s)	-15.395	-35.877
Zn4(OH)6SO4(s)	-7.203	-35.603

Mineral	log IAP	Sat. index
Zn5(OH)8Cl2(s)	-7.75	-46.25
Zn-Al LDH(s)	-5.292	-25.122
ZnCl2(s)	-8.54	-16.031
ZnCO3(s)	-19.238	-8.438
ZnCO3:1H2O(s)	-19.238	-8.978
ZnF2(s)	-21.759	-21.588
ZnSO4:1H2O(s)	-7.797	-7.427

D3.4: Eh 300

Mineral	log IAP	Sat. index
Al(OH)3 (am)	4.03	-7.445
Al(OH)3 (Soil)	4.03	-4.898
Al2O3(s)	8.062	-13.163
Al4(OH)10SO4(s)	8.127	-14.573
AlAsO4:2H2O(s)	-27.378	-11.578
AlOHF2(s)	-17.926	-18.333
AlOHSO4(s)	-3.964	-0.734
Alunite	-5.189	-5.066
Anglesite	-10.567	-2.704
Anhydrite	-5.679	-1.363
Antlerite	-15.089	-23.877
Aragonite	-17.121	-8.842
Arsenolite	-12.609	-11.047
Artinite	-14.791	-25.122
As2O5(s)	-62.816	-28.107
As2S3(am)	-123.251	-76.866
Atacamite	-9.099	-17.058
Azurite	-45.965	-28.812
Bianchite	-7.799	-6.038
Birnessite	9.709	-8.382
Bixbyite	3.69	3.577
Boehmite	4.031	-5.263
Brochantite	-17.453	-33.909
Brucite	2.323	-15.47
Ca3(AsO4)2:4H2O(s)	-55.872	-36.972
Ca3(PO4)2 (am1)	-49.642	-24.713
Ca3(PO4)2 (am2)	-49.642	-21.921

Mineral	log IAP	Sat. index
Ca3(PO4)2 (beta)	-49.642	-20.393
Ca4H(PO4)3:3H2O(s)	-75.622	-28.31
CaCO3xH2O(s)	-17.121	-10.034
CaCrO4(s)	-13.317	-11.215
CaHPO4(s)	-25.979	-6.515
CaHPO4:2H2O(s)	-25.98	-6.845
Calcite	-17.121	-8.691
CaS(s)	-34.565	-45.745
Cd metal (alpha)	-19.088	-33.061
Cd metal (gamma)	-19.088	-33.168
Cd(OH)2(s)	-3.361	-17.58
Cd3(OH)4SO4(s)	-18.076	-40.636
Cd3(PO4)2(s)	-66.667	-34.067
Cd3OH2(SO4)2(s)	-26.07	-32.78
Cd4(OH)6SO4(s)	-21.436	-49.836
CdCl2(s)	-12.099	-11.553
CdCl2:1H2O(s)	-12.099	-10.451
CdCl2:2.5H2O(s)	-12.1	-10.143
CdF2(s)	-25.317	-24.386
CdOHCl(s)	-7.73	-11.455
CdSO4(s)	-11.355	-11.499
CdSO4:1H2O(s)	-11.355	-9.821
CdSO4:2.67H2O(s)	-11.356	-9.592
Cerrusite	-22.008	-8.657
Chalcanthite	-10.361	-7.685
Chalcopyrite	-73.924	-37.751
Chloropyromorphite(c)	-102.11	-17.68
Chloropyromorphite(soil)	-102.11	-21.71

Mineral	log IAP	Sat. index
Cinnabar	-59.285	-12.463
Claudetite	-12.609	-11.096
Cotunnite	-11.311	-6.372
Covellite	-39.245	-16.435
Cr(VI)-Ettringite	-24.958	-88.359
Cr(VI)-Jarosite	-42.234	-23.718
CrO3(s)	-15.632	-12.453
Cryolite	-60.723	-26.652
Cu azide	-20.875	-13.034
Cu(OH)2(s)	-2.365	-11.978
Cu2(OH)3NO3(s)	-66.274	-75.967
Cu3(AsO4)2:2H2O(s)	-69.91	-34.81
Cu3(PO4)2(s)	-63.68	-26.83
Cu3(PO4)2:3H2O(s)	-63.682	-28.562
CuCO3(s)	-21.8	-10.3
CuCrO4(s)	-17.997	-12.557
CuF2(s)	-24.322	-25.843
CuF2:2H2O(s)	-24.323	-19.865
CuOCuSO4(s)	-12.723	-23.864
Cupric Ferrite	-8.816	-16.082
CuSO4(s)	-10.359	-13.743
Diaspore	4.031	-3.469
Dolomite (disordered)	-34.233	-17.975
Dolomite (ordered)	-34.233	-17.383
Epsomite	-5.674	-3.478
Ettringite	-2.045	-61.233
FCO3-Apatite	-164.322	-48.92
Fe(OH)2 (am)	2.202	-11.846

Mineral	log IAP	Sat. index
Fe(OH)2 (c)	2.202	-10.688
Fe(OH)2.7Cl.3(s)	-4.537	-1.497
Fe2(SO4)3(s)	-30.435	-28.173
Fe3(OH)8(s)	-4.251	-24.473
FeAsO4:2H2O(s)	-34.635	-14.435
Ferrihydrite	-3.226	-7.037
Ferrihydrite (aged)	-3.226	-6.527
FeS (ppt)	-34.679	-31.796
Fluorite	-19.642	-9.069
Galena	-39.453	-24.046
Gibbsite (C)	4.03	-4.348
Goethite	-3.226	-4.085
Goslarite	-7.8	-5.702
Greenockite	-40.241	-25.886
Greigite	-151.772	-106.737
Gypsum	-5.68	-1.064
Halite	-3.997	-5.524
Hematite	-6.451	-5.818
Hercynite	10.264	-14.538
Hg(OH)2(s)	-22.405	-18.909
Hg3O2CO3(s)	-86.65	-57.07
HgCl2(s)	-31.143	-9.226
HgSO4(s)	-30.399	-20.891
Hinsdalite	-26.769	-24.269
H-Jarosite	-25.668	-21.636
Huntite	-68.458	-39.146
Hydrocerrusite	-46.589	-27.829
Hydromagnesite	-66.129	-58.691

Mineral	log IAP	Sat. index
Hydroxyapatite	-73.305	-28.972
Hydroxylpyromorphite	-97.741	-34.951
Hydrozincite	-37.882	-48.02
K2Cr2O7(s)	-33.847	-16.114
K2CrO4(s)	-18.215	-17.591
K-Alum	-13.255	-7.902
KCl(s)	-5.661	-6.561
K-Jarosite	-26.959	-16.578
Langite	-17.454	-35.949
Larnakite	-13.139	-12.837
Laurionite	-6.942	-7.565
Lepidocrocite	-3.226	-4.597
Lime	2.315	-31.563
Litharge	-2.572	-15.66
Mackinawite	-34.679	-31.079
Maghemite	-6.451	-12.837
Magnesioferrite	-4.128	-22.683
Magnesite	-17.113	-9.531
Magnetite	-4.249	-8.92
Malachite	-24.165	-18.965
Massicot	-2.572	-15.868
Matlockite	-17.92	-8.745
Melanothallite	-11.103	-17.746
Melanterite	-5.796	-3.462
Metacinnabar	-59.285	-12.861
Mg(OH)2 (active)	2.323	-16.471
Mg2(OH)3Cl:4H2O(s)	0.275	-25.725
Mg3(PO4)2(s)	-49.617	-26.337

Mineral	log IAP	Sat. index
MgCO3:5H2O(s)	-17.115	-12.575
MgCrO4(s)	-13.309	-19.23
MgF2(s)	-19.634	-11.573
MgHPO4:3H2O(s)	-25.972	-7.797
MgS(s)	-34.557	-52.237
Minium	8.012	-68.075
Mirabilite	-7.254	-5.657
Mn2(SO4)3(s)	-20.294	-15.577
Montroydite	-22.405	-18.688
Morenosite	-8.57	-6.351
Na2Cr2O7(s)	-30.519	-20.489
Na2CrO4(s)	-14.887	-17.937
NaF(s)	-10.606	-10.111
Na-Jarosite	-25.295	-20.8
Natron	-18.695	-16.984
Nesquehonite	-17.114	-12.591
Ni(OH)2 (am)	-0.573	-14.046
Ni(OH)2 (c)	-0.573	-11.363
Ni3(AsO4)2:8H2O(s)	-64.537	-39.037
Ni3(PO4)2(s)	-58.305	-27.005
Ni4(OH)6SO4(s)	-10.286	-42.286
NiCO3(s)	-20.009	-9.061
NiS (alpha)	-37.453	-31.933
NiS (beta)	-37.453	-26.433
NiS (gamma)	-37.453	-24.733
Nsutite	9.709	-7.795
Orpiment	-123.251	-75.352
Otavite	-22.796	-10.745

Mineral	log IAP	Sat. index
Pb azide (alpha)	-21.083	-12.108
Pb metal	-18.3	-22.541
Pb(OH)2(s)	-2.573	-11.078
Pb10(OH)6O(CO3)6(s)	-142.338	-133.578
Pb2(OH)3Cl(s)	-9.514	-18.307
Pb2O(OH)2(s)	-5.145	-31.335
Pb2O3(s)	10.584	-50.456
Pb2OCO3(s)	-24.58	-24.27
Pb3(AsO4)2(s)	-70.532	-35.032
Pb3(PO4)2(s)	-64.303	-20.773
Pb3O2CO3(s)	-27.152	-38.844
Pb3O2SO4(s)	-15.711	-26.878
Pb4(OH)6SO4(s)	-18.284	-39.384
Pb4O3SO4(s)	-18.283	-40.99
PbCrO4(s)	-18.204	-5.336
PbF2(s)	-24.529	-16.968
PbHPO4(s)	-30.866	-7.061
PbO:0.3H2O(s)	-2.572	-15.552
Periclase	2.323	-20.18
Phosgenite	-33.319	-13.509
Plattnerite	13.156	-38.246
Plumbgummite	-47.068	-14.278
Portlandite	2.315	-21.171
Pyrite	-55.831	-37.02
Realgar	-51.049	-30.319
Retgersite	-8.57	-6.502
Siderite	-17.234	-6.688
Smithsonite	-19.238	-8.361

Mineral	log IAP	Sat. index
Spharelite	-36.682	-25.68
Spinel	10.385	-28.821
Strengite	-31.52	-5.177
Struvite	-26.58	-13.32
Sulfur	-21.153	-19.107
Tenorite(am)	-2.364	-11.249
Tenorite(c)	-2.364	-10.399
Thenardite	-7.25	-7.627
Thermonatrite	-18.691	-19.392
Tsumebite	-35.804	-26.014
Vaterite	-17.121	-9.284
Vivianite	-49.985	-12.194
Wurtzite	-36.682	-27.934
Zincite	0.198	-11.577
Zincosite	-7.797	-12.228
Zn metal	-15.53	-42.251
Zn(NO3)2:6H2O(s)	-122.895	-126.061
Zn(OH)2 (am)	0.198	-12.797
Zn(OH)2 (beta)	0.198	-12.062
Zn(OH)2 (delta)	0.198	-11.646
Zn(OH)2 (epsilon)	0.198	-11.814
Zn(OH)2 (gamma)	0.198	-12.034
Zn2(OH)2SO4(s)	-7.599	-15.099
Zn2(OH)3Cl(s)	-3.974	-19.165
Zn3(PO4)2:4H2O(s)	-55.994	-20.574
Zn3AsO42:2.5H2O(s)	-62.223	-34.723
Zn3O(SO4)2(s)	-15.395	-35.877
Zn4(OH)6SO4(s)	-7.203	-35.603

Mineral	log IAP	Sat. index
Zn5(OH)8Cl2(s)	-7.75	-46.25
Zn-Al LDH(s)	-5.292	-25.122
ZnCl2(s)	-8.54	-16.031
ZnCO3(s)	-19.238	-8.438
ZnCO3:1H2O(s)	-19.238	-8.978
ZnF2(s)	-21.759	-21.588
ZnSO4:1H2O(s)	-7.797	-7.427

D4 Mass distribution

D4.1: Eh 150

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	1.23E-15	100	0	0	0	0
Ca+2	0.002994	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021437	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	1.76E-12	0.001	0	0	1.56E-07	99.999
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	1.15E-12	100	0	0	0	0
H+1	0.008421	100	0	0	0	0
H3AsO3	4.91E-07	100	0	0	0	0
Hg(OH)2	5.53E-18	0	0	0	4.99E-10	100
HS-1	1.87E-09	1.182	0	0	1.57E-07	98.818
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	8.83E-61	100	0	0	0	0
NO3-1	1.46E-80	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Pb+2	5.79E-08	100	0	0	0	0
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

D4.2: Eh 200

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	6.93E-14	100	0	0	0	0
Ca+2	0.002994	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021437	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	8.59E-12	100	0	0	0	0
H+1	0.008421	100	0	0	0	0
H3AsO3	4.91E-07	100	0	0	0	0
Hg(OH)2	3.68E-11	7.383	0	0	4.62E-10	92.617
HS-1	1.89E-16	0	0	0	4.62E-10	100
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	1.56E-55	100	0	0	0	0
NO3-1	1.45E-73	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

D4.3: Eh 250

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	3.89E-12	100	0	0	0	0
Ca+2	0.002994	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021437	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	6.43E-11	100	0	0	0	0
H+1	0.008421	100	0	0	0	0
H3AsO3	4.91E-07	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	1.91E-23	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	2.76E-50	100	0	0	0	0
NO3-1	1.43E-66	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

D4.4: Eh 300

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Al+3	0.00278	100	0	0	0	0
AsO4-3	2.18E-10	100	0	0	0	0
Ca+2	0.002994	100	0	0	0	0
Cd+2	1.16E-08	100	0	0	0	0
Cl-1	0.021437	100	0	0	0	0
CO3-2	0.002552	100	0	0	0	0
CrO4-2	3.65E-07	100	0	0	0	0
Cu+2	6.29E-08	100	0	0	0	0
DOC (Gaussian DOM)	0.000333	100	0	0	0	0
DOM1	2.87E-05	100	0	0	0	0
F-1	1.32E-05	100	0	0	0	0
Fe+2	0.002292	100	0	0	0	0
Fe+3	4.82E-10	100	0	0	0	0
H+1	0.008421	100	0	0	0	0
H3AsO3	4.9E-07	100	0	0	0	0
Hg(OH)2	4.99E-10	100	0	0	0	0
HS-1	1.92E-30	100	0	0	0	0
K+1	0.000151	100	0	0	0	0
Mg+2	0.003004	100	0	0	0	0
Mn+3	5.1E-06	100	0	0	0	0
N3-1	2.86E-05	100	0	0	0	0
Na+1	0.00696	100	0	0	0	0
NH4+1	0.000726	100	0	0	0	0
Ni+2	3.75E-06	100	0	0	0	0
NO2-1	4.87E-45	100	0	0	0	0
NO3-1	1.42E-59	100	0	0	0	0
Pb+2	5.79E-08	100	0	0	0	0

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
PO4-3	2.16E-06	100	0	0	0	0
SO4-2	0.007287	100	0	0	0	0
Zn+2	2.29E-05	100	0	0	0	0

D5 Finite solids

D5.1: Eh 150

Solid	Equilibrium amount (mol/l)
Metacinnabar	4.99E-10
Covellite	1.56E-07

D5.2: Eh 200

Solid	Equilibrium amount (mol/l)
Metacinnabar	4.62E-10

D5.3: Eh 250

No soils precipitate are predicted by the model.

D5.4: Eh 300

No soils precipitate are predicted by the model.

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12516663-39417/https://projectsportal.ghd.com/sites/pp17_02/barwonwaterbasicconc/ProjectDocs/12516663-REP_Big Swamp Conceptual Geochemical Modelling Report.docx

Document Status

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Barwon Water

Boundary Creek and Big Swamp remediation: Options assessment

13 December 2019

CDM Smith

Executive Summary

This report details the results of a Remediation Options Assessment (ROA) for identification of preferred remediation options to address ASS impacts to Big Swamp and Boundary Creek, in response of a Section 78 Notice issued to Barwon Water.

The framework developed to identify the preferred remediation option for management of ASS impacts at the site comprised:

- Technology identification – a comprehensive literature review for initial identification of a broad spectrum of available options for remediation of ASS impacts. The outcome of this task was identification of 17 remediation options.
- Preliminary screening – a screening process to restrict more detailed and site-specific assessment only to those options considered to be potentially feasible for the site. Following preliminary screening, seven remediation options were retained for detailed assessment.
- Detailed assessment – the retained remediation option (developed at a conceptual level) were assessed against a range of weighted criteria and indicators.

A risk assessment was also performed on the selected practically achievable remediation options to identify potential risks and required management measures associated with implementation of each option, in accordance with one of the requirements of the Section 78 Notice.

Inputs and feedback from the RWG technical experts and the community were sought at various stages of the process to assist with development of key aspects of the ROA.

Results of the weighted scoring from the detailed assessment of the options retained after preliminary screening provides the following ranking:

1. Managed Groundwater Levels and Wetland Flooding
2. Aerial liming
3. In-stream treatment
4. Aerobic wetland
5. Soil Mixing
6. RAPS
7. Excavation and disposal

These results, being the outcome of a multi-parameter assessment, provide an indication of the remediation options that, overall, are likely to achieve the best outcomes for the project.

The 'managed groundwater levels and wetland flooding' remediation option is considered to be the preferred remediation option being the one that, overall, has the highest likelihood of achieving the project objectives. Other remediation options considered as part of the ROA can be retained either to integrate with the preferred remediation option or as contingency measures.

The outcomes of the risk assessment process indicate that the risks associated with the practical remediation measures can be adequately managed through implementation of mitigation measures. The risk mitigation measures generally include collection of additional data to improve understanding and assessment of risks, undertaking monitoring activities to confirm if the identified risks are present and implementation of contingency measures to treat unacceptable risks.

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Document history & status

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Section 1 **Introduction**

1.1 Background

Barwon Water has engaged CDM Smith Australia Pty Ltd (CDM Smith) to undertake a Remediation Options Assessment (ROA) for management of acid sulfate soils (ASS) issues at Big Swamp and Boundary Creek, in response to a Ministerial Notice (the notice) issued by Southern Rural Water (SRW) under Section 78 of the Water Act 1989 (the Act).

The works supporting preparation of this ROA have been prepared in general accordance to our proposal 001238-PRP dated 20 September 2019.

1.2 Description of the issues

Big Swamp is a peat swamp along Boundary Creek, a tributary of the Barwon River, in the Otway Ranges of Victoria, Australia. Sediments in Big Swamp contain significant amounts of pyrite (FeS_2), one of the iron sulfides commonly associated with ASS.

A combination of drier climate conditions, anthropogenic modifications to the Boundary Creek catchment and pumping from the Barwon Downs borefield by Barwon Water has caused several environmental impacts, including:

- Oxidation of ASS in Big Swamp, leading to release of acidic water (i.e. water with low pH, low alkalinity, high acidity and elevated concentration of metals) into Boundary Creek and Barwon River.
- Encroachment within Big Swamp of plant species relying on deeper groundwater levels.
- Increase occurrence of days of 'no flow' (i.e. flow rate below detection at the Yeodene flow gauge) in Boundary Creek downstream of Big Swamp (Reach 3).

1.3 Identification of the Areas for Remediation

To assist with identification of the areas to be covered by the Remediation Plan required by the Section 78 Notice, Barwon Water has conducted a risk assessment on the whole extent of the Lower Tertiary Aquifer (LTA) system potentially affected by historical pumping activities from the Barwon Downs borefield.

The results of the risk assessment (Barwon Water, 2019) indicate the following:

- Big Swamp and Boundary Creek are two areas of potential 'high risk' where impacts have been confirmed by the results of monitoring activities, and/or high value groundwater dependent ecosystems are known to exist.
- Other areas of potential 'high risk' have been identified, however for these areas, impacts have not been confirmed.

Based on these results, Barwon Water has adopted the following prioritisation approach for preparation of the Remediation Plan:

- Priority for remediation is on the areas of potential 'high risk' where impacts have been confirmed by monitoring and high value GDEs are known to exist, including:
  - Boundary Creek reaches 2 and 3
  - Vegetation in Boundary Creek in reaches 2 and 3
  - Big Swamp

According to this prioritised approach and the requirements of the Section 78 Notice, this ROA has been prepared to support development of a remediation strategy for Big Swamp and Boundary Creek.

1.4 Objectives

The objectives of the ROA are to:

- Develop a vision and identify objectives for the Big Swamp and Boundary Creek remediation project (the project).
- Identify potential technologies that could be applicable to achieve the project objectives.
- Prepare a framework to support transparent and independent assessment of the identified remediation options, based on a range of performance criteria and indicators.
- Provide a concept for an integrated approach to remediation by combining the most suitable ('preferred') remediation options resulting from the assessment.

1.5 Scope of Works

The following scope of works was undertaken to support development of the ROA:

- Review of relevant information and technical reports related to the site, including results of surface water groundwater modelling (Jacobs, 2019b), geochemical modelling (GHD, 2019), ecological study (Eco Logical, 2019), and surface water quality assessment (Austral, 2019) and incubation testing (Monash University, 2019).
- Participation in two technical workshops and two remediation working group (RWG) meetings to assist in development of the ROA.
- Review of available guidance for the preparation of remediation option assessment, including the framework outlined in EPA Victoria Publication 840.2 *The Cleanup and Management of Contaminated Groundwater* (April 2016) and the guidelines developed by CRC Care Pty Ltd as part of the National Remediation Framework initiative.
- A comprehensive literature review on ASS management practices and technologies, including the National guidance for the management of acid sulfate soils in inland aquatic ecosystems (Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council, 2011).
- A preliminary screening of a broad range of potentially applicable remediation options for management or treatment of ASS impacts and selection of options to be retained for detailed assessment.
- Detailed assessment of the retained options and scoring of these options based on a technical, logistical, financial, timing, regulatory, community and sustainability considerations.
- Identification of options presenting the highest scores ('preferred options') and development of a remediation strategy (using one or a combination of the preferred options as required) aimed at meeting the project objectives and vision.
- Undertaking a risk assessment of practical remediation measures that could be adopted at the site.
- Preparation of this report outlining the results of the ROA.

1.6 Supporting Information

The supporting information used to develop the ROA are referenced in Section 11. The ROA has also considered relevant feedback from technical and community working groups received during the workshops and meetings held to support development of the remediation process.

Section 2 **Remediation Process Overview**

2.1 12-Step Remediation Process

The 12-Steps planning procedure from the Rehabilitation Manual for Australian Streams (Cooperative Research Centre for Catchment Hydrology Land and Water Resources Research and Development Corporation (LWRRDC and CRCCH), 2000) was adopted to assist in developing the remediation strategy for the Boundary Creek and Big Swamp Remediation Plan (Figure 2-1).

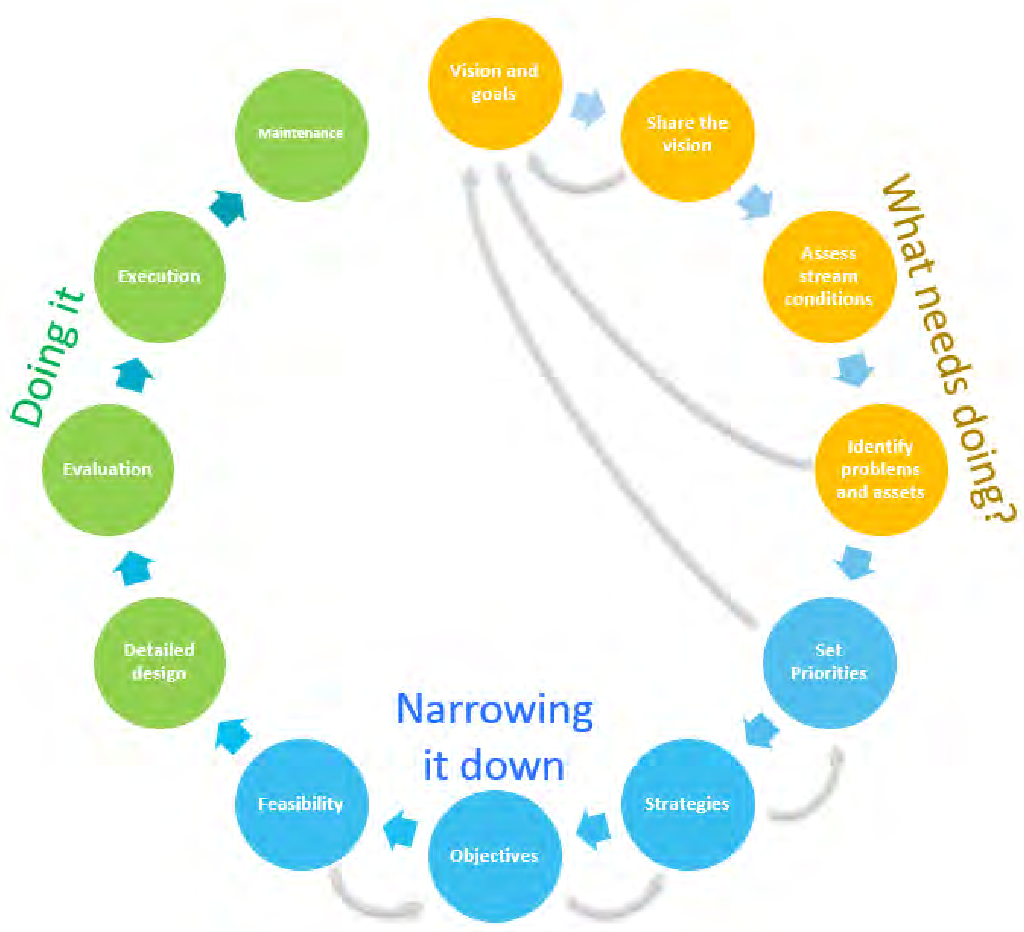

Figure 2-1 12-Steps Stream Rehabilitation Process adopted for the remediation strategy.

In Figure 2-1, the blue arrows represent movement between steps, and the grey arrows represent the reassessment of past steps as a result of reality checks and community feedback.

2.2 Collaborative Approach

As recommended in the 12-Steps Rehabilitation process ('Share the Vision'), a collaborative approach was adopted to assist in developing project visions and objectives that were relevant to the community, aligned with the requirements of the Section 78 notice and technically sound.

To assist this engagement and consultation process, the Boundary Creek and Big Swamp RWG was established in May 2018, providing an opportunity to interested community stakeholders to actively engage with Barwon Water in the design of the remediation plan for Boundary Creek and Big Swamp.

The RWG nominated three technical experts to provide independent advice on various aspects of the remediation concept as needed by the working group, as follows.

- **Dr Vanessa Wong** (Monash University, Senior Lecturer, School of Earth Atmosphere and Environment)
- **Prof Richard Bush** (Monash University) (Global Innovation Chair, International Centre for Balanced Land Use Office - DVC (Research and Innovation) (Earth Sciences))
- **Dr Darren Baldwin** (Independent Consultant) (Charles Sturt University, Visiting Adjunct Professor, School of Environmental Sciences)

This previous work provided the basis for development of the project vision and objectives, which were discussed and developed as part of the following workshops and meetings:

- Technical workshop held at Barwon Water offices in Geelong on 10 October 2019. The workshop was attended by the RWG technical experts (Darren Baldwin and Richard Bush), Monash University Professor Perran Cook and a range of consultants providing advice on surface water, groundwater, ecology, geochemistry and remediation.
- RWG meeting held in Colac on 23 October 2019. The meeting was attended by representatives from Barwon Water, SRW, CDM Smith and the RWG (including technical experts Darren Baldwin, Richard Bush and Vanessa Wong).

2.3 Project Vision

The project vision, which describes the intended end point of the remediation efforts, was developed in consideration of the requirements of the Section 78 notice, inputs from the technical workshop and community aspirations.

The following vision was presented and discussed and agreed during the RWG meeting:

To implement a **practical** remediation strategy that achieves an **improvement to the environment and the community**, so that:

- Big Swamp and Boundary Creek have healthy and sustained ecological systems
- The impacts to Barwon River are minimised and monitored
- Fire risks/threats are mitigated

2.4 Project Objectives

To assist in realising the project vision, **six project objectives** were developed and agreed during the first technical workshop and RWG meeting:

8. Maintain groundwater levels above the top of the non-oxidised sediments in Big Swamp (to prevent oxidisation of deeper sediments within the swamp)
9. Control of the acid discharge (i.e. pH, sulfate and metals) from Big Swamp into Boundary Creek
10. Maintain minimum flows in Reach 3 of Boundary Creek all year round
11. Manage potential formation of acidity downstream of Big Swamp, which may be triggered as a result of implementation of some remediation options (i.e. swamp inundation)
12. Preserve/improve the ecological values of Big Swamp and Boundary Creek. This objective is focused around addressing the changes to the vegetation assemblages within the swamp post the initial acidic event and fire. The result is a drying of the swamp, creating a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities
13. Reduce the peat fire risk in Big Swamp

2.5 Role of the Remediation Option Assessment

As discussed, the project vision provides a statement of an aspirational goal for the remediation project, where a recognisable project endpoint is described at a relatively high level.

While the project vision is largely aspirational and may be not achievable (LWRRDC and CRCCH, 2000) the project objectives provide a set of more detailed, measurable and specific indicators that can be used to assess on how the remediation project is progressing. The objectives should be developed so that they are instrumental to achieve the project vision.

The ROA is equivalent to the 'feasibility' step of the 12-Steps rehabilitation process, where potentially applicable remediation option (identified as part of the 'strategy' step) are assessed by undertaking 5 tasks (LWRRDC and CRCCH, 2000):

- Financial cost evaluation
- Regulatory approval evaluation
- Assessment of environmental gains and potential side effects
- Assessment on the ability to meet project objectives
- Weighted feasibility

The approach followed for the Big Swamp and Boundary Creek ROA has been conducted in general accordance to the above principles as well as other relevant guidelines related to site remediation and assessment, as described in more details in Section 5.

Section 3 **Remediation Conceptual Model**

This section presents a remediation conceptual model (RCM) of key site properties and acid generation, neutralisation and transport mechanisms that are considered relevant for development of the ROA. Additional technical details on these concepts are provided in the Jacobs, GHD, Eco Logical and Monash University reports, which have provided the basis for development of the RCM.

3.1 Catchment Description

Land use around Big Swamp and Boundary Creek is a mixture of cleared agriculture land and state forest that has been extensively modified since European settlement.

The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment. Surface water features of regional importance within these catchments are the Barwon River and the Gellibrand River.

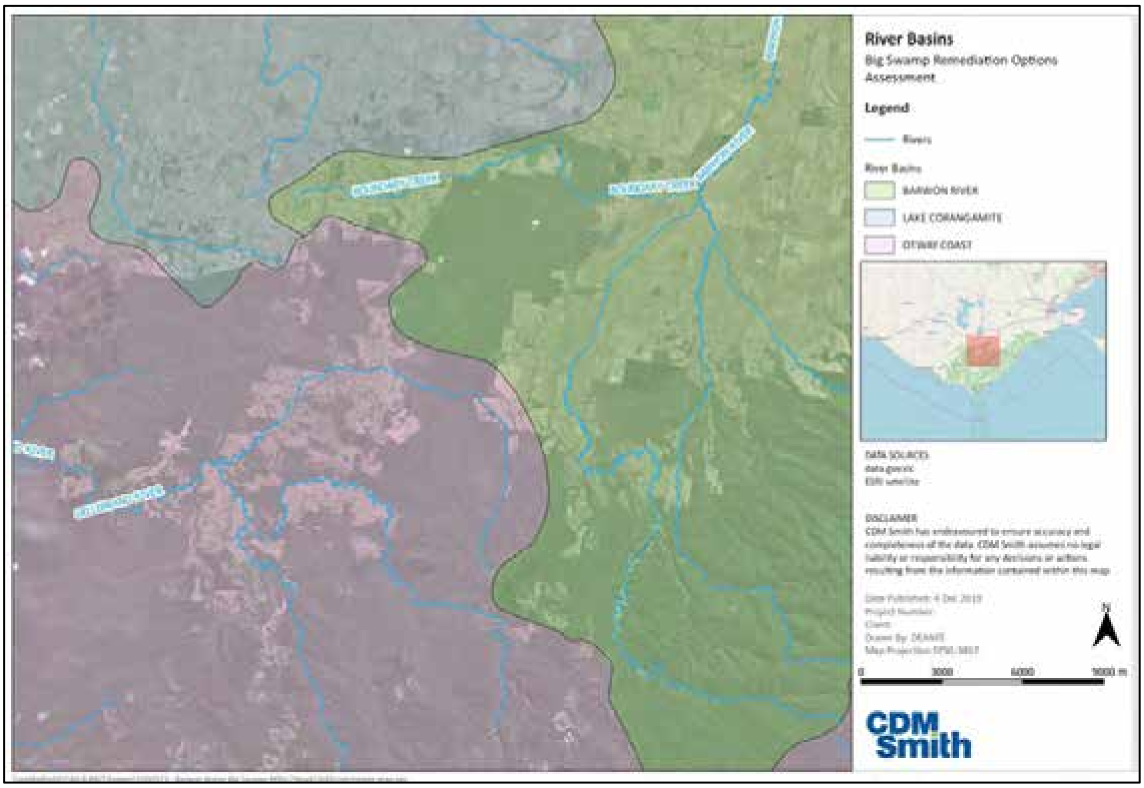

Figure 3-1 Catchment Identification

The Barwon River and its tributaries rise in the Otway Ranges and flow north through Forrest and Birregurra, draining the southern part of the catchment. The Barwon River East Branch and West Branch join just upstream of the confluence with Boundary Creek. Boundary Creek flows for approximately 18 km in an easterly direction across the Barongarook High and joins the Barwon River around Yeodene.

The Gellibrand River is in the Otways Coast catchment, rises near Upper Gellibrand and flows in a westerly direction toward Gellibrand. It discharges into the ocean at Princetown.

The Barwon Downs borefield is located approximately 30 km south east of Colac and taps into the Lower Tertiary Aquifer (LTA) at depths up to 600 m at the borefield. The LTA covers an area of approximately 500 km^2 below the surface and it outcrops at the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment (near Gellibrand).

3.2 Climate

Climate conditions in the Boundary Creek catchment are summarised in Figure 3-2 (Jacobs, 2018a) and Figure 3-3 (Jacobs, 2019b)

Figure 3-2 Cumulative deviation from mean annual rainfall at Forest State gauge (BOM gauge 090040)

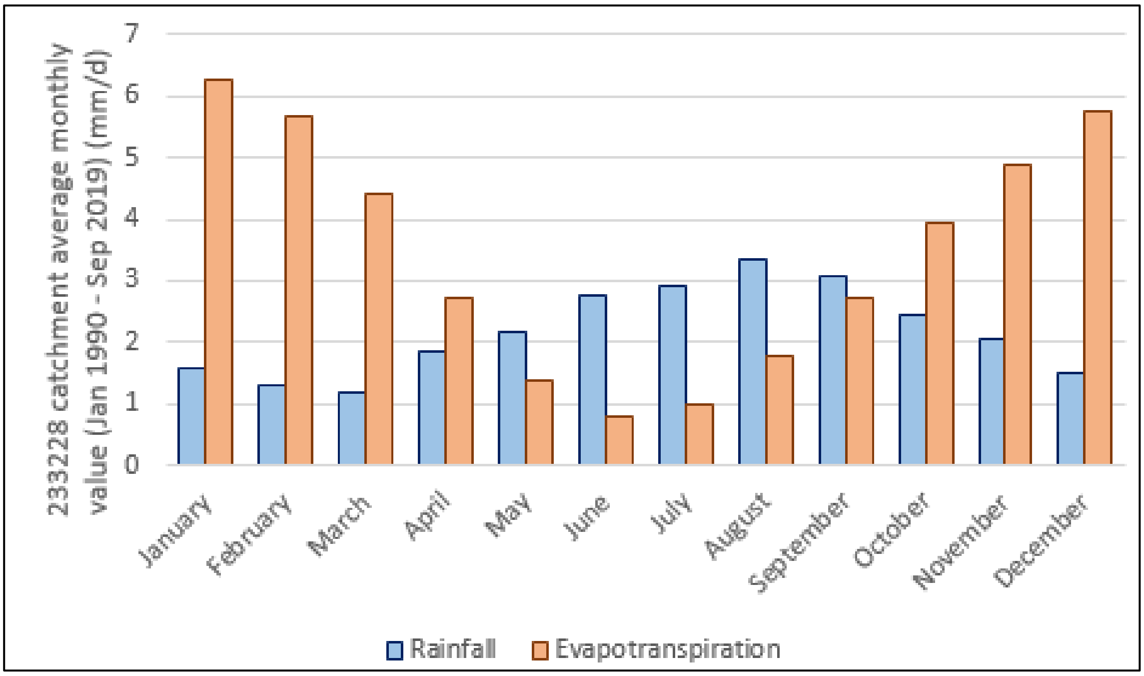

Figure 3-3 Monthly average rainfall and evapotranspiration (mm/d) which falls over the Boundary Creek catchment upstream of the Yeodene township (233229) between 1990 – Sep 2019

Figure 3-2 (presenting rainfall as cumulative departure from the mean) indicates periods of drought (i.e. a declining trend in the graph) between 1900-1955, 1995-2010 (millennium drought) and 2014-2017.

Figure 3-3 (presenting average rainfall and Morton's wet areal potential evapotranspiration for the Boundary Creek Catchment) indicates that rainfall is higher than evapotranspiration between May and September.

Future climate projections for the Barwon River catchment (DELWP, 2016), indicate between 5%-20% reduction in rainfall, between 4%-5% increase of evapotranspiration and between 2%-5% reduction in runoff by 2040 (median projected model outputs, highest greenhouse gas concentration scenario).

Overall, these predictions indicate that future climate conditions or the Barwon River catchment are expected to be hotter and drier, with increased demand for water for public, domestic, commercial and agricultural use.

3.3 Surface Water (Boundary Creek)

3.3.1 Catchment Description

For the purpose of this RCM, Boundary Creek can be divided in three reaches (Jacobs, 2018a and 2018b), as described below (Figure 3-4):

- **Reach 1** – This is the upper reach of the creek, flowing predominantly over outcropping bedrock which comprises impermeable Palaeozoic sandstone, siltstone and mudstone.

  The downstream end of Reach 1 is defined by McDonalds Dam, a large on-stream water storage (160 ML capacity) constructed approximately in 1979.

  Supplementary flows by Barwon Water are released into a small tributary that joins Boundary Creek in Reach 1, upstream of McDonalds Dam.

- **Reach 2** – From the outlet of McDonalds Dam to the downstream end of Big Swamp, flowing predominantly over the outcropping LTA comprising permeable sands of the Mepunga, Dilwyn and Pebble Point formations.

  This reach can be further subdivided in three sub-reaches:

  - Reach 2a, a likely artificial channelised section immediately downstream of McDonalds Dam.
  - Reach 2b, a densely vegetated and marshy area known as the 'damplands' characterised by highly braided flow pathways and waterlogged conditions.
  - Reach 2c, corresponding to Big Swamp, a large peat swamp covering an area of approximately 11 ha (Section 3.4)

- **Reach 3**- Downstream of Yeodene Swamp to the confluence with the Barwon River, flowing over the outcropping Mid-Tertiary Aquitard (MTD) comprising the silty clays of the Gellibrand Marl. This reach has been modified to support agricultural activity.

Figure 3-4 also indicates presence of shallow Quaternary Alluvium sediments that are interpreted to occur locally along the Boundary Creel flow path, overlying the regional formations. Quaternary Alluvium includes the deposits and acid sulfate soils that occur throughout Big Swamp.

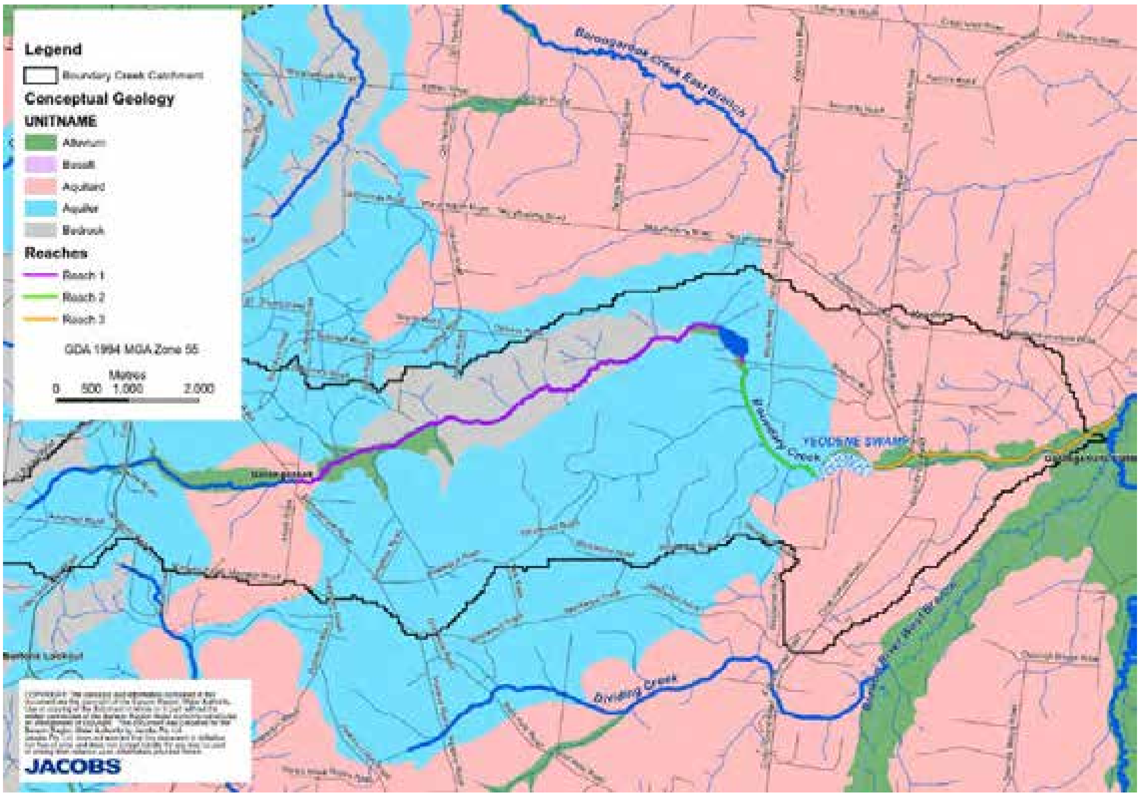

Figure 3-4 Simplified geology of the Boundary Creek catchment (Jacobs, 2018b)

3.3.2 Streamflow

Location of streamflow gauges along Boundary Creek and availability of flow data are summarised in Figure 3-5 and Figure 3-12 (Jacobs, 2019b).

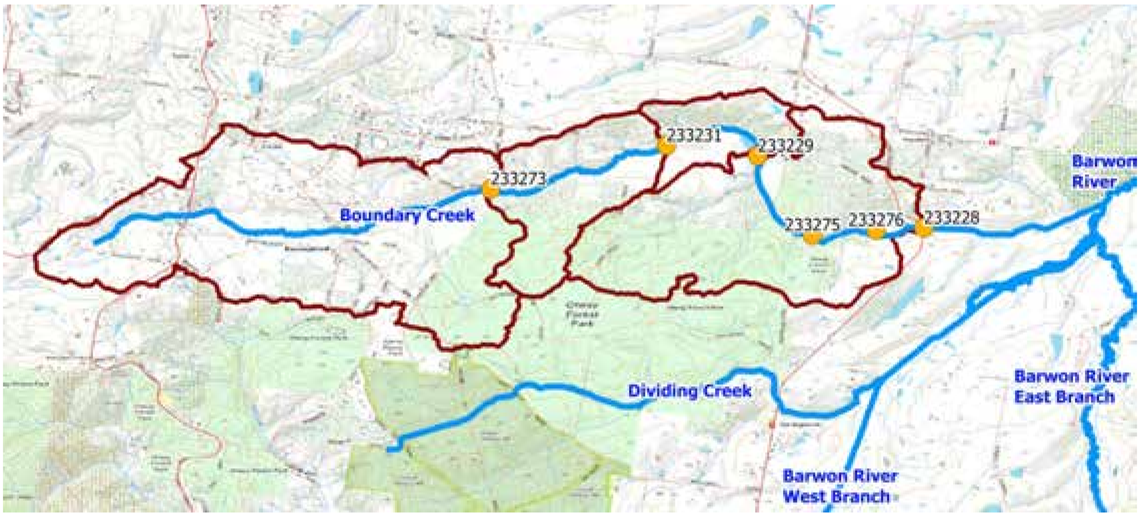

Figure 3-5 Flow gauge locations along Boundary Creek (Jacobs, 2019b). Streamflow gauge ME763 (not in figure) located along Boundary Creek at Yeodene

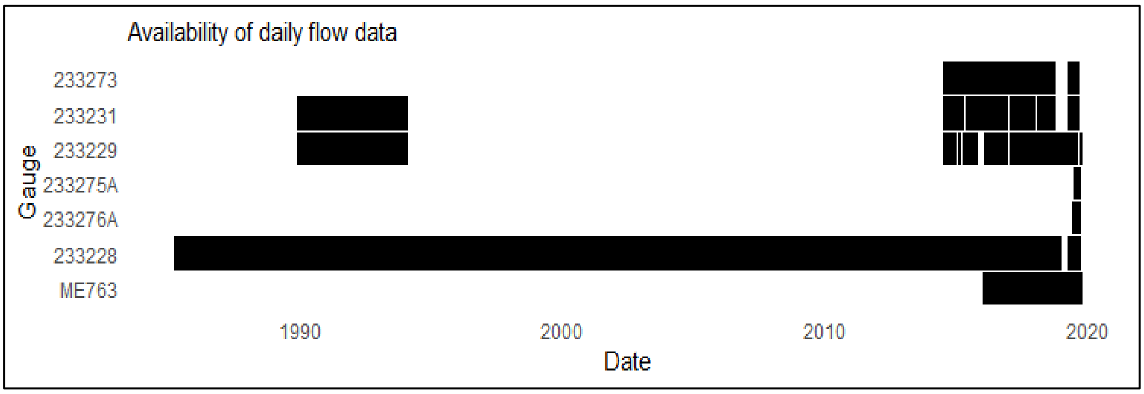

Figure 3-6 Timeline of available streamflow data (Jacobs, 2019b)

Analysis of historical average monthly flow in Boundary Creek at the Yeodene streamflow gauge (233228) are provided in Figure 3-7. The data indicates that Boundary Creek streamflow is lower in summer than in winter because of annual rainfall variability. In addition to seasonal variability, the figure indicates a decline in streamflow from approximately 1999, characterised by lower winter flows and periods of no flow during summer.

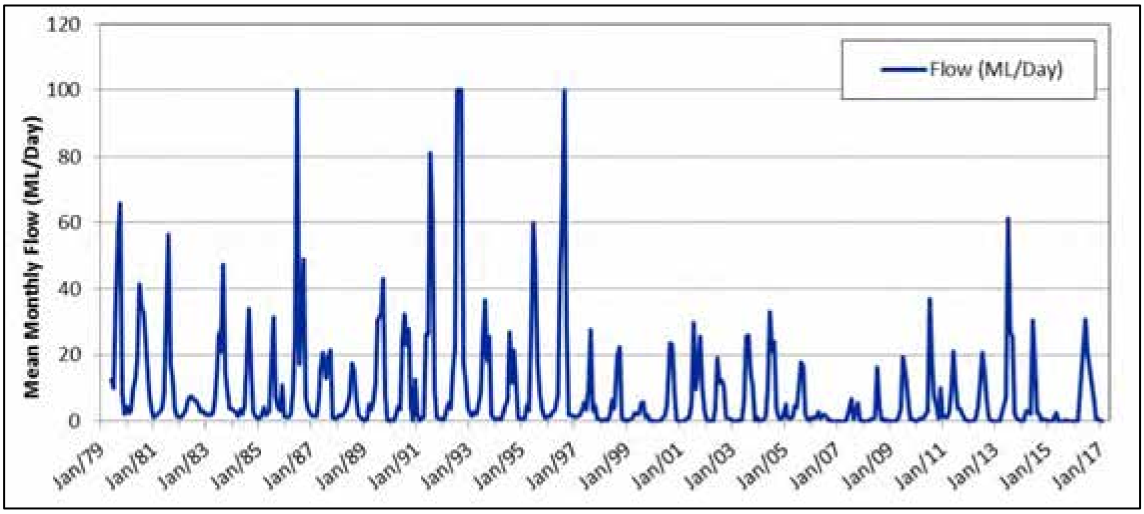

Figure 3-7 Average monthly flow in Boundary Creek at Yeodene (Jacobs, 2018b)

The average daily flow at the Yeodene flow gauge over the monitoring period (March 1985 to October 2019) is 7.5 ML/day, with pre 1999 average monthly flow at 10.3 ML/day and post 1999 average monthly flow at 5.6 ML/day (WMIS, 2019). The average monthly flow during the low flow period (defined by Jacobs as December to March) for the entire flow record is 1.1 ML/day. Prior to 1999 this low flow average monthly flow was 1.7 ML/day, dropping to 0.6 ML/day for the post 1999 period.

The cause of reduced streamflow in Boundary Creek at Yeodene have been investigated by Jacobs, and identified as the combination of the following main contributing factors (Jacobs, 2018b):

- Groundwater extraction from the Barwon Down borefield and associated decline in groundwater levels in the LTA.
- Periods of droughts.
- The construction of McDonalds Dam.
- Failure to fully release the 2 ML/d supplementary flows supplied by Barwon Water downstream of McDonalds Dam.

- Drainage from agricultural channels historically realised in the area are, more recently, the fire trenches constructed by the Country Fire Authority (CFA) to control t peat fires in Big Swamp.

3.3.3 Loss Analysis

Streamflow data from gauge 233229 (Boundary Creek downstream of McDonalds Dam) and gauge 233228 (Boundary Creek at Yeodene) were analysed to estimate Boundary Creek gain/losses between these two streamflow gauges (Jacobs, 2019b). The results of this analysis (performed using recorded streamflow data in the period 2015-2018 and inputs from the Jacobs surface water model to infill missing streamflow data where required) are summarised in Figure 3-8.

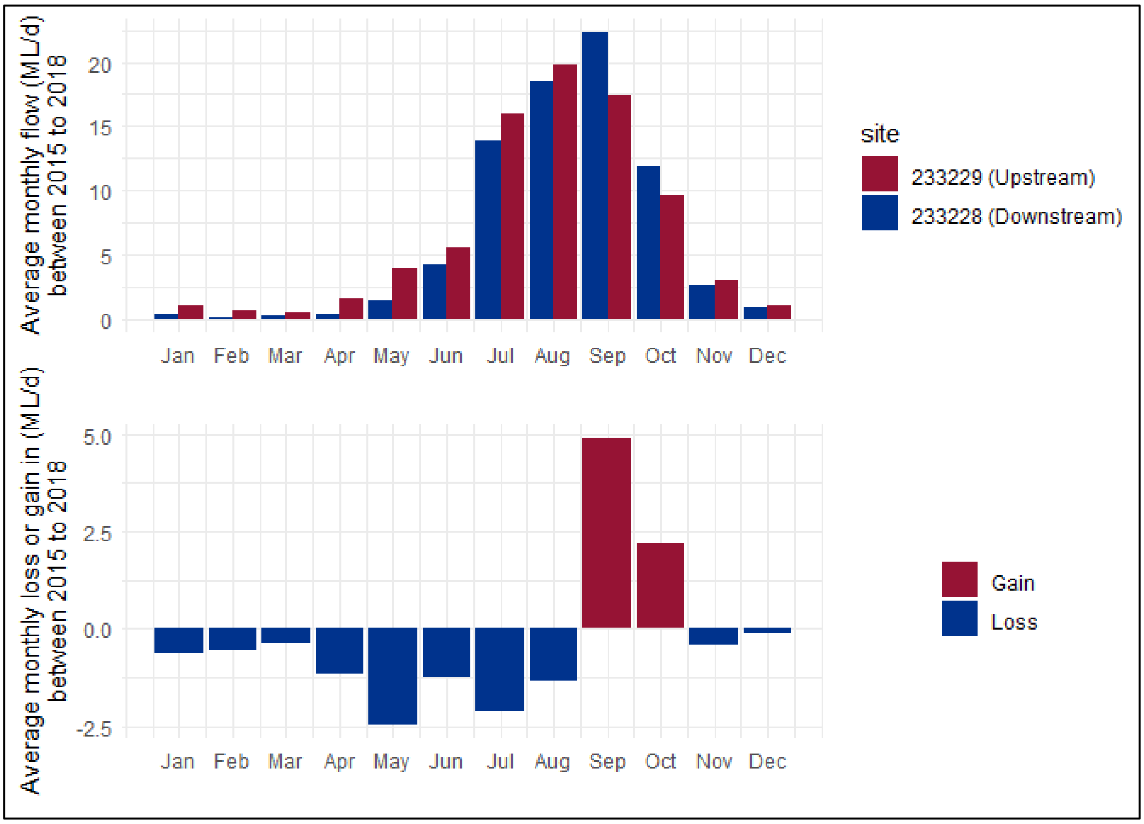

Figure 3-8 Boundary Creek average monthly gains/losses (Jacobs, 2019b)

The results indicate that Boundary Creek is gaining in September and October and losing the remainder of the years. The losses, that are assumed to represent infiltration to groundwater, are in the range of 0.5 ML/d to 2.5 ML/d.

3.3.4 Surface Water Quality

The following sources of surface water quality data have informed this assessment:

- Electrical conductivity and pH data monitored at the Yeodene stream gauge at monthly intervals since 1985 (Jacobs, 2018b).
- Surface water sampling collected in May and August 2017 at selected sites along Boundary Creek (Jacobs, 2018b).
- Results of Austral surface water sampling as part of the investigation into sediments and macroinvertebrates in the Upper Barwon River (Austral, 2019).

3.3.4.1 Yeodene gauge data (Jacobs, 2018b)

Jacobs analysed the water quality data recorded at the Yeodene gauge, specifically pH versus stream flow. The overview of this data indicates:

- Prior to 1990 the median pH was 6.5 although readings below pH 5 were recorded when flows were reduced in some summers and autumns.
- Between 1990 and 1992 the median pH was 5.1 with readings below 4 recorded in the reduced flow periods of summer and autumn.
- Between 1992 and 1999 the median pH was 5.9, with only two readings below 4.
- From 1999 onwards, the median pH dropped to 3.8, with rare readings above 5.

Cease to flow days in the creek were compared to the measured pH (Figure 3-9), which suggests a correlation between cease to flow events and a progressive lowering in pH values. Cease to flow events have occurred annually since 1999 and over this time pH has fallen and not recovered.

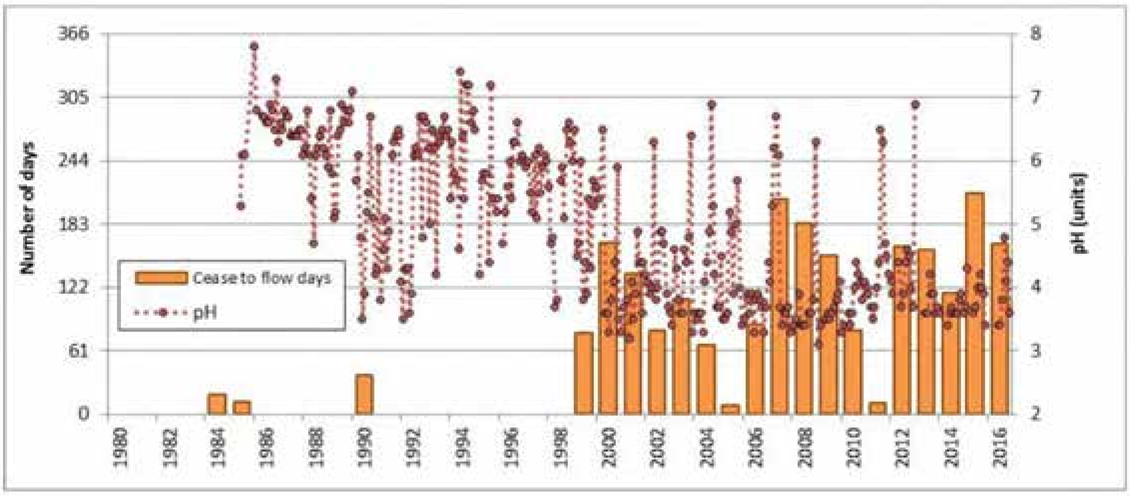

Figure 3-9 Number of cease to flow days in Boundary Creek at Yeodene gauge vs monthly pH readings at Yeodene gauge (Jacobs, 2018b)

3.3.4.2 Surface water sampling (Jacobs, 2018b)

Two surface water sampling events in May and August 2017 (Jacobs, 2018b) were conducted at locations shown in Figure 3-10 and summarised below:

- The most significant changes in surface water quality along Boundary Creek occur through Big Swamp.
- The changes in water quality include reduced pH, increased salinity and increased concentration of dissolved metals and sulfate, consistent with the effects of acid sulfate soil impact.
- The higher winter flows of more than 15 ML/day did not significantly impact the concentrations of dissolved metals or acidity levels.

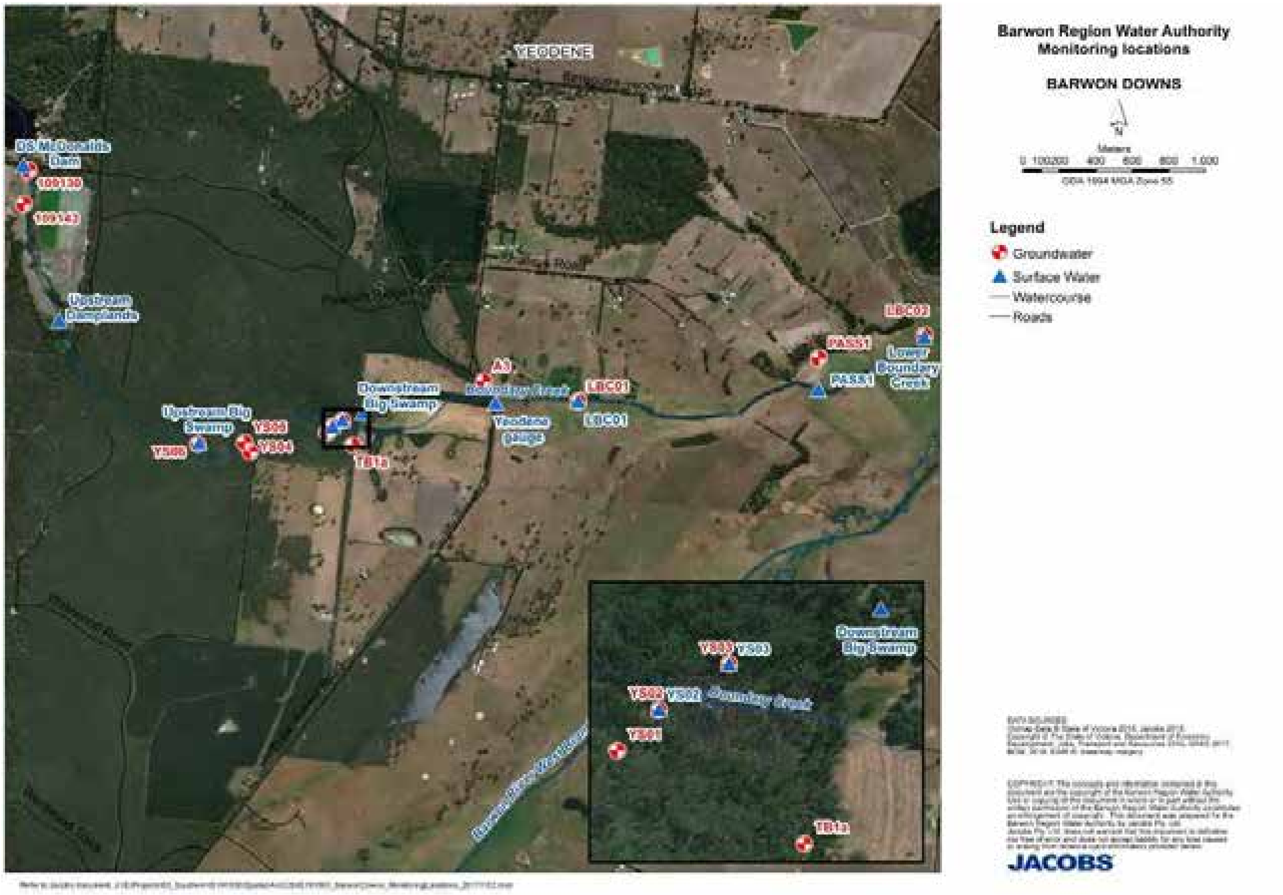

Figure 3-10 Location of groundwater and surface water monitoring locations (Jacobs, 2018b)

3.3.4.3 Austral Study (Austral, 2019)

Austral undertook an investigation of sediments, water quality and macroinvertebrates in the Upper Barwon River at selected survey sites in October 2019. The sampling locations are shown in Figure 3-11.

The results of the in-situ water quality and metals laboratory analyses for water indicate the following:

- At the time of sampling, pH was low in the East and West branches of the Barwon River, although by Site 4 (just upstream of the Boundary Creek confluence) the pH was neutral (7.4).
- Boundary Creek downstream of the swamp has a low pH (3.94 at the Colac-Forest Road crossing) and remains low pH to the Barwon River confluence (5.55 just upstream of the confluence with the Barwon River).
- The drop in pH in the Barwon River between upstream of the Boundary Creek confluence and downstream of the confluence is just 0.6 pH units (7.4 to 7.34), and by Site 7 (3 km downstream of the confluence) pH is 7.9. Downstream of Site 7 the pH remains constant between 7.8 and 8.0.
- These samples represent springtime conditions. Sampling in the autumn is recommended to provide a more thorough understanding of seasonable water quality and stream health.

Sediment samples were also taken (0 to 20 cm and 20 to 40 cm) and analysed for metal concentrations. The results of the sediment sampling indicate the following:

- There is an impact in the Barwon River from the Boundary Creek confluence to Site 8, with no impact discernible by Site 9, approximately 20 km downstream of the Boundary Creek confluence.

- Historical (both shallow and deep samples) metal concentrations in Boundary Creek (Site 5) show high concentrations of aluminium, arsenic and chromium, suggesting that the concentration of these metals has not varied significantly due to changes at the swamp.
- For iron, lead and zinc in Boundary Creek (Site 5), the concentrations are higher in the shallow sediments than the deep, suggesting that the concentrations of these metals have increased more recently due to the drying and rewetting of the swamp.
- There is a spike in metals such as arsenic at Site 10, suggesting other catchment activities may be impacting the Barwon River.

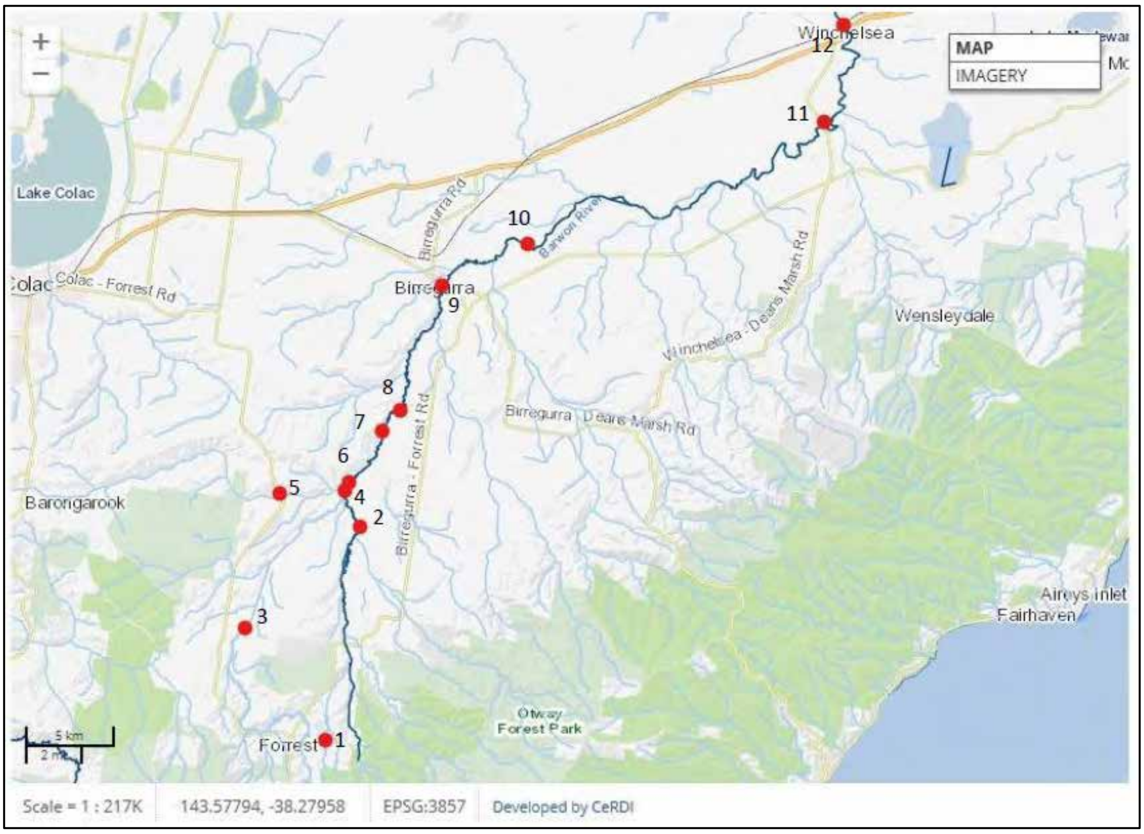

Figure 3-11 Barwon River and Boundary Creek sampling locations (Austral, 2019)

3.4 Big Swamp

Big Swamp is an approximately 11 ha peat swamp of quaternary alluvial sediments presenting a dominance of clays and silts with sparse intervals of sand. A conceptual model showing Boundary Creek Reaches 2, Big Swamp and Boundary Creek Reach 3 (Jacobs, 2018a) is presented in Figure 3-12.

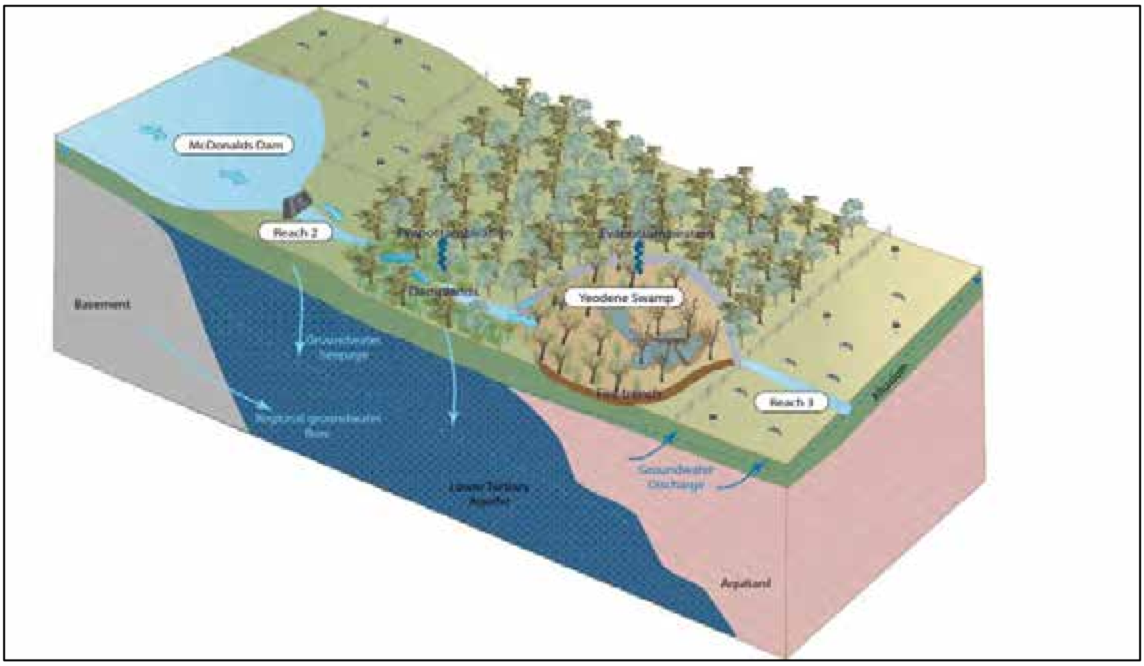

Figure 3-12 Boundary Creek and Big Swamp Conceptual Model (Jacobs, 2018a)

As indicated in Figure 3-12, the Swamp is located at the transition between the LTA aquifer and the MTD aquitard, however this transition has not been delineated. Quaternary alluvial sediments locally overly the LTA and the MTD and act as a localised aquifer that is inferred to be likely disconnected from the LTA (Jacobs, 2019a).

Two major fire events occurred at Big Swamp, reportedly in 1998 and 2010, causing major loss of vegetation across the swamp and ignition and ongoing smouldering of the peat. In 2010, the CFA excavated a fire trench (approximately 2 m wide, 2 m deep and 1 km long) along the southern and eastern boundaries of the swamp to contain the peat fire (Figure 3-13). The underground fire is also interpreted to have caused removal of organic content within the swamp and loss of soil structure, with signs of settlement evident across the area.

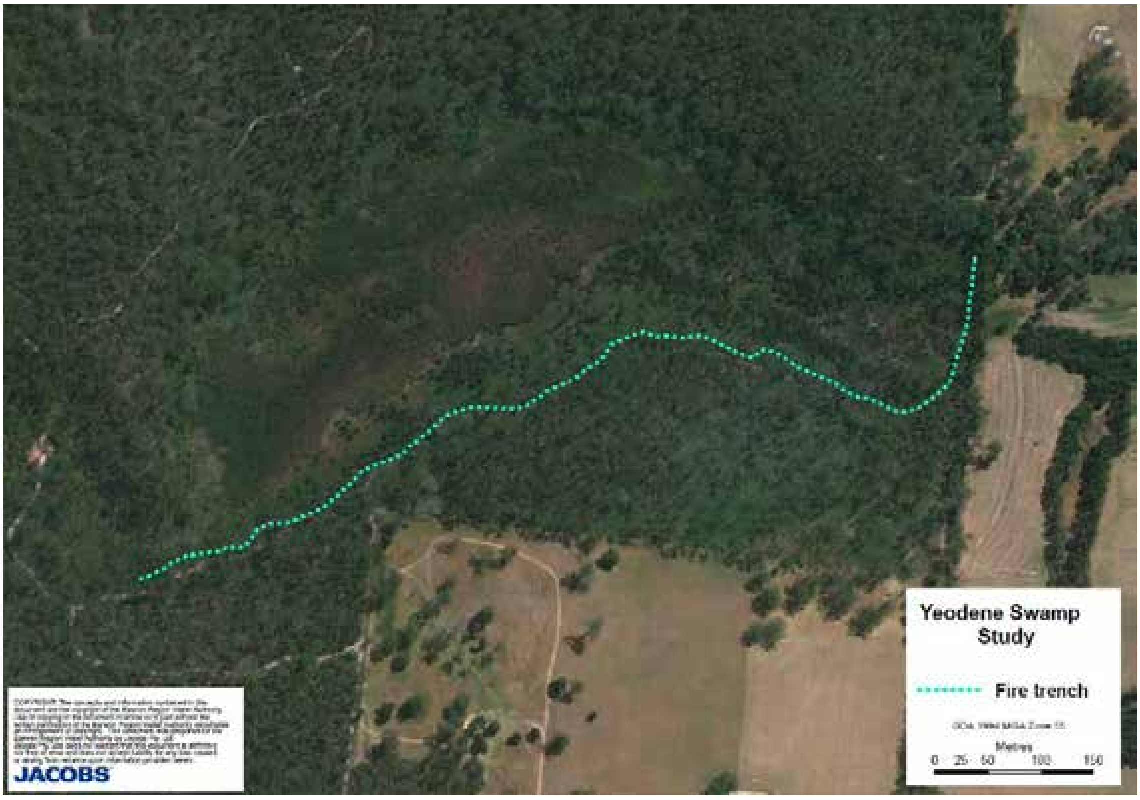

Figure 3-13 Approximate Extent of Fire Trench (Jacobs, 2018b)

Surface flows through Big Swamp appears to primarily develop through a defined channel along the northern boundary and, depending of flow rates, a series of channels mostly localised the central portion of the swamp (Figure 3-14). These channels seem to converge towards the northern channel towards the eastern end of the swamp.

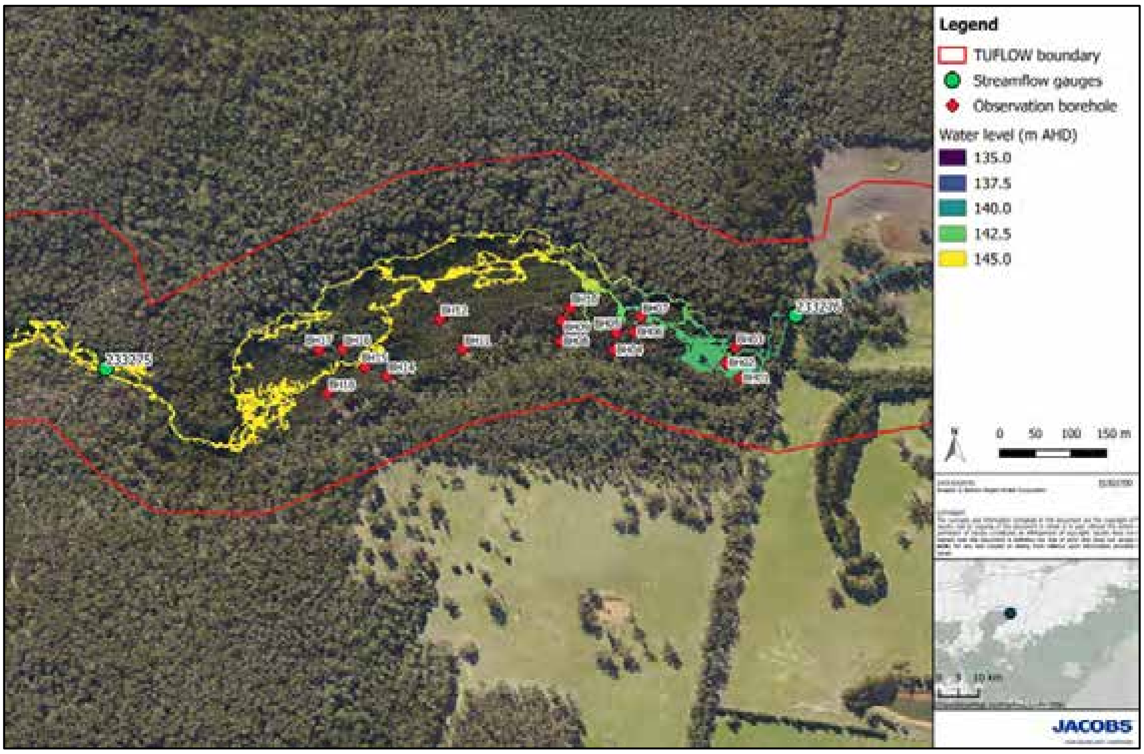

Figure 3-14 Modelled surface water flow paths (5 ML/d steady state flow released upstream of McDonalds Dam) (Jacobs, 2019b)

According to Eco Logical (2019), the current channels have been scoured and deepened by high rates of erosion in the swamp following the fires. Prior to the fire and before the current dry conditions, Eco Logical infers that surface water flow across the eastern and central sections would have occurred through a series of finer, more braided channels compared to the limited number of channels presently observed.

Because of high concentrations of iron sulphide minerals (predominantly pyrite, FeS_2) and limited buffering capacity, the alluvial sediments in Big Swamp are also described as ASS. Recent soil investigations by Jacobs (2019a) comprised collection of 181 soil samples from 18 boreholes installed across Big Swamp (Figure 3-15).

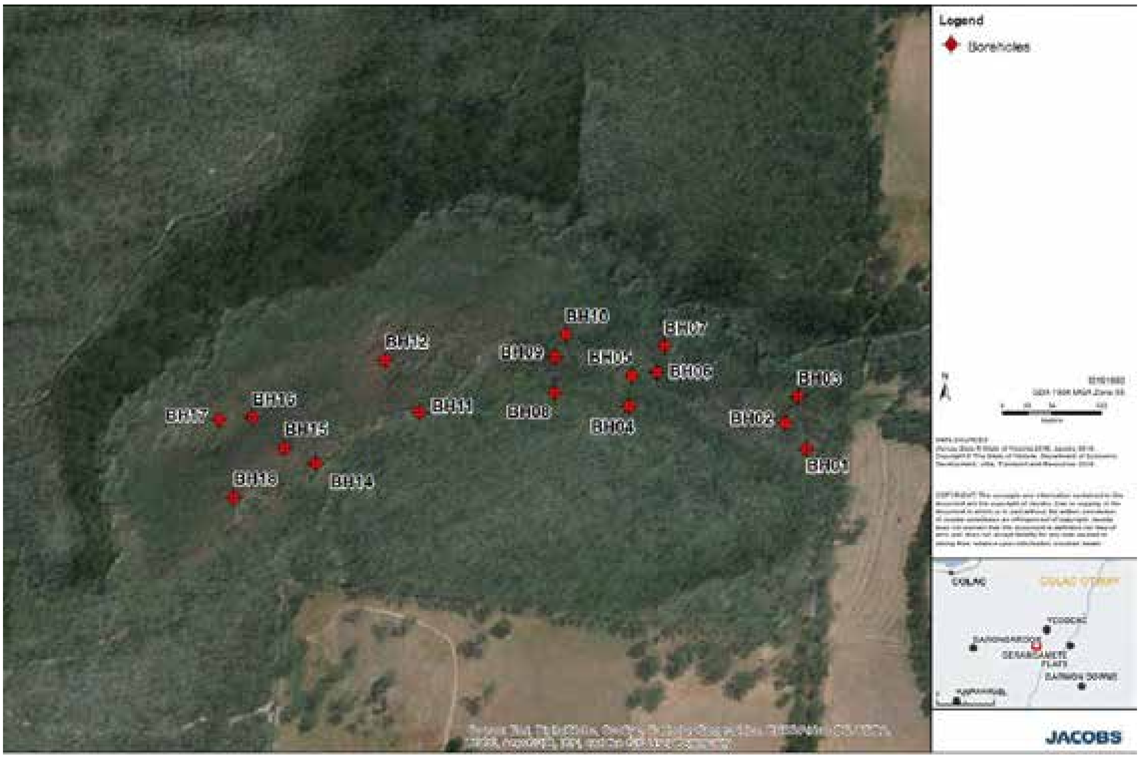

Figure 3-15 Borehole Locations (Jacobs, 2019a)

Results of static geochemical testing within each soil core indicate significant concentration of existing and potential acidity at all borehole locations, from near surface to the maximum investigations depths of 6 m below ground level (bgl). It has been interpreted (GHD, 2019) that dryer conditions and lowering of groundwater levels across Big Swamp have caused oxidation of ASS with consequent reduction of pH and increase of sulfate and metal concentrations.

These findings are summarised in the following figures:

- Figure 3-16 (Jacobs, 2019a), showing trends in potential and existing acidity with depth from 0.5 m soil aggregate samples.
- Figure 3-17 (GHD, 2019), showing interpreted net acidity distribution between borehole locations.

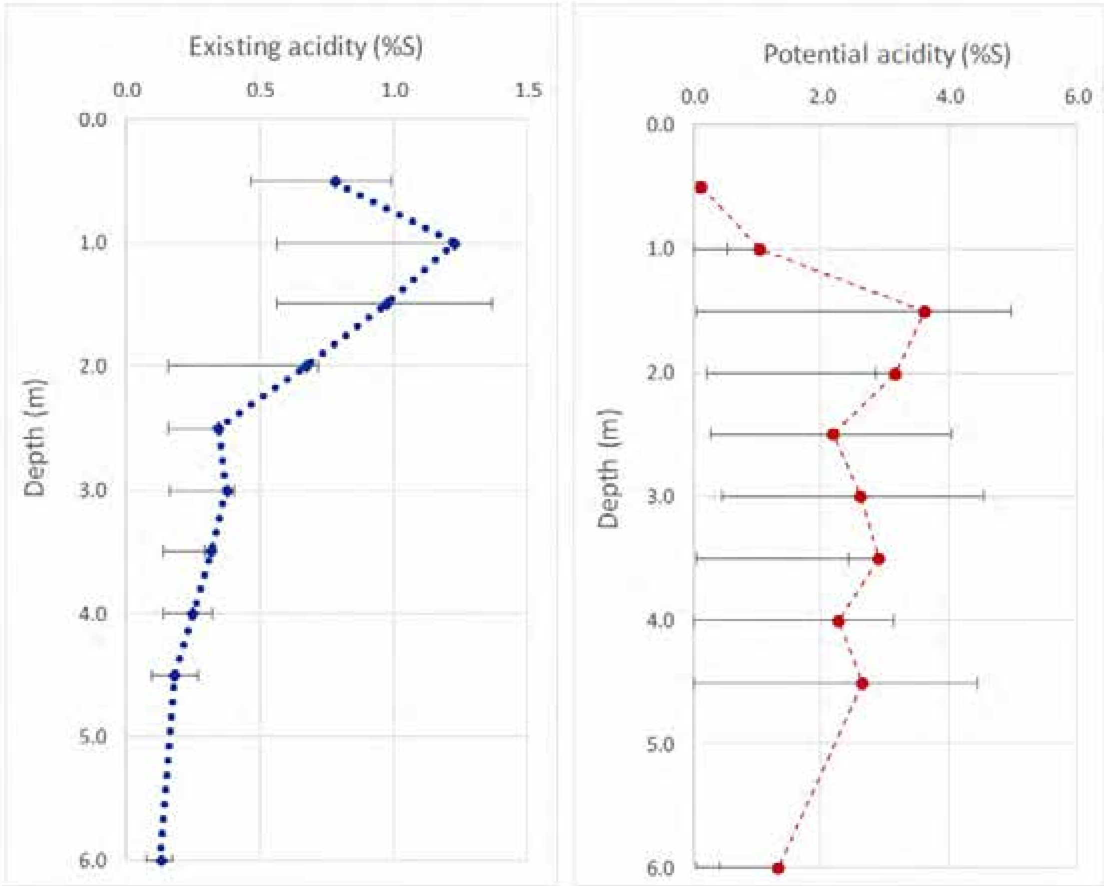

Figure 3-16 Average, 25th and 75th percentile (show as error bars) of existing and potential acidity with depth (aggregate from 0.5 m intervals) (Jacobs, 2019a)

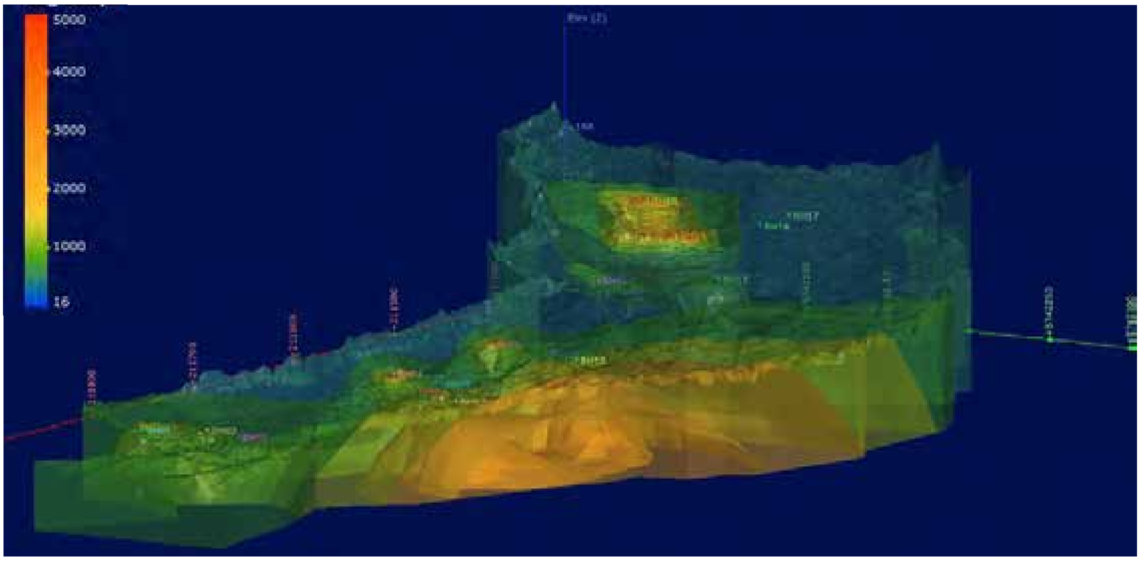

Figure 3-17 Net Acidity 3D model (GHD, 2019)

3.5 Groundwater

3.5.1 Groundwater levels and flow direction

Groundwater in the quaternary alluvium aquifer beneath Big Swamp is monitored by a network of 16 groundwater monitoring wells installed at locations depicted in Figure 3-15 (no monitoring well is installed at location BH13).

Data from a June 2019 gauging round indicate depth of between 1.4 m bgl and -0.1 m bgl (i.e. artesian conditions) across the groundwater monitoring network.

Interpreted groundwater elevations depicted in Figure 3-18 (Jacobs, 2019a) indicate a steep hydraulic gradient towards the swamp from the north and a gentler hydraulic gradient towards the swamp from the south. The hydraulic gradient through the swamp trends to the east in a broadly similar direction to the flow path of Boundary Creek.

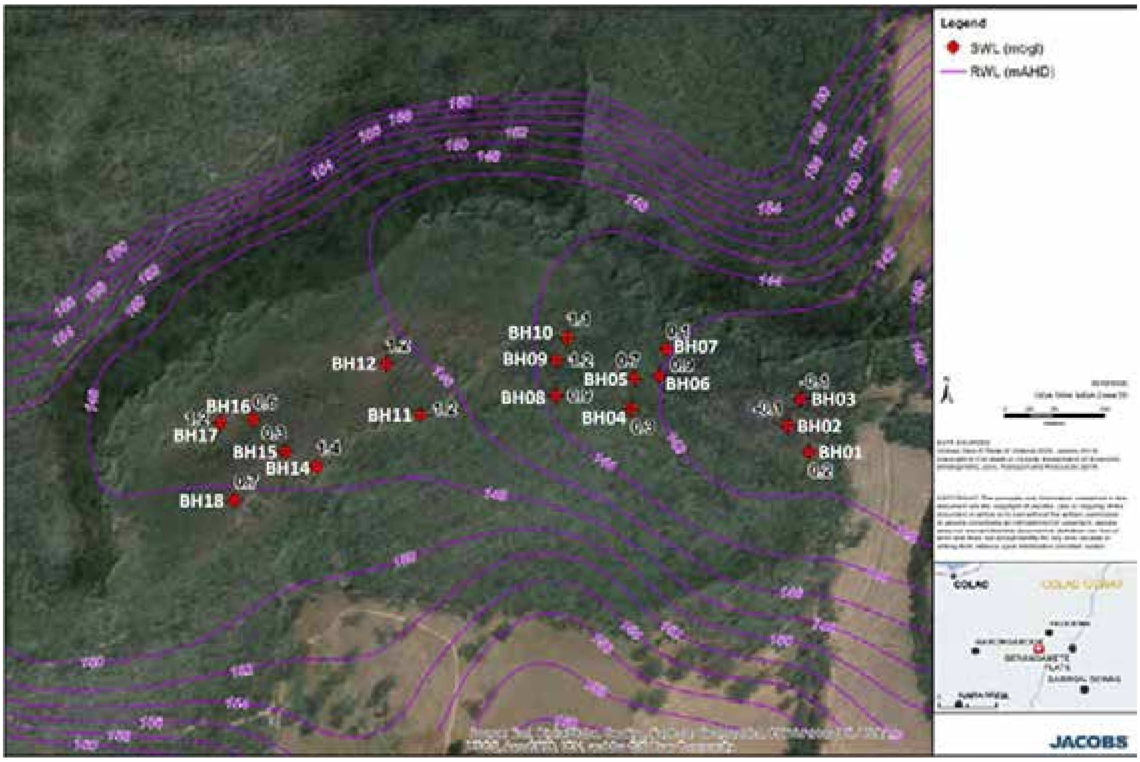

Figure 3-18 Depth to water table and groundwater elevation (Jacobs, 2019a)

Groundwater modelling outputs (Jacobs, 2019b) suggest a more pronounced seasonal changes in groundwater elevation across the western part of the swamp (i.e. in the range of 2.5 m for boreholes BH14 to BH18) compared to the eastern end of the swamp (i.e. less than 0.5 m for boreholes BH01 to BH03). The implication of this interpretation is that there is a higher potential to desaturate and activate ASS within the alluvium aquifer within the western end of Big Swamp. Based on interpretation of actual acidity distribution along three transect across Big Swamp (Figure 3-19), there appears to be a correlation between areas of higher actual acidity (lower pH) and areas where there modelled changes of groundwater levels are more pronounced.

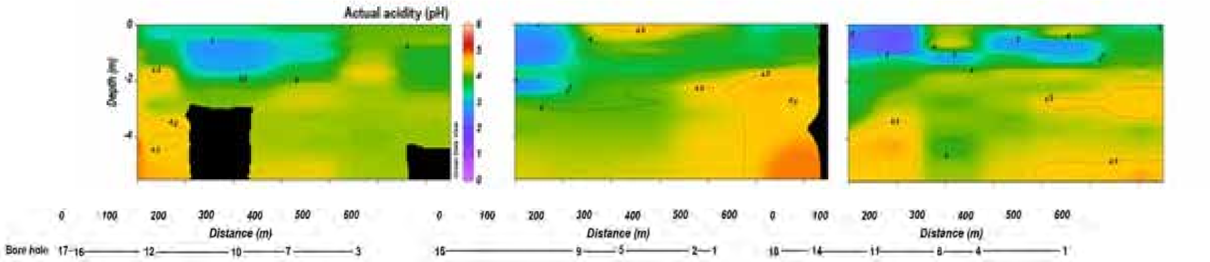

Figure 3-19 Distribution of actual acidity along three transects across Big Swamp (Monash University, 2019)

3.5.2 Groundwater quality

Groundwater quality is described in the Yeodene Swamp Study (Jacobs, 2018b) and summarised in the following points:

- Reach 1 (basement) – electrical conductivity between 4,000 and 6,000 µS/cm and slightly acidic (between 5.5 and 7.0 pH units). The slight acidity observed in this unit is not interpreted to be related to acidic event in the Big Swamp as groundwater is often slightly acidic.
- Reach 2 (lower tertiary aquifer) – typically fresh with electrical conductivity between 220 and 890 µS/cm and slightly acidic (between 5.5 and 7.0 pH units) and dissolved major ions are dominated by Cl and Na, consistent with rainfall recharge.
- Reach 3 – electrical conductivity between 1,300 and 2,500 µS/cm and ranging between slightly acidic and slightly basic (between 5.5 and 7.6 pH).

Groundwater quality in the shallow alluvial aquifer was monitored in May and August 2017 (Jacobs, 2018b) and can be summarised as follows:

- The pH indicates that the shallow alluvial aquifer has been affected by acid sulfate soils, with groundwater at YS01, YS03 and YS05 the most affected (ranging between 1.58 and 2.72 in May 2017 and 2.59 and 3.80 in August 2017), followed by locations A3 and TB1a downstream of Big Swamp (Figure 3-10). The groundwater upstream and downstream of the swamp does not appear to be affected by acid sulfate soils, with the pH consistent with regional groundwater pH.
- The impact of acid sulfate soils is also evident in the concentration of sulfate and chloride in the groundwater samples, with a higher proportion of sulfate relative to chloride in the groundwater with lower pH values, as is typical of groundwater affected by acid sulfate soils.
- The dissolved metal analysis also shows elevated dissolved metal concentrations (aluminium and zinc) coincident with lower pH groundwater related to the acidic leaching of metals from soils.

3.6 Groundwater/Surface Water Interactions

The nature of groundwater and surface water interaction in the Boundary Creek catchment is complex and changes spatially and temporally. The Yeodene Swamp Study (Jacobs, 2018b) summarises these interactions as follows:

- In Reach 1 of Boundary Creek the creek receives groundwater discharge from the basement, however, due to the low permeability of the basement rock, groundwater inflow volumes in this reach are small.
- In Reach 2 the groundwater elevations in the Lower Tertiary Aquifer have fallen to below the base of the creek and this reach of the creek has transitioned from a gaining stream to a losing stream (creek water is now lost to the aquifer via seepage).

- In Reach 3, where Boundary Creek intersects the aquitard, groundwater levels are above the streambed, indicating that Boundary Creek is a gaining stream through this reach. The low permeability of the aquitard limits the volumes of groundwater discharge in this reach.

Measurements of groundwater and surface water levels collected in May and August 2017 indicate that the Damplands and Yeodene Swamp were losing during May 2017 and that the lower reaches of Boundary creek were gaining. In August 2017 the Damplands and the upper parts of the swamp were losing but in some of the lower parts of the swamp the groundwater levels were equal to surface water levels, indicating a neutral hydraulic gradient and a zero net water exchange (e.g. at YS02). The lower parts of Boundary Creek were gaining in August 2017.

The groundwater-surface water modelling (Jacobs, 2019b) includes an analysis of surface water losses (described in more detail in Section 3.3.3). The results indicate that between McDonalds Dam and the Yeodene gauge, Boundary Creek is gaining in September and October, and losing the remainder of the months. The losses, that are assumed to represent infiltration to groundwater, are in the range of 0.5 ML/d to 2.5 ML/d.

3.7 Geochemical Characterisation Acidity Generation Processes

This section summarises key concepts from the conceptual geochemical model (GHD, 2019).

3.7.1 Terminology

The following generalised terms are generally used to describe the complex acidity associated with ASS:

- **Actual Acidity**: the soluble and exchangeable acidity already present in the soil and readily available for reaction, including pore waters containing metal species capable of hydrolysis (e.g. Fe^{2+}, Fe^{3+} or Al^{3+} ions). It is this acidity that is typically be mobilised and discharged following a rainfall event.
- **Retained Acidity**: the less available acidity retained from sparingly soluble and insoluble sulfur compounds (other than sulfides) that slowly produce acid (e.g. jarosite and natrojarosite).
- **Existing Acidity**: collective term that includes actual and retained acidity.
- **Potential Acidity**: The latent acidity in ASS that will be released if the sulfide minerals they contain (i.e. pyrite) are fully oxidised.
- **Net Acidity**: The result obtained when the acid neutralising capacity is subtracted from the sum of existing and potential acidity.

3.7.2 Acidity Source Formation

Big Swamp can be described as an inland acid sulfate soil (ASS) system where oxidisable sulfide mineral (mostly pyrite, FeS_2) formed through reduction of available iron and sulfate under reducing conditions promoted by decomposition of organic matter.

In addition, generation of monosulfidic black oozes (MBOs), the precursors to pyrite, can also form. MBOs are characterised by a gel-like consistence, ultra-fine grain size and high reactivity (with respect to oxidation). MBOs can form as thick accumulations (i.e. >1 m thickness) in drains, waterways and other waterlogged setting. If mobilised or resuspended during runoff events (i.e. following high rainfalls), they can oxidise readily once exposed to oxygen and can cause severe acidification and/or deoxygenation of receiving surface water environments.

3.7.3 Acidity Generation Processes

ASS sulfidic minerals (of which the most prevalent is pyrite, FeS_2) are stable under waterlogged, anaerobic conditions, where the water quality is consistent with low inputs of any oxidised components such as iron or nitrate.

Sulfidic soils are termed potential acid sulfate soils (PASS), as they hold the potential to generate acidity from the sulphides they contain. PASS will tend to have a pH ≥4 as this is the pH above which active bacterial sulfate reduction, the process generating the sulfides, can occur.

However, disturbances of ASS (i.e. drought, excavation, dewatering or surcharging activities) causing exposure to air (oxygen) can lead to of the release of this potential acidity to generate acidic conditions (these soils are defined as actual acid sulfate soils (AASS), tend to have a pH ≤4).

Simplified geochemical reactions relevant to the processes involved in the release of acidity from soils include:

- $FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} 2SO_4^{2-} + 2H^+$ (1)

  (Conversion of pyrite to ferrous iron, sulfate and acid.)

- $Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2\ H_2O$ (2)

  (Oxidation of ferrous iron to ferric iron, consuming acid.)

- $Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3\downarrow + 3H^+$ (3)

  (Precipitation of ferric hydroxide and acid generation, at pH>4.)

- $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO4^{2-} + 16H^+$ (4)

  (Microbially mediated oxidation of pyrite by ferric iron, and production of soluble ferrous iron and acid, at pH<4.)

The soluble ferrous iron produced by reactions (1) or (4) can be transported at significant distances downstream of the ASS source, where it can be oxidised to form insoluble iron oxy-hydroxides consuming oxygen and producing acid:

- $Fe^{2+} + 1/4O_2 + 3/2H_2O \rightarrow FeO.OH\downarrow + 2H^+$ (5)

  (Oxidation of ferrous iron and precipitation of goethite).

Other precipitates associated with iron oxidation include jarosite, natrojarosite and schwertmannite. Jarosite is a yellow mineral that is formed under strongly oxidising and highly acidic conditions (a pH of less than 3.7 units is required).

These minerals slowly decompose (usually by hydrolysis) leading to formation of iron precipitates, sulfate and acid. For example, in the case of jarosite:

- $KFe_3(SO4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3\downarrow + 2SO4^{2-} + 3H^+ + K^+$ (6)

Similar reactions occur during oxidation of MBOs (FeS):

- $FeS + 2O_2 \rightarrow Fe^{2+} + SO_4^{2-}$ (7)

  (MBO oxidation consuming oxygen and releasing sulfate and acidity as ferrous iron; ferrous iron has then the potential to oxidise to ferric iron (reaction (2)) and hydrolyse (reaction (3)), generating acid)

The various acid sources and acidification reactions described above are summarised in Figure 3-20 (GHD, 2019), where a distinction is also made between primary and secondary acidification processes.

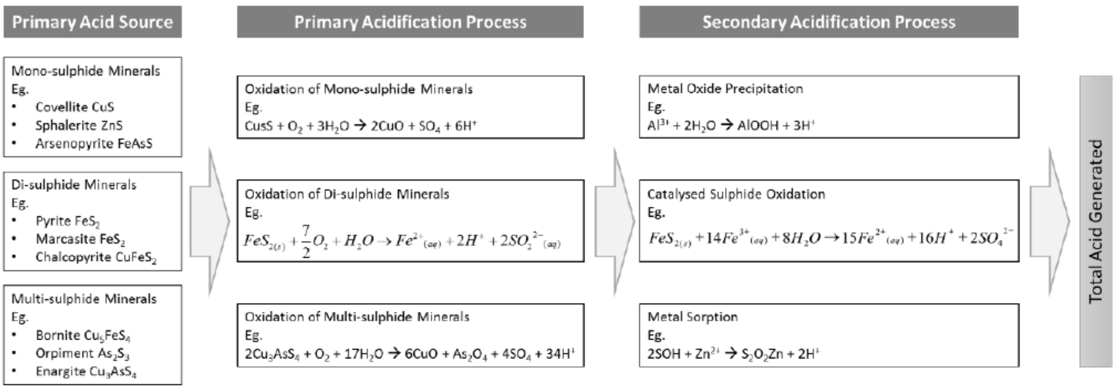

Figure 3-20 Potential acid sources and primary and secondary acidification processes (GHD, 2019)

It is important to mention that cations in aqueous solution behave as acids (Lewis acids), and thus for any acidity budget estimates, consideration should be given to other metals other than Fe.

A summary on the potential occurrence of acid generation processes at Big Swamp and Boundary Creek, based on a review of available surface water and groundwater quality data, is provided below (GHD, 2019):

- The primary acidification process in Big Swamp is oxidation of iron sulfide minerals, with pyrite being the main acid source mineral.
- Secondary acidification processes (i.e. pyrite oxidation by ferric iron and hydrolysis of jarosite) are also considered to have the potential to be periodically occurring in Big Swamp, however the data are considered insufficient by GHD to confirm these trends.
- There is limited evidence to suggest that any primary acid source minerals are present in Reach 3 of Boundary Creek.
- Elevated concentration of ferrous and ferric iron in Reach 3 of Boundary Creek indicates an export of acidity from Big Swamp and the potential for secondary acidification processes though oxidation of ferrous iron to ferric iron and then precipitation of ferric hydroxides.

3.7.4 Effects of ASS Oxidation

The effects of ASS oxidation include acidification of soil, surface water and groundwater; mobilisation of metals (i.e. aluminium, arsenic and iron); formation of precipitates in connected water systems which can affect both the flora and fauna through coating the leaves and gills causing suffocation and corrosion of steel and concrete structures.

3.7.5 Acidity Neutralisation Processes

The acid neutralising capacity (ANC) is a measure of the soil's intrinsic ability to buffer acidity and resist lowering of pH. ANC can be provided by dissolution of calcium and/or magnesium carbonates (typically sourced from invertebrate shells), cation exchange reactions, and by reaction with the organic and clay fractions.

Addition of finely crushed limestone ($CaCO_3$) is commonly used as a management strategy for mitigation of ASS impacts, according to the following reactions:

- $CaCO_{3(s)} + H^+{}_{(aq)} \rightarrow Ca^{2+}{}_{(aq)} + HCO^{3-}{}_{(aq)}$ (8)
- $HCO^{3-}{}_{(aq)} + H^+{}_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)}$ (9)

(Dissolution of calcite with neutralisation of acid and production of alkalinity.)

Other neutralising agents can also be used, based on project specific considerations.

Another approach to manage ASS issues is to permanently flood acidified ASS sediments, which can stop further pyrite oxidation and promote iron and sulfate reducing conditions:

- $4Fe(OH)_3 + CH_2O + 8H^+ \rightarrow 4Fe^{2+} 11H_2O + CO_2$ (10)

  (iron reduction)

- $2CH_2O + SO_4^{2-} + 4H^+ \rightarrow 2CO_2 + H_2S + 2H_2O$ (11)

  (sulfate reduction)

- $M^{2+} + H_2S + 2HCO^{3-} \rightarrow MS + 2H_2O + 2CO_2$ (12)

  (reaction of a generic reduced metal, M^{2+}, with H_2S to form insoluble metal monosulphide.)

These reactions illustrate that bacteria use organic matter (CH_2O) as electron donor and iron oxide ($Fe(OH)_3$) and sulfate (SO_4^{2-}) as electron acceptors for their metabolism. In this process, they consume acid (H^+) and produce carbon dioxide (CO_2), reduced iron (Fe^{2+}), sulfur (H_2S) and water (H2O).

These two reactions occur sequentially, with iron reduction taking place first and sulfate reduction then taking place once all the iron oxide is consumed. Once sulfate reduction commences, the H_2S produced will react with Fe^{2+} produced from iron reduction to form reduced inorganic sulfur compounds such as iron monosulfide, which then converts to pyrite over time.

The availability of a carbon source is an important consideration in maintaining the stability of the metal sulphides (if formed) so that:

- Reducing condition are maintained
- Alkalinity is provided to buffer acid that may be generated by the sulphide oxidation.

In general, inland ASS soils are characterised by high organic matter content, high sulfide mineral content and low or absence of readily weathered minerals to provide buffering, resulting in significant decreases in pH in response to sulfide mineral oxidation. This general process was described by GHD in response to the review of available data on the Big Swamp sediments, which appear to have limited buffering capacity because of insignificant amounts of soluble carbonate minerals and slow kinetic reactions for the reduction of dissolved sulfate to sulfide and precipitation as of sulfide minerals (GHD, 2019).

3.8 Key Fate and Transport Mechanisms

The key fate and transport mechanisms that are likely to occur at Big Swamp include:

- Accumulation of actual and retained acidity in the soil profile as a result of ASS oxidation (i.e. including exposure to air). Where groundwater is shallow, capillary rise of mobile acidity products through the soil profile could also occur.
- Mobilisation and transport of actual and retained acidity by interaction of surface water or overland flow with shallow oxidised sediments.
- Mobilisation of and transport of actual and retained acidity by groundwater interacting with deeper oxidised sediments, with potential discharge into a surface water body (i.e. Boundary Creek). The significance of acidic discharges from groundwater into a surface water depends on groundwater level elevations compared to surface water elevation, hydraulic conductivity of the aquifer and hydraulic gradients.

3.9 Vegetation

An ecological assessment of Big Swamp was undertaken by Eco Logical covering the wetland and riparian extent of Big Swamp. This assessment identifies the following vegetation communities (Figure 3-21):

- Riparian Fern Scrub (EVC A120) throughout much of the swamp plain in the western and central sections of the swamp.
- Swampy Riparian Woodland (EVC 83) along the main channel and adjacent terraces of Boundary Creek.
- Wet Verge Sedgeland (EVC 932) at the western end of the swamp in a small patch adjacent to the main channel.
- Damp Sands Herb-rich Woodland (EVC 3) on the lower slopes to the south and east of the swamp plain.
- Lowland Forest (EVC 16) on the slopes surrounding Big Swamp, upslope from areas historically effected by water-logging or inundation.

Eco Logical identified three ecohydrological zones:

- Swamp plain – previously experienced near-continuous waterlogging with periods of inundation, however in recent years this part of the swamp has experienced significant drying. The dry conditions present throughout much of the swamp plain are unlikely to support a Riparian Fern Scrub community in the long term, leading to a gradual shift to a terrestrial damp woodland community over time.
- Main channel – surface flow modelling indicates that even under relatively low flows (e.g. 2ML / day) water persists in the channel. As a result, communities in this zone are likely to be more tolerant of long-term reductions in surface flows and the associated reduction in water tables within the swamp.
- Damp woodlands – unlikely to have experienced inundation in normal years, however, species would still have been heavily dependent on ground water with near-constant access to water within the root zone of mature trees and shrubs.

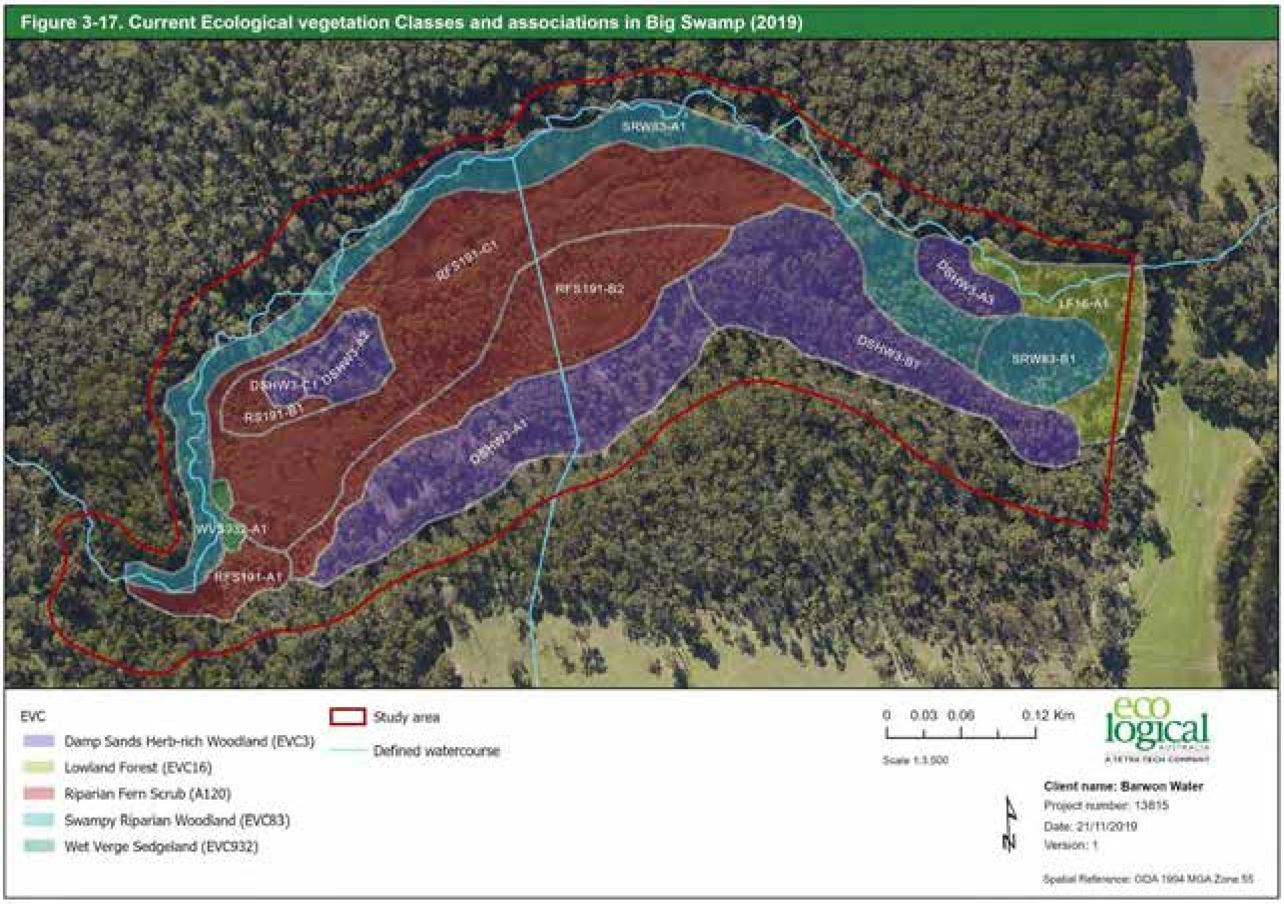

Figure 3-21 Current ecological vegetation classes and associations in Big Swamp (Eco Logical, 2019)

Section 4 **Overview of ASS Remediation Strategies**

4.1 Available Guidance

Several sources of information related to the management and remediation of ASS impacts have been reviewed to support preparation of this ROA, including:

- National and interstate best practice guidance on the management of ASS issues in inland and coastal landscapes.
- Technical publications describing technologies for the treatment of acid mine drainage, which presents several similarities with ASS issues.
- Selected papers presenting case studies and technology performance reviews.
- Online resources, such as the Interstate Technology and Regulatory Council (ITRC) Mining Waste Treatment Technology Selection (www.itrcweb.org/miningwaste-guidance/) and the Global Acid Rock Drainage (GARD) Guide (www.gardguide.com).

4.2 ASS Management Principles

According to the *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*, the hierarchy of an ASS management strategy is:

1. Minimising the formation of ASS in inland aquatic ecosystems.
2. Preventing oxidation of ASS, if they are already present in quantities of concern; or controlled oxidation to remove ASS if levels are a concern but the water and soil has adequate neutralising capacity.
3. Controlling or treating acidification if oxidation of ASS does occur.
4. Protecting connected aquatic ecosystems/other parts of the environment if treatment of the directly affected aquatic ecosystem is not feasible.
5. Limited further intervention.

The above guidance is generally aligned with EPA Victoria Publication 655.1 *Acid Sulfate Soil and Rock* (July 2000), which indicates the following hierarchy of management:

1. Avoid disturbance
2. Minimise disturbance
3. Prevent oxidation
4. Treat to reduce or neutralise acidity
5. Off-site reuse or disposal.

The following sections provide a brief overview of common approaches for management of ASS. In most cases, several management strategies are required in order to effectively control ASS issues.

4.3 Minimise or Prevent Further Oxidation

The simplest way to minimise or prevent further oxidation is to adopt water table management strategies to ensure that ASS materials remain under sufficient depth of water. This strategy provides two benefits:

- The low solubility of oxygen in water provides a limiting factor to development of primary oxidation processes in previously oxidised ASS sediments.

- Elevating the water table minimises the risks of deeper un-oxidised ASS sediments being exposed to oxygen and initiating acid forming reactions.

This strategy is most effective when there is a plentiful and reliable supply of water. However, in cases where water is limited, artificial structures can be installed so that water levels are maintained across critical areas with highest potential for generation of acidity.

4.4 Inundation of Acidified Areas

Permanent inundation (or reflooding) of drained, acidified areas is a management strategy that has several benefits, including:

- prevent further ASS oxidation;
- contain acidity in the landscape/decreasing acid export;
- assist with ecological restoration; and,
- neutralise in situ acidity within the wetland by reversing key geochemical processes.

The last point relates to the potential for inundated areas to encourage natural microbial sulfate and iron reduction processes to neutralise acidity, generate alkalinity and precipitate metals. If organic matter ($2CH_2O$) is available in the inundated areas, sulfate reducing bacteria can use ferric iron (Fe^{3+}) and sulfate (SO_4^{2-}) as terminal electron acceptors, consuming protons and generating bicarbonate alkalinity (HCO_3^-):

- $CH_2O + 4Fe(OH)_3 + 8H^+ \rightarrow 4Fe^{2+} + CO_2 + 11H_2O$
- $2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^-$

The reduction of sulfate is an important mechanism for removing reduced metals (which may otherwise re-oxidise and release acidity), because formation of highly insoluble sulfides is enacted. For example:

- $Fe^{2+} + H_2S \rightarrow FeS + 2H^+$

It is noted that this strategy in most effective when the following conditions occur:

- Reduced metals can be effectively precipitated and retained in the system, minimising the potential for acidity to be exported outside of the system.
- The alkalinity generated by iron and sulfate reduction can be retained in the system to neutralise acidity in the system.
- The system is maintained in an anoxic saturated state preventing re-oxidation of metals and associated generation of acidity.

4.5 Isolation of Impacted Areas

If it is not feasible to restore an ASS impacted ecosystem, the focus will then be on protecting connected ecosystems from potential adverse effects caused by transport of acidification by-products though surface water, groundwater or overland flow.

Physical isolation of ASS sediments is a potentially effective method for protecting connected ecosystems; however, should only be considered when the benefits are greater than the negative effects of isolation.

Isolation can have negative effects on aquatic ecosystems, increased ASS oxidation rates and potential risks of mobilisation of acidification by products (i.e. wind erosion of dry ASS sediments or high flow events breaching the integrity of the isolation barrier).

Isolation techniques include diverting flow of creek across impacted areas, construction of impermeable barriers or flow regulators.

4.6 Dilution of Acidic Discharge

Dilution is a management approach that relies on mixing poor quality water with high quality water to reduce impacts on the receiving environments.

However, because of the relatively large volume of water required for effective dilution of acidic waters (up to 100 to 1000 times the volume of the system, depending on the inherent buffering capacity, or alkalinity, of the dilution water), coupled with the cost and sustainability consideration of using high quality water for management of impacts, dilution as a mitigation option in inland aquatic ecosystems may be useful in only a few cases.

4.7 Soil Neutralisation

These technologies can be broadly described as addition of acid neutralising compounds to raise pH and increase alkalinity of the soil. Under these conditions, the aqueous solubility of most metals is reduced, and they tend to precipitate out of solution.

Technical consideration for implementation of soil neutralisation technologies include the selection of the neutralising agent to be employed, method of application and application rates.

4.7.1 Neutralising Compounds

There are many types of neutralising compounds available for the treatment of ASS, which differ on their theoretical neutralising capacity, pH, solubility, moisture content, purity, particle size distribution, suitable application methods and health and safety considerations.

Commercially available products include calcium carbonate ($CaCO_3$) in the form of finely crushed limestone ('aglime'), dolomite (a rock comprising varying proportions of calcium carbonate and magnesium carbonate ($MgCO_3$), magnesite ($MgCO_3$), quick lime (CaO), hydrated lime ($Ca(OH)_2$), burnt magnesia (MgO), burnt dolomite (CaO/MgO), soda ash (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$).

Industry by-products with neutralising capacity can also be used in some applications and tend to be considered for their generally lower costs and sustainability considerations. Some examples include by-products of the cement manufacturing industry such as fly ash, and bauxite residues.

4.7.2 Application Methods

4.7.2.1 Surface

Surface applications involve spreading the neutralising compound over all or a part of the ASS affected catchment.

The aim of surface applications is to neutralise the acidity of the water draining from the catchment and improve surface soil conditions as the neutralising compounds slowly penetrate through the profile (depending on soil properties, precipitation and surface application rates).

Depending on the area requiring treatment and access constraints, surface application can be undertaken using truck mounted devices, specialised spreading equipment (i.e. pressurised slurries) or by air (i.e. fixed wing aeroplane or helicopter).

4.7.2.2 Mechanical

Mechanical applications involve incorporation of the neutralising compound into the soil requiring treatment using conventional earth moving equipment or large diameter mixing devices.

In the first case, the soil is typically excavated, and incorporation of the neutralising compound is carried out on a specifically built treatment pad. In the second case (usually referred to as 'deep soil mixing'), the neutralising compound is added directly to the in-situ soil with no need for excavation.

4.7.2.3 Injection

Injection applications involve injection of specifically formulated mixtures of neutralising agents and other compounds (slurries) that are injected under pressure in the subsurface with the aim of achieving a uniform distribution in the volume of soil requiring treatment.

4.7.3 Application Rates

For surface applications using lime (either granular or in a pelletised form), rates in the range of 2.5-5.0 t/ha are generally reported. For mechanical and injection applications, the mass of neutralising agent required is usually evaluated based on the acid-forming properties of the materials to be neutralised, which is determined from laboratory results.

Depending on the complexity of the project, required application rates can be also assessed using pilot trials, use of geochemical modelling tools or development of trial/error procedures.

4.8 Passive Systems for Treatment of ASS Impacted Water

4.8.1 In-stream Limestone Sand

This technology is based on placing piles of limestone sand directly in the streambed of high gradient streams. The piles are washed downstream during high flow events, with the limestone increasing pH and alkalinity of the streams as it progressively dissolves in the water.

Figure 4-1 Limestone sand placed along a polluted stream

Coating of limestone particles with Fe hydroxides (armouring) can occur, but the energy of the water in the stream causes agitation and scouring of limestone to keep fresh limestone surfaces available for reaction.

Selection of the locations of piles is based on access constraints and water quality objectives along various reaches of the stream. Application rates are calculated using empirical formulas, which consider the annual acid load into the stream.

4.8.2 Limestone Diversion Wells

Limestone diversion wells (LDWs) consist of in-ground wells (1.5-1.8 m in diameter and 2.0-2.5 m in depth) containing crushed limestone aggregates into which part of a fast-flowing stream flow is diverted, usually via a pipeline.

The turbulence caused by the water flowing into the well enhances dissolution of limestone, as wells as minimising the potential for armouring of the limestone surfaces.

Figure 4-2 Limestone diversion well

The water leaving the diversion well, with increased pH/alkalinity and carrying limestone particles abraded from the well, is then reintroduced into the stream where further pH neutralisation and metal precipitation occurs.

LDWs are generally employed at sites with suitable topographic fall between the stream diversion point and the intake of the well (minimum of 10 m vertical change), so that enough hydraulic force is applied to the limestone, promoting abrasion and grinding of the aggregate.

LDWs are maintenance intensive systems (i.e. require frequent re-filling of limestone, cleaning of leaves and debris, etc.) and are not generally suitable for sites that are remote or difficult to access. In addition, aluminium and other metals may precipitate in the receiving stream as a result of increase pH and alkalinity.

4.8.3 Open Limestone Drains

Open limestone drains (OLDs) are open channels containing coarse limestone aggregate (15-30 cm diameter) used to increase pH and alkalinity of the waters requiring treatment. A typical OLD may have 0.3 m to 1 m of limestone at the bottom and 1 m to 3 m of water with a residence time of at least 14 hours (Figure 4-3).

Figure 4-3 Example of an OLD

To minimise reduction of treatment efficiency caused by formation of Fe and Al precipitates on the surface of the aggregate (armouring), OLD are constructed with high gradients (>20%) if site conditions allow. One of the drawbacks of steep OLDs is that they require additional aggregate volume to achieve the required residence time.

Depending on the characteristic of incoming water, a properly designed OLD can raise pH to 6-8 and generate alkalinity in the range of 40-60 mg/L $CaCO_3$. A settling pond is usually required after the OLD to retain the metal precipitates, prior to final discharge of the treated water in the environment.

4.8.4 Anoxic Limestone Drains

Anoxic limestone drains (ALDs) are buried trenches lined with an impermeable material, backfilled with coarse limestone aggregate (15-30 cm diameter) and buried under clay (Figure 4-4). The ALD is then filled with the water requiring treatment and maintained in a saturated condition so that ingress of oxygen is prevented and armouring of the limestone is minimised.

Figure 4-4 ALD under construction (Skousen, 2005)

Dissolution of limestone within the ALD increases pH and alkalinity of the water requiring treatment, creating favourable conditions for metal precipitation. Typically, an ALD is followed by an aerobic treatment unit (such as an aerobic wetland or settling pond) where dissolved metals are oxidised, precipitated and retained prior to final discharge of the treated water in the environment.

ALDs are typically constructed to achieve residence times of approximately 14 hours, increase of water pH to 6-8 and alkalinity generation in the range of 250-300 mg/L $CaCO_3$.

For best performances, ALDs should receive incoming water with low concentrations of dissolved oxygen (<1 mg/L), aluminium (<1 mg/L), ferric iron (Fe^{3+}) and sulfate (<1,500 mg/L). If these conditions are not met, precipitation of iron oxide/hydroxides, aluminium hydroxide hydrate and gypsum is likely to occur, causing armouring of the limestone and plugging of the void spaces within the drain.

4.8.5 Constructed Wetlands

Constructed wetlands are a form of passive system for treatment of acidic discharges that relies on a combination of physical, chemical, microbial and plant-mediated processes for amelioration of water quality. These include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms.

The key considerations when determining the type and size of a constructed wetland include:

- The influent water acidity load, pH and redox state.
- Water flow rates (including assessment of seasonal variability) and retention times.
- The area available for a wetland.
- Access requirements for ongoing monitoring and maintenance.

The main types of constructed wetlands are discussed in the following sections.

4.8.5.1 Aerobic Wetlands

The main process undertaken within constructed aerobic wetlands is aeration of the water requiring treatment, which encourages dissolved iron to oxidise, precipitate and settle (Figure 4-5).

Figure 4-5 Aerobic Wetland

Aerobic wetlands can be described as shallow excavations (lined or unlined) filled with 300-900 mm of soil where shallow water (depths in the range of 100-300 mm) flows horizontally through planted vegetation. Plants are an important component of the wetland because they increase water retention time by preventing channelised flow, increase dissolved oxygen concentrations and have the potential to uptake some of the metals in the incoming waters.

Aerobic wetlands are usually designed with variable water depths to encourage plant community diversity and with a series of ponds (containing no plants) to allow settling of metal precipitates.

Because of the acidity generated by the hydrolysis of iron ($Fe^{3+} + 3\ H_2O \dashrightarrow Fe\ (OH)_3 + 3\ H^+$) and the increased toxicity associated with metal precipitates retained in the wetland, these systems are usually suited for treatment of mildly acidic or net alkaline waters with pH greater than 4.5 and low to moderate concentration of iron and other metals. Aerobic wetlands are often included as a final step in treatment processes containing other technologies, such as OLD or ALD, where they act as oxidation stages and/or settling ponds.

The size of the wetland is an important factor in the success of water treatment. Design must consider total acidity loads and water flow rates. General design criteria indicate iron removal rates of 10-20 g of $Fe/m^2/d$ and 0.5-1.0 g of $Mn/m^2/d$.

Because of large area requirements and limitations associated with available space, aerobic wetlands are often undersized, leading to inadequate retention times and poor effluent water quality.

4.8.5.2 Anaerobic Wetlands

Anaerobic wetlands (also referred to as compost wetlands) have shallow water depths (in the range of 100 mm) and a thick permeable anoxic substrate (≥ 300 mm) comprising various forms of organic matter (Figure 4-6).

Figure 4-6 Anaerobic Wetland

As the water moves horizontally through the substrates, several microbial processes are enacted to neutralise acidity, generate alkalinity and remove metals from solution. These processes can be summarised in the following equations:

- $2CH_2O + SO_4^{2-} + 2H^+ \rightarrow 2\ CO_2 + H_2S + 2H_2O$

  (Reduction of sulphate to hydrogen sulphide, consuming protons i.e. acidity.)

- $2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO^{3-}$.

  (Reduction of sulphate to form hydron sulphide (H_2S), with generation of bicarbonate alkalinity.)

- $M^{2+} + H_2S + 2HCO^{3-} \rightarrow MS + 2H_2O + 2CO_2$

  (Reaction of a generic metal, M^{2+}, with H_2S to form insoluble metal monosulphide.)

Wetland plants are usually incorporated in the wetland design, since they stimulate microbial processes and act as an organic carbon source; however, they may not survive in highly acidic environments. Limestone can be also be mixed with the organic material to increase generation of alkalinity. The presence of anaerobic conditions prevents or mitigates metal precipitation and armouring of the limestone.

Aluminium dissolved in the water entering the anaerobic wetland is poorly soluble at pH above 4.5 and generally precipitates on the top of the organic layer due to the increase of pH via sulfate reduction and limestone dissolution.

Because the effluent from an anaerobic wetland has low dissolved oxygen and potentially soluble metals in the reduced form, it is normal practice to add further treatment steps such as an aeration/settling pond or an aerobic wetland to oxygenate the water and remove residual iron concentrations. The acidity released by metal hydrolysis is compensated by the alkalinity added in the anaerobic wetland.

Since anaerobic wetlands produce alkalinity, they can be used to treat waters with net acidity (300-500 mg/L), low pH (around 4.0), high dissolved oxygen (> 2 mg/L) and moderate to high metal concentrations. Typical sizing guidelines for anaerobic wetlands are 3.5-7 $g/m^2\ d^{-1}$ (acidity) and 10 $g/m^2\ d^{-1}$ (iron).

4.8.5.3 Reducing and Alkalinity Producing Systems

Reducing and alkalinity producing systems (RAPS) combine the benefits of ALDs and anaerobic wetlands. While many design variations are possible (i.e. vertical flow wetland, vertical flow ponds and vertical flow reactors), the basic concepts of RAPS are common and can be summarised as follows:

- Use mixtures of limestone and organic matter, combining organic and inorganic approaches to water treatment.
- Rely on alkalinity generation by dissolution of limestone and sulfate reducing bacteria activity.
- Promote reducing conditions in the water so that metal sulphide precipitation can occur and armouring of limestone is minimised.
- Provide sites for metal absorption in the organic matter layer.
- Raise the pH of water to near neutral conditions.

The type of RAPS selected for water treatment is generally dependent on site-specific conditions such as topography, available surface area for the treatment system, soils and geology, groundwater flows, etc., as well as the availability of resources for setting up and maintaining the treatment system. As a result, RAPS have been implemented in various forms, ranging from fully engineered constructions to relatively unmodified natural systems (Figure 4-7).

Figure 4-7 Vertical flow wetland

The main difference between a RAPS and an anaerobic wetland is that in a RAPS, water flows in a predominantly vertical manner, so that the interaction of water with organic matter and limestone is greatly increased. Underlying drainage pipes at the bottom of the RAPS convey the water into a settling pond or an aerobic wetland, where precipitation and sedimentation processes can take place before discharging the water to the receiving environment.

Because of the increased efficiency realised by vertical flow conditions, RAPS require less surface area compared to anaerobic wetlands (as little as 20% for the same degree of treatment). For influents containing significant quantities of ferric iron (Fe^{3+}) and/or sediment, vertical-flow systems should be preceded by either a settling pond or an aerobic wetland so as to limit accumulation of solids on the organic layer surface. For treating highly acidic discharges, several vertical flow cells can be placed in sequence, separated by settling ponds.

The drawback of RAPS is that the site must have sufficient natural relief to overcome the head losses associated with water flow across the organic layer and limestone (in the range of 1.5 m). Additionally, at least 1 m of freeboard is advisable on top of the organic layer (to guarantee sufficient driving head), so a minimum relief in order of 2.5 m is required to allow water flow without the need for active pumping.

General design guidelines for RAPS recommend limestone drainage layer thickness in the range of 60-100 cm, organic layer thickness in the range of 15-60 cm and loading rate of 25-30 $g/m^2\ d^{-1}$ (acidity) with a 15 hours retention time in the limestone layer.

4.8.6 Aeration and Settling

Aeration (i.e. increase of dissolved oxygen concentration in water) and settling are used to collect treated or partially treated waters discharging from a range of passive treatment systems (such as OLDs, ALDs or RAPS) to promote oxidation, precipitation and settling of metals. In cases of net alkaline discharges containing high concentrations of iron where no further alkaline addition is needed, aeration and settling may be the only process required to achieve suitable treatment.

Aeration can be achieved by mechanical or chemical means. When topography and land availability allow, passive mechanical means (such as aeration cascades) are typically employed. Assuming aeration can achieve a dissolved iron concentration of 8 mg/L, a single aeration step is generally suitable for treatment of water with 30-50 mg/L of iron (based on stochiometric and efficiency considerations). If higher iron concentrations are present, successive aeration steps with settling units between them are required.

Settling for removal of metal precipitates can be achieved in settling ponds or clarifiers. Coagulants and flocculants may be required to assist the settling process in case of large flow rates and limitation of available land.

Available design recommendations for settling ponds include the following:

- Water residence time of 8-72 hours.
- The length-to-width ratio should be within the range 2:1 to 5:1, to help minimise possible streaming and short-circuiting.
- The depth of the pond should be in the range of 3 m to prevent resuspension of settled particles due to the horizontal velocity of water and / or wind.
- The most effective shape of ponds, from a hydraulic point of view, is rectilinear. However, amenity considerations may lead to less effective shapes requiring larger land area requirements than initial calculations would suggest.
- Sludge captured in the settling pond requires periodic removal (typically every few years) and is often a significant cost element in the long-term operation of this type of passive treatment system.

4.8.7 Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are subsurface structures filled with reactive material (i.e. organic matter/limestone or zero valent iron) that are designed to intercept and treat impacted groundwater (Figure 4-8). Organic material can promote bacterially mediated sulphate reduction, which results in generation of alkalinity and precipitation of dissolved metals in the form of sulfide precipitates within the barrier.

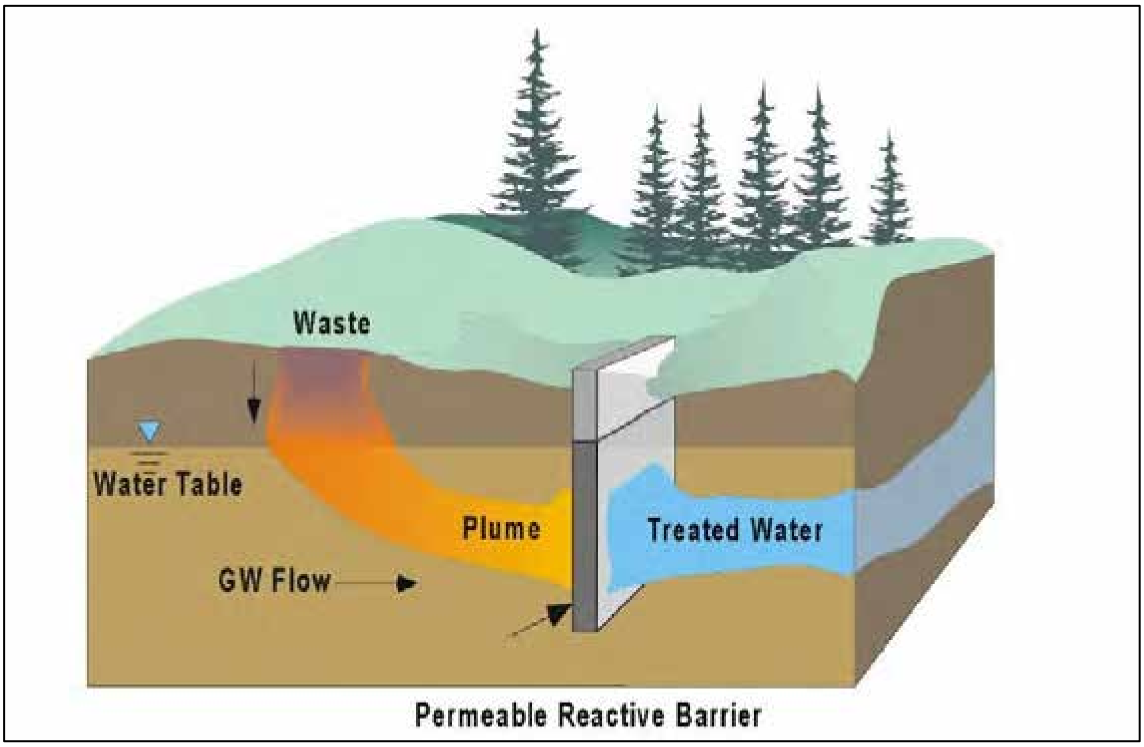

Figure 4-8 PRB diagram (US EPA, 1998)

The key factors that may limit the lifetime of PRBs are the mass of available reactive material and the available volume of pore spaces (and permeability) of the barrier. Metal precipitation and substrate compaction can result in a decrease in porosity and permeability of the barrier. Typical width of PRBs are between 1.4 – 4.0 m and residence times within 3 – 90 days.

4.9 Active Systems for Treatment of ASS Impacted Water

Active systems for treatment of acidic water discharges include physical, chemical and biological approaches that manage a broad range of influent characteristics, flow regimes and discharge criteria. The main processes employed by active systems include:

- pH control or precipitation.
- Electrochemical concentration.
- Biological mediation / redox control (sulphate reduction).
- Ion exchange / absorption or adsorption / flocculation and filtration.

Active systems can be classified as fixed plant (where the water requiring treatment is directed to a conventional water treatment plant) or in-stream (where portable active or passive systems perform the treatment within or adjacent to the affected water body).

4.9.1 Fixed Plant

For the purpose of this ROA, it is assumed that a fixed plant based on pH increase with inorganic alkaline amendments (calcium hydroxide or calcium oxide) followed by oxidation and sedimentation (by flocculation and clarification) would be used to treat water at the site. This general approach is one of the most widely applied for treatment of acid mine drainage worldwide because of its effectiveness and relatively low cost.

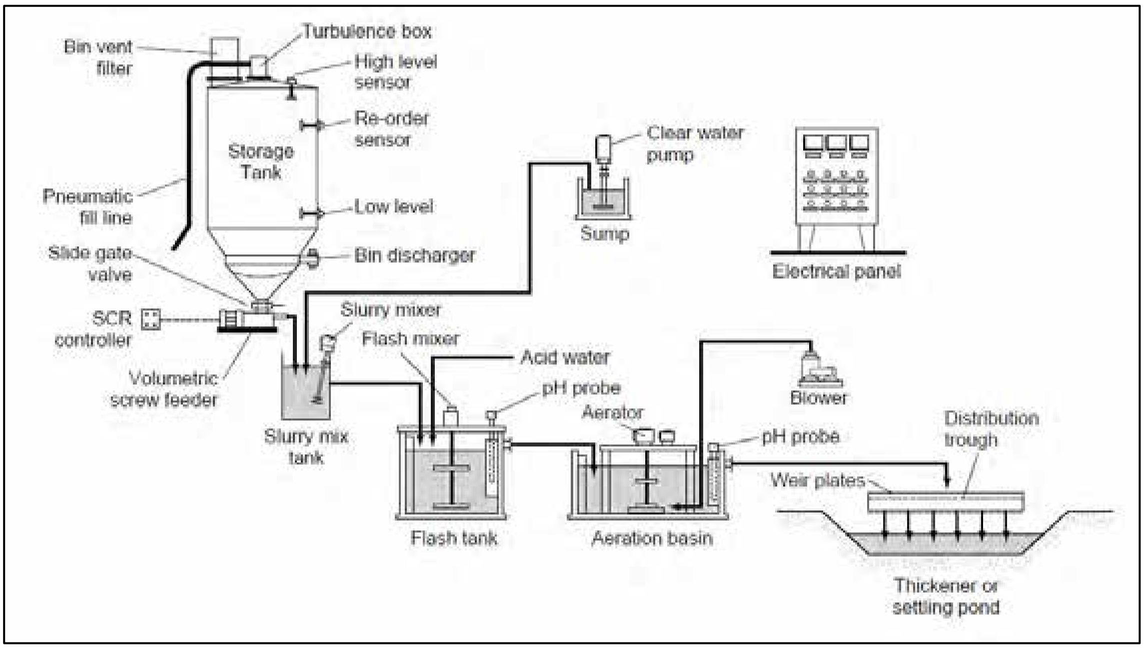

Figure 4-9 Conventional water treatment utilizing lime. (Source: AMD Treat, US DoI)

Despite the general concept behind the treatment process being relatively simple, numerous variations are possible depending on project-specific parameters and factors, including total suspended solids content, flow rate, iron/manganese concentrations, chemical costs, health and safety considerations and available land area.

4.9.2 In-stream Treatment

In-stream treatment systems generally use pH control/precipitation methods for the treatment of water by using small portable plants (manual, semi-automated or fully automated) with low capital costs. The common feature of these systems is the capability for storage and dispensing of alkaline reagents (such as calcium hydroxide or calcium oxide) in the water body requiring treatment (Figure 4-10).

Figure 4-10 In-stream dosing system

The main advantages of these systems are the limited requirements for power, reduced operation and maintenance intensity and flexible implementation. One of the main disadvantages is that direct dosing of alkaline reagents in streams or channels has the potential to transport metal precipitates downstream of the treatment location.

For the above reasons, in-stream treatment is generally only suitable for the following circumstances:

- Emergency response or other short-term treatment applications, where a large quantity of reagent needs to be dosed into a water body or stream over a short period of time.
- Long-term treatment applications, where a relatively low dose rate is required over an extended period.

4.10 Limiting Further Intervention

Limiting further intervention or adopting a range of targeted contingency measures may be an acceptable management strategy in particular cases.

The decision of limiting intervention and/or deferring broad scale management strategies is usually supported by a suitable set of monitoring data and a properly developed risk assessment process.

When a strategy of limited further intervention is being considered, the following steps should be undertaken to support the decision:

- Engage the stakeholders and community to explain the rationale behind the limited further intervention strategy.
- If necessary, refine the assessments of the risk to both adjacent ecosystems and landholders as a consequence of the decision not to take further action.

- Implement a monitoring and reporting regime to enable periodic review of the quality of affected aquatic ecosystem and connected waters.

4.11 General Considerations for Options Assessment

4.11.1 Active vs. Passive Systems

Advantages and disadvantages of active and passive treatment systems are summarised in Table 4-1

Table 4-1 Comparison of Active and Passive Systems

System Type	Advantages	Disadvantages
Active	• Ability to meet high and variable flow rates • Effective removal of contaminants from water • Precise process control, such that they can be engineered and operated to produce a specific water chemistry • Suitability in locations where only a small land area is available (however sludge capture may still require large land areas)	• High capital cost • High ongoing O&M costs • Power and other infrastructure requirements • Loss of amenity values
Passive	• Overall treatment costs are less compared to an equivalent active system • Less requirement for specialised operators • Can enhance amenity values	• Relatively new technologies and lack of understanding of some relevant processes (i.e. sulfate reduction) and experience of long-term application • Precise adjustment to change of influent quality and flow rates is not possible • Performance of passive systems is subject to seasonal and other variations

4.11.2 Inflow Water Characteristics

Figure 4-11 depicts acid load guidelines for selecting effective active and passive treatment systems. Contours shown are for acid loads in tonne $CaCO_3$/d.

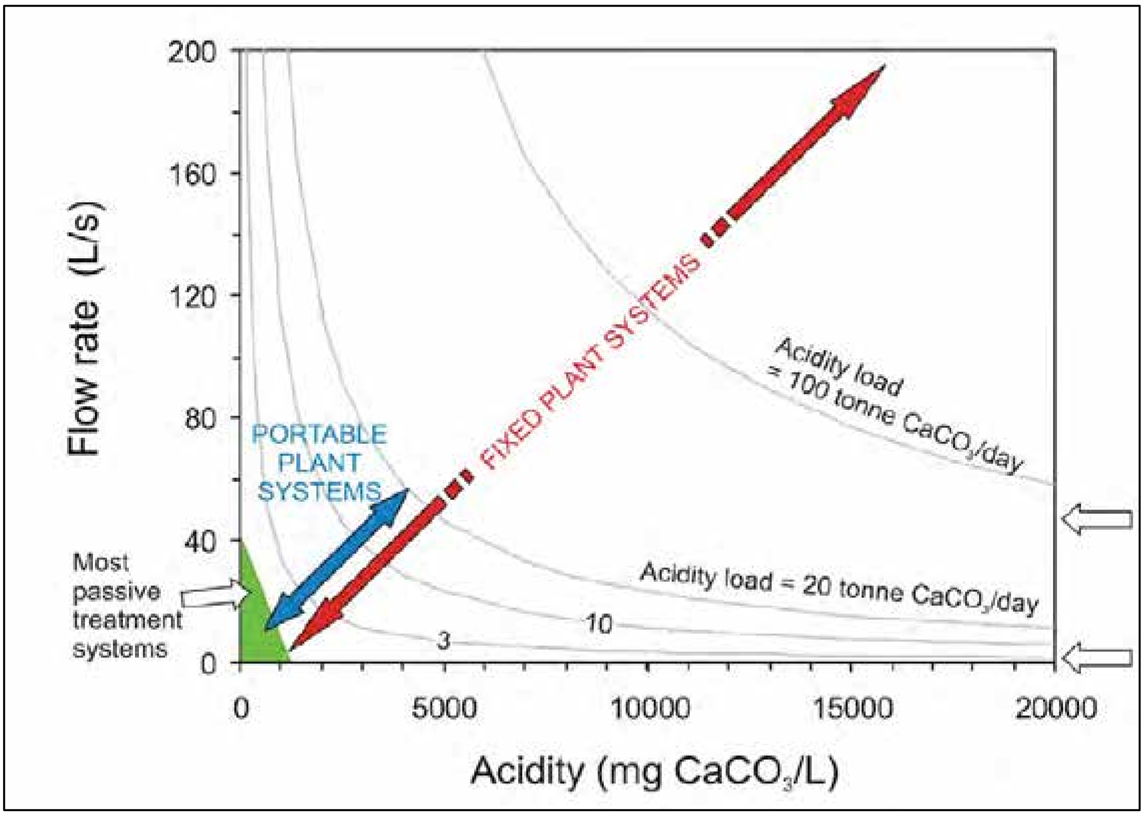

Figure 4-11 Applicability Range of Active and Passive Systems (Taylor et al., 2005)

The guideline indicates that passive systems are best suited to the treatment of waters with low acidity (<800 mg $CaCO_3$/L) and low acidity loads (100–150 kg $CaCO_3$ per day).

Section 5 **Remediation Option Assessment Framework**

The framework for identification of the most suitable remediation option (or combination of options) for management of ASS impacts at the site has been developed in general accordance with the guidelines provided in the following publications:

- Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), National Remediation Framework, *Guideline on performing remediation options assessment,* Version 0.1 (August 2018).
- CRC CARE National Remediation Framework, *Guideline on performing cost-benefit and sustainability analysis of remediation options,* Version 0.1 (August 2018).
- EPA Victoria, Publication 840.2, *The cleanup and management of polluted groundwater*, February 2014.
- Government of Western Australia, Department of Environment Regulation, Contaminated Sites Guidelines. *Assessment and management of contaminated sites* (December 2014).
- UK Environment Agency, Contaminated Land Report 11, *Model Procedures for the Management of Land Contamination* (September 2004).
- Battelle Memorial Institute, *Guidance for Optimizing Remedy Evaluation, Selection, and Design*, (March 2010).
- Interstate Technology & Regulatory Council (ITRC), *Remediation Management of Complex Sites*, (2017).

5.1 Technology Identification

This task involved a comprehensive literature review for initial identification of a broad spectrum of available options for remediation of ASS impacts, based on CDM Smith's experience, published technology performance data and guidance from national and international sources.

The outcome of this task was identification of 17 remediation options (Section 5.1). Included in the identified options are the six remediation options previously identified in the Yeodene Swamp Study (Jacobs, 2018b), which are presented in this ROA with some modifications to their original inception to reflect the outcomes of the technical workshop, community meeting and feedback from the RWG Expert Panel.

5.2 Preliminary Screening

The purpose of this task is to restrict more detailed and site-specific assessment only to those options considered to be potentially feasible for the site. The preliminary screening was therefore conducted at a relatively high level considering the following parameters:

- Suitability of the technology to treat the ASS impacts at the site (i.e. consideration of relevant soil, surface water and groundwater parameters).
- Potential constraints associated with site morphology (i.e. presence or absence of steep inclines, land availability, etc.) and requirement for technology implementation.
- Assessment of likelihood of regulatory or community acceptance to the technology.

As part of preliminary screening, information on technology application, governing principles, typical performances, advantages and limitations were also collected and summarised to provide the basis for relative ranking of technologies performed as part of detailed assessment.

Following preliminary screening, seven remediation options were retained for detailed assessment.

5.3 Detailed Assessment

To support detailed assessment of the shortlisted technologies, the following steps were performed:

- Development of a high-level concept design for each retained option, using a range of site-specific data or general assumptions.
- Estimate of **relative cost** of each technology using publicly available data and software (AMDTreat v5.0.2 Plus) developed by the Pennsylvania Department of Environmental Protection, the West Virginia Department of Environmental Protection, the U.S. Geological Survey's (USGS) and the Office of Surface Mining Reclamation and Enforcement (OSMRE).
- Liaison with other technical consultants working on the project (Jacobs, GHD and Monash University) to obtain site-specific information on expected design requirements, performances and risks associated with each remediation option.
- Review of application national and international guidance for selection of suitable project-specific categories for the assessment of each option. The following set of six categories was considered to enable a broad assessment of the various facets associated with each option:
  - Technical
  - Logistical
  - Financial
  - Stakeholders
  - Timing
  - Sustainability
- Development of indicators for each category to assist with ranking the merits of each option. Ranking ranged from 1 (low/least preferable) to 5 (high/most preferable), according to the general guidelines provided in Table 5-1.

Table 5-1 Ranking Guidelines

Category	Description	1	3	5
A – Technical	Ability of the technology to achieve the remediation objectives, considering nature, distribution and concentration of the contaminants and the site-specific geological and hydrogeological setting.	Not proven or outside recommended ranges for chemicals to be treated. Site specific conditions preventing or limiting effective implementation.	Proven effectiveness and within recommended ranges for chemicals to be treated. Several pilot scale trials required to develop detailed design.	Proven effectiveness and within recommended ranges for chemicals to be treated. Minimal pilot scale trials required prior to implementation.
B – Logistical	Practical considerations associated with implementation of the technology at the site.	Large footprint (>2 ha), complex access/organizational issues requiring engineering and administrative controls and high O&M intensity.	Medium footprint (<2 ha), access/organizational issues requiring administrative controls and medium O&M intensity.	Small footprint (<1 ha), limited access/organizational issues and low O&M intensity.
C – Financial	Relative cost of implementing the technology for a nominal 10-year timeframe	Fixed costs > $5 M Ongoing costs > $100k/yr	Fixed cost $1 to $5 M Ongoing costs $50k/yr to $100/yr	Fixed costs < $1 M Ongoing costs < $50k/yr
D – Stakeholders	Likelihood of regulatory and community approval.	Unlikely to meet regulatory or stakeholder approval.	Standard level of permitting required and aligned with stakeholder's expectations.	Minimal permitting requirements and strongly supported by the community.

Category	Description	1	3	5
E – Timing	The envisaged timeframe required for the technology to meet the selected clean-up objectives.	More than 2-years for design and construction. More than 5 years to realise relevant project objectives. No source reduction, long treatment timeframes (>50 years) envisaged.	Between 1 and 2-years implementation time. Between 1 and 5 years to realise relevant project objectives. Some potential for source reduction potentially leading to shorter treatment timeframes (between 10 and 50 years).	Less than 1-year implementation time. Less than 1 year to realise relevant project objectives. Substantial source reduction short treatment timeframes (less than 10 years).
F - Sustainability	Includes consideration such as remediation hierarchy, use of resources, emissions and impacts on future generations.	High use of resources (chemical or natural), landfill space. High and/or non-recoverable impacts on the natural environment.	Moderate use of resources (chemical or natural), landfill space. Moderate impacts on the natural environment, likely to be recoverable.	Low use of resources (chemical or natural), landfill space. Low impacts on the natural environment.

- Development of a weighting system to allow prioritisation of more categories that were considered more important for the project.
- Discussion on the proposed categories, indicators and weighting system as part of the 10 October 2019 workshop and the 23 October 2019 RWG meeting so that feedback from technical and community stakeholders could be incorporated in the ROA framework.
- Ranking of the indicators and calculating scores for each category. The scores were normalised to remove the effect of different numbers of indicators defined for each category (i.e. all the categories have the same weight regardless of number of indicators).
- The normalised scores for each option were then weighted and summed to assist with identifying preferred options for the site. Various permutations using different weights were performed to account for feedback from the community and for sensitivity analysis.
- Based on the outcomes of the previous steps, the preferred options were integrated to develop a strategy aimed at meeting the project objectives and fulfil the project vision.

Results of the ROA are provided in the following sections.

Section 6 **Preliminary Screening**

6.1 Identification of potentially applicable remediation options

Table 6-1 presents a summary of the 17 remediation options identified for preliminary screening and provides the following information:

- The underlying principle of the remediation option.
- A high-level description of possible implementation at the site.
- Advantages and disadvantages of the remediation option.
- A discussion on key issues related to implementation including technical, logistical and regulatory/community considerations.

Table 6-1 Remediation Options Identified for Preliminary Screening (Options from Yeodene Swamp Study (Jacobs, 2018b) listed first)

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O1	True 'do nothing'	Limited further intervention	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018b). During the first technical workshop, it was agreed that a true 'do nothing' approach should reflect historical conditions and management practises at the site, which include the following: • Supplementary flow not passed entirely at McDonalds Dam • Continued presence of existing drainage channels across Big Swamp • Water users along Reach 3 of Boundary Creek unable to access water allocation during periods of 'no flow' • Unlikely recovery of groundwater levels in the LTA aquifer to pre-pumping conditions in the short term (i.e. 5 years)	• Lowest financial cost	• High socio-environmental cost • Does not satisfy notice requirements.	• It is unlikely that a 'do nothing' approach will meet any of the project objectives.
O2	Implementation of contingency measures	Limited further intervention	This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018b). During the first technical workshop, it was recognised that a range of contingency measures have been identified to ameliorate some of the issues associated with historical conditions at the site. These contingency measures include: • Minimum supplementary flow of 2 ML/d passed entirely at McDonalds Dam (already implemented) • Infilling of existing drainage channels across Big Swamp (potentially applicable) • Construction of a water pipeline to provide water to users along Reach 3 of Boundary Creek (to be implemented) • No interim pumping from the LTA until the s78 notice is lifted.	• Low financial cost • Provides water security to water users downstream of Big Swamp.	• High socio-environmental cost • Does not satisfy notice requirements.	• It is unlikely implementation of the planned contingency measures will meet all of the project objectives. • The aim of considering this option is to provide a baseline assessment of future trajectory of environmental outcomes for the Big Swamp, Boundary Creek and Barwon River in consideration of a range of existing/potential contingency measures implemented or to be potentially implemented at the site (i.e. in addition to the remediation options).

O3	Direct treatment of soils with neutralising agents (wetland liming)	Treatment to neutralise acidity (soil and water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages spreading of agricultural lime (or other suitable neutralising agent) over all or a part of Big Swamp to neutralise acidity of the upper soil profile as wells as increasing pH and alkalinity of the water leaving Big Swamp and discharging into Boundary Creek. Once the areas requiring treatment and the treatment rate (expressed as mass of neutralising agent per unit area) have been evaluated, a variety of implementation methods are possible, including terrestrial and aerial applications.	• Effective duration longer compared to in-stream liming methods; in some cases, effects last 10 to 20 years. • Lower amount of metals including aluminium is expected to be exported to streams. Also expected to result in less aluminium precipitate on stream bottom compared to other stream liming methods.	• Clearing of vegetation for construction of access tracks in case of terrestrial application over the entire swamp area. • Impacts of the neutralising agent on the terrestrial and aquatic ecosystems sensitive to rapid pH change from direct application to plant (i.e. leaf scorching) or indirectly through soil and pore water chemistry changes. • Grain diameter of the neutralising agent must be evaluated to minimise potential for downstream transport during high rainfall events, which may cause uneven coverage of the treatment area. • Metal precipitation in Boundary Creek associated with increased surface water pH.	• Terrestrial applications (i.e. using truck mounted equipment, pressure hose for slurry applications or manual spreading) are likely to be challenging because of access constraints and soft consistency of the soil across Big Swamp. • Aerial application by helicopter is likely to overcome some of the logistical constraints related to terrestrial applications, however, will incur increased costs and results in less control on application to understorey leading to increased risk of damage to vegetation. • This technology is generally more effective when application of the neutralising agent is targeted at water discharge areas (i.e. areas of high groundwater levels during periods of high rainfall) compared to uniform application over the entire swamp area. • Compared to surface water liming, this technology generally provides more sustained treatment timeframes, requiring less frequent applications. • Because dissolution and penetration of the neutralising agent is associated with rainfall (amongst other factors), this method is generally less suitable for dry and severely acidified environments.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O4	Oxic (aerobic) limestone drain (OLD)	Treatment to neutralise acidity (water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages construction of an open drain channel filled with limestone (or other suitable material) downstream of Big Swamp to improve quality of Boundary Creek water (i.e. increase pH/alkalinity and decrease dissolved metals concentration). Key design parameters of OLDs are mass and size of the limestone aggregate, slope of the drain and water residence time (in the range of several hours). The slope of the drain is inversely proportional to residence time, however higher slopes increase OLDs' efficiencies by limiting the potential for metal precipitation on the surface of the aggregate (armouring). Armouring reduces limestone pore space and surface area, decreasing the limestone dissolution rate and acid neutralising capacity.	• Low cost • Simple implementation	• Armouring of the alkaline materials caused by metal precipitation has the potential to be detrimental to efficiency and longevity of the limestone drain. • Ongoing maintenance is required to ensure treatment efficiency is maintained over time. • Depending on quality (i.e. pH, metal and anion/cation concentrations) of the water leaving the OLD, a settling pond may be required for collection of precipitates prior to discharge in Boundary Creek.	• Construction of an OLD (and potentially settling pond) with adequate slope and residence time to treat Boundary Creek water is likely to impact on the following: – Hydrological and hydrogeological regime of Boundary Creek (Reach 2/Reach 3) and Big Swamp. – Amenity and natural environment of Big Swamp and Reach 3 of Boundary Creek. • Large excavations required for construction may disturb ASS

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O5	Dilution of acidic discharge	Treatment to neutralise acidity (water)	This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages provision of additional water volumes (i.e. in addition to the supplementary flow of 2 ML/d released upstream of McDonalds Dam as part of the contingency measures) to improve water quality in Boundary Creek. Implementation of this option will require construction of a dedicated water infrastructure and identification of a sustainable source to supply water in the long term (this option does not address generation of acidity in Big Swamp, which will continue). The Yeodene Swamp Study (Jacobs, 2018b) assumes that the additional water volumes will be delivered through McDonalds Dam. However, to increase effectiveness and minimise potential side effects to natural environments downstream of the release point, the additional water volumes could also be delivered downstream of Big Swamp (i.e. in the upper reaches of Reach 3 of Boundary Creek). While not mentioned in the Yeodene Swamp Study (Jacobs, 2018b), the additional water may also be amended with neutralising agent to increase pH/alkalinity and therefore volumetric requirements.	• Relatively simple implementation • Can be readily implemented and used as seasonal relief to downstream water quality in Boundary Creek particularly during higher acid loads times or events.	• Geochemical modelling conducted as part of the Yeodene Swamp Study (Jacobs, 2018b) indicates that, using low alkalinity additional water, significant volumes are required to improve the quality (i.e. reduction of metal concentration and increase of pH) of Boundary Creek water. • The water volumes required to achieve dilution of acidic discharge are not available in the region and could potentially trigger water management issues in other parts of Victoria. • Deliveri of significant volumes of additional water is likely to have significant impacts on the hydrology, hydrogeology and natural environments downstream of the delivery point, which will require detailed assessment to support detailed design and implementation of this option.	• Addition of neutralising agents to the additional water (by construction of an automated dosing station) is likely to reduce the volumes of water required to improve water quality at Boundary Creek. • A settling pond will be needed downstream of the water delivery point to capture metal precipitates.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O6	Water flow diversion and Big Swamp isolation	Reduce export of existing acidity	This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages isolation of Big Swamp (source of acidity) and diversion of Boundary Creek flow so that the swamp is by-passed and transport of acid drainage to Reach 3 of Boundary Creek is minimised. Implementation of this option would require building a channel so that water flowing into Boundary Creek does not disperse into Big Swamp, as well as construction of a series of impermeable structures to prevent groundwater within the alluvial swamp sediment to discharge into Reach 3 of Boundary Creek. Additional water retention structures may be also required to minimise risks of acid flushes from Big Swamp into Reach 3 of Boundary Creek.	• This option could be effective in improving water quality in Boundary Creek by breaking the pathway between source (Big Swamp) and downstream environments.	• This option is likely to have significant impacts on the hydrology, hydrogeology and natural environments of Boundary Creek (Reach /Reach 3) and Big Swamp, which will require detailed assessment to support detailed design and implementation of this option. • Implementation of this option, in the absence of contingency measures, has the potential to worsen intensity of 'acid flushes' associated with drying and wetting cycles. • Dryer conditions across Big Swamp will also increase fire risks.	• This option is likely to severely impact on the natural environment of Big Swamp, which is likely to dry out further and continue to generate acidity. It is therefore considered that this option is unlikely to gain stakeholder's approval unless: – A water retention system and artificial water recharge are implemented so that surface water and groundwater levels can be maintained at acceptable conditions across Big Swamp; – It is demonstrated to be the only alternative to manage acid discharges to Boundary Creek and Barwon River; – The community agrees that Boundary Creek and Barwon River are of higher value compared to Big Swamp.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O7	Flooding of Big Swamp (natural anaerobic wetland) and managed groundwater levels	Treatment to neutralise acidity (water) and prevent (further) oxidation	This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages flooding of Big Swamp to create permanently waterlogged areas where microbially mediated iron reducing and sulfate reducing reactions have the potential to increase alkalinity, raise pH and remove dissolved metals by precipitation. For sulfate reduction reactions to occur, the following conditions must be realised in the re-flooded portions of Big Swamp: • A permanent water coverage having enough depth to maintain generally anaerobic conditions within the water column. • Presence of a bioavailable organic carbon source (electron donor). • pH between 5 and 8. • Presence of sulfate and low concentration of competing electron acceptors such as nitrate (NO_3^-), manganese (Mn^{4+}) and ferric iron (Fe^{3+}). Implementation of this option envisages the following steps: • construction of water retention structures (likely to be located at the downstream side of Big Swamp) to realise a permanent water coverage across a significant portion of Big Swamp. • infilling of existing drainage channels across Big Swamp to assist with water retention. • supply of additional water volumes to achieve the required permanent water coverage. • supply of additional organic carbon source (and potentially sulfate) in case of deficiencies of these elements in the natural environment. In addition to promoting favourable geochemical conditions to neutralise acidity, this option would aim to maintain or increase groundwater levels in the Big Swamp alluvium aquifer to prevent or minimise further oxidation of ASS sediments.	• Reversal of iron sulfides oxidation processes. • Minimise further oxidation. • Relatively low cost. • Barrier installation is a proven technology and can be supported by adequate modelling.	• The delivery of supplementary flow to maintain waterlogged conditions and higher groundwater levels will result in increased surface water flow in Big Swamp, which has the potential to enhance mobilisation and downstream transport of acidification by-products accumulated in near-surface sediments. • Preliminary results from laboratory incubation work from Monash University and GHD geochemical modelling suggest that there is a risk that the soluble ferrous iron generated under reducing conditions will not precipitate in Big Swamp and will be transported downstream in Boundary Creek (refer to Section 7.3.6.3.2 for additional details). • Visual amenity will be impacted because vegetation not tolerant to higher groundwater levels or permanently waterlogged conditions is likely to retreat or die following inundation of Big Swamp.	• Groundwater and surface water modelling are required to assist in assessment of the following technical aspects associated with this option: – availability of additional water volumes to be delivered to Big Swamp to achieve the required minimum groundwater levels. – extent and location of the water retention structures required to maintain groundwater at the desired levels. – potential impacts to hydrological and hydrogeological regime of Boundary Creek upstream and downstream of Big Swamp. • Geochemical modelling is required to assist with assessment of nature and rate of reactions that may be triggered by inundation of Big Swamp and the potential for mobilisation of acidity (both existing and as a consequence of iron reduction).

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O8	Soil excavation/ treatment and rehabilitation	Treatment to neutralise acidity (soil)	This option involves excavation and removal of the oxidised ASS sediments within Big Swamp, which are treated (or disposed) according to EPA Victoria ASS management guidelines. Construction of access tracks and significant removal of vegetation will be required to implement this option. The excavation is likely to be progressed as separate cells to minimise potential exposure of non-oxidised sediments to oxygen. Following removal of the oxidised sediments, lime would be added at the base of the excavations to neutralise potential future acidity generation and then the excavation would be backfilled with suitable imported fill. After remediation and backfilling, the site would be landscaped and revegetated to resemble the original character of Big Swamp.	• Could effectively remove the source of acidic discharges into Boundary Creek and Barwon River • The extent of excavation areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed. • Based on a comparison of aerial images captured since 2010 (when the majority of Big Swamp vegetation was severely affected by a fire), it appears that low lying vegetation would re-establish within 3 to 5 years after re-planting.	• The soft consistency of the soil across Big Swamp is likely to pose significant logistical constraints to implementation of this option. • Irrespective of the extent of excavations, implementation of this option will severely impact on the natural environment of Big Swamp and the hydrological/ hydrogeological regime of Boundary Creek. • This option is the less likely to achieve rehabilitation of the site to its original values. However, removal of acid generating sediments within Big Swamp is likely to be an effective solution to reduce acid impacts to the waters of Boundary Creek and Barwon River. •	• This option is the least preferred approach based on EPA Victoria ASS management hierarchy. • It is considered that this option is unlikely to gain stakeholders approval, **unless**: – It is demonstrated that removal of oxidised sediments is the only alternative to manage acid discharges to Boundary Creek and Barwon River; – The community agrees that Boundary Creek and Barwon River are of higher value compared to Big Swamp; – Remediation of Big Swamp to a satisfactory 'engineered end-point' as opposed to rehabilitation to some of its original values is an acceptable outcome for the project.
O9	Soil mixing	Treatment to neutralise acidity (soil)	This option involves the use of a large diameter (one to three metres) hollow-flight auger fitted with special mixing 'paddles' (or other suitable device) to achieve mixing of a neutralising agent with the oxidised sediments in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require to be rehabilitated through landscaping and planting of vegetation.	• Compared to surface liming, this option has the potential to achieve effective neutralisation of oxidised ASS sediments at depth. • The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.	• The soft consistency of the soil across Big Swamp is likely to pose significant logistical constraints to implementation of this options.	• If applied on a large scale, this option will severely impact on the natural environment of Big Swamp although would be less than Option 8.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O10	Alkaline slurry injection	Prevent (further) oxidation and treatment to neutralise acidity (soil)	This option involves injection of a slurry composed of alkaline and impermeable materials to minimise oxygen infiltration and neutralise acidity. Depth of application would be typically to the top of the unoxidized ASS in Big Swamp. Construction of access tracks and significant removal of vegetation will be required to implement this option. Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require rehabilitation through landscaping and planting of vegetation.	• Compared to surface liming, this option has the potential to achieve effective neutralisation of oxidised ASS sediments at depth. • The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.	• Same considerations as Option 9 'Deep soil mixing'. • Additionally, soil heterogeneity could limit the ability to achieve uniform distribution of the injected amendments.	• If applied on a large scale, this option will severely impact on the natural environment of Big Swamp, although would be relatively less than Option 8 and Option 9.
O11	In-stream limestone sand	Treatment to neutralise acidity (water)	This option involves placement of limestone sand (or other suitable neutralising agent) directly in the streambed of Boundary Creek. The sand is carried into the stream during high flow periods where it dissolves releasing alkalinity and increasing pH.	• No maintenance, simple, and relatively inexpensive.	• Water quality improvement may be inconsistent. • Effectiveness diminishes with time. Limestone sand must be applied repeatedly, usually at least once per year. • Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH.	• Unlikely to be effective, considering the limited flow and gentle slopes of Boundary Creek, limiting the potential for downstream transport of the neutralising sand.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O12	Active treatment system	Treatment to neutralise acidity (water)	This option involves installation of an active treatment system to treat water quality in Reach 3 of Boundary Creek. The system would be installed at the downstream end of Big Swamp and will comprise a range of equipment (i.e. tanks, mixers, pumps) to dose dry or liquid chemicals in the Boundary Creek water to increase alkalinity/pH and remove metals (by precipitation and settling). Depending on system configuration and design parameters, precipitation of metals could be achieved in a settling pond or above ground clarifiers.	• Compared to passive systems, active systems are better suited to manage high acid loads, high flows and variability in acid loads. They also require a smaller footprint compared to passive systems.	• Disadvantages of active systems include: – higher capital and ongoing costs; – infrastructure requirements (power, water, access roads, etc.); – potential generation of large volumes of low-density sludges requiring management; – potential acquisition of land to operate system; – effects on amenity (noise, visual impacts, etc.).	• An in-stream systems could be used to treat Boundary Creek water, and off-set some of the disadvantages associated with fixed plant systems.
O13	Limestone diversion wells	Treatment to neutralise acidity (water)	This option envisages that a portion of the flow in Boundary Creek downstream of Big Swamp is diverted into a series of limestone-filled wells to increase alkalinity/pH and precipitate metals. Following treatment, the flow is diverted back into Boundary Creek.	• Typical pH increases are about ½ to 2 units during average flows. • Multiple diversion wells can be installed to increase effectiveness.	• Typically, this option is suitable for treating small flows and likely to fail in cases when a stream has a variety of flow regimes during the year. • High maintenance (weekly to biweekly) is required. • Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH.	• Unlikely to be suited for site conditions.

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O14	Anoxic limestone drains (ALD) and settling pond	Treatment to neutralise acidity (water)	This option envisages construction of a buried drain lined with impermeable material, filled with limestone (or other suitable neutralising agent) and covered by impermeable materials. The water seeping downstream of Big Swamp is diverted into the limestone (to maintain saturated conditions and anoxic conditions) where dissolution of the limestone increases alkalinity and pH. Low oxygen conditions in the ALD would prevent precipitation of metals and armouring issues. The water leaving the ALD is then directed into an aerobic settling stage where metals are precipitated and removed from the water. Removal of metal precipitates (sludges) i required at periodic intervals.	• Increases efficiency of other treatment types. For example, anoxic limestone drains can be used to pre-treat water prior to entering a wetland system. • ALDs can also be used as a post-treatment system to add additional alkalinity.	• Water pre-treatment may be required prior to the ALD to remove dissolved oxygen and generate reducing conditions to promote conversion of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}). • The infrastructure required for precipitation and settling of metals (i.e. settling tank, engineered section of Boundary Creek or settling pond) is likely to impact on the natural environment of Big Swamp and Reach 3. • Anoxic condition in the drain are likely to reduce issues associated with iron armouring of alkaline materials. • Variable alkalinity output. • Effluent pH difficult to maintain over time. • Treatable effluent limited to low oxidised metal concentrations (aluminium and ferrous iron) and low dissolved oxygen.	• High concentration of Al (i.e. >25 mg/L) in the water requiring treatment will form floc in the ALD, progressively reducing its permeability and efficiency. • Large excavations required for construction may disturb ASS

ID	Technology	Principle	Site Implementation	Advantages	Disadvantages	Key Issues
O15	Constructed aerobic wetland	Treatment to neutralise acidity (water)	Construction of an aerobic wetland to remove metals by oxidation and hydrolysis.	• Relatively inexpensive. • Lower maintenance than active treatment systems. • Can improve amenity.	• Metal removal efficiencies vary because pH is seldom constant. • pH decreases as metals are removed. • Land area required must be large. • Limited useful life. Substrate becomes saturated with metals and must be replenished or replaced. Most are constructed within a 15-to 25-year lifetime.	• This option is generally suited for water streams that are slightly alkaline, with a pH greater than 5.5 pH units and contain low to moderate concentrations of metals. • These conditions are unlikely to be realised by the Boundary Creek waters downstream of Big Swamp. • Large excavations required for construction may disturb ASS
O16	RAPS (reducing and alkalinity producing systems)	Treatment to neutralise acidity (water)	Construction of a vertical flow anaerobic wetland to increase alkalinity, raise pH and remove metals by precipitation of insoluble hydroxides, carbonates and sulfides. The anaerobic wetland comprises an organic-rich substrate at the top, a layer of limestone at the bottom and a drainage system. The wetland is constructed within a watertight basin and water flowing from the top across the organic layer and the limestone layer is collected by the drainage system and released into an aerobic settling pond. Alkalinity is generated by microbial process in the organic layer (if sulfate is available) and through dissolution of the limestone. An aeration and settling stage may be required prior to discharge to increase oxygen and promote precipitation of residual dissolved metals.	• Area required for RAPS is relatively small compared to other passive systems. • Treat poorer quality water compared to passive systems.	• Drainage system limited by high concentrations of aluminium and ferric iron. • Noxious odour (hydrogen sulfide) produced in vicinity of the system. • Risk of people or animal drowning.	• The construction of an anaerobic wetland is likely to impact on the natural environment of Big Swamp and Reach 3. • Large excavations required for construction may disturb ASS
O17	Permeable reactive barrier	Treatment to neutralise acidity (groundwater)	Construction of permeable reactive barriers in Big Swamp (perpendicular to groundwater flow direction) to intercept and treat acidic groundwater.	• Relatively low maintenance and installation costs. • Ability to treat a range of contaminants.	• Construction of a permeable reactive barrier is likely to have some impact on the natural environment of Big Swamp. • Clogging and periodic removal of barrier material will be required.	• The ability of permeable reactive barriers to ameliorate water quality in Boundary Creek depends on the acid load associated with groundwater. • Excavations required for construction may disturb ASS

6.2 Technology Screening

Based on the information presented in Table 6-1, the following remediation options **have not been carried forward** for detailed assessment:

- **O1 - Do nothing**. The main reasons for removing this remediation option is the likely inability of meeting any of the project objectives based on magnitude and inferred persistence of acid generating processes within Big Swamp. This option would also fail to meet the requirements of the Section 78 Notice.
- **O2 - Contingency measures**. This option comprises implementation of various contingency measures including efficient delivery of a supplementary flow of 2 ML/d to Boundary Creek downstream of McDonalds Dam, infilling of key drainage lines across Big Swamp and construction of a water pipeline to water users along Reach 3 of Boundary Creek. Because the contingency measure of most relevance to the ROA (i.e. provision of 2 ML/d supplementary flow) has already been implemented, this option is removed from detailed assessment and used as a baseline to compare the other options.
- **O4 - Oxic limestone drain.** This option was removed because the concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. Armouring of the limestone aggregate caused by metal precipitates is likely to impact on the long-term effectiveness of the OLD. The relatively gentle slopes of the site do not provide favourable conditions for installing the OLD with the recommended 20% gradient that is indicated as one of the main design factors to limit the severity of armouring issues. In addition, an OLD constructed in accordance to the recommended design water retention time of 3 hours, will require approximately 310 m^3 of limestone aggregate (assuming a porosity of 40%) for each ML/d of water requiring treatment, equivalent to an open channel 5 m wide, 1 m deep and 60 m long. It is considered that such a structure (refer to Figure 4-3 for an example of an actual OLD) will impact on the visual amenity of the area downstream of Big Swamp.
- **O5 - Dilution of acidic discharges.** This option is removed because of the large water volumes (estimated by Jacobs in the range of 60-250 ML/d depending on flow conditions) required to achieve effective dilution of acidity and acidity impacts in Boundary Creek. It is considered that sourcing and delivery of such volumes of dilution water would be impracticable, unlikely to be accepted by the authority (dilution for management of contamination is usually considered an unacceptable management practise by EPA Victoria) and a risk of impacting on water availability in other parts of Victoria.
- **O6 - Water flow diversion and Big Swamp isolation**. This option is removed because of the technical challenges associated with providing an effective hydraulic barrier to prevent acidic discharges from Big Swamp to the surrounding receiving environments and the additional impacts to Big Swamp caused by further declines of surface water and groundwater water levels that are likely to eventuate as a result of decreased inflows into the swamp. The progressive acidification of Big Swamp and the drier environment caused by hydraulic isolation will also increase fire risk and potential for episodic and high intensity ‘acid flushes’ in case the integrity of the barrier is compromised during high rainfall events. It is also unlikely that this option would gain regulatory approval and/or community support.
- **O10 – Alkaline slurry injection**. This option is removed because a generally equivalent option (soil mixing) has been retained for detailed assessment. Soil mixing was retained over slurry injection because it is considered to be easier to implement in consideration of the high liming rates required to neutralise ASS in Big Swamp, the low hydraulic conductivity of the majority of the alluvium sediments in Big Swamp and the potential for preferential pathways to affect homogeneity of treatment.
- **O10 - In-stream limestone sand**. This option has been removed because during periods of low flow the limestone sand is unlikely to be transported downstream in Boundary Creek, resulting in low consistency of this technology in managing water quality impacts. In addition, a generally equivalent option (active treatment) has been retained for detailed assessment which has the advantage of providing more consistent outcomes in terms of treatment efficient and water quality results.

- **O13 - Limestone diversion wells**. This option has been removed because the high concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. In addition, limestone diversion wells require a very high O&M intensity (i.e. weekly) to maintain system efficiency and replacement of the limestone aggregate.
- **O14 - Anoxic limestone drain.** This option has been removed because the concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. In addition, the high retention times required for effective limestone dissolution (in the range of 13 hours) generally require construction of large structures. For example, an ALD designed to treat 4 ML/d of impacted water would typically be 1.5 m deep (1 m of limestone and 0.5 m of impermeable cover), 5 m wide and 1,000 m long (assuming limestone porosity of 40%). It is considered that construction and ongoing maintenance of such a structure downstream of Big Swamp would be impracticable.
- **O17 - Permeable reactive barrier.** This option has been removed because the surface water and groundwater modelling results provided by Jacobs appear to indicate that groundwater discharges into Reach 3 of Boundary Creek account only for a small proportion of the total flow (i.e. less than 0.3 ML/d, refer to Section 7.3.6.3.1) and therefore groundwater transport does not significantly contribute to acidic impact to Boundary Creek.

The following remediation options have been retained for detailed assessment:

- **O3 - Wetland liming.**
- **O7 - Flooding of Big Swamp and managed groundwater levels.**
- **O8 - Soil excavation, disposal and rehabilitation.**
- **O9 - Soil mixing.**
- **O12 – Active treatment system.**
- **O15 - Constructed aerobic wetland**. This technology would not treat impacted water from Big Swamp, however is has been retained because it could be uses as a final step of a treatment train including other remediation options.
- **O16 - RAPS.**

Detailed assessment of the above remediation options is discussed in Section 7.

Section 7 **Detailed Assessment**

7.1 Input Parameters

Input parameters supporting development of the retained remediation options are summarised in Table 7-1.

Table 7-1 Summary of Input Parameters

Parameter	Adopted Value	Justification
Soil parameters		
Wetland area	11 ha	Based on review of aerial image.
Average soil net acidity	5 % as S	Based on average existing and potential acidity results from borehole samples collected within Big Swamp (Figure 3-16) (Jacobs, 2019a).
Average depth of soil to be treated	2 m	Based on measured depth to groundwater and average existing and potential acidity results from borehole samples collected within Big Swamp (Figure 3-16) (Jacobs 2019a).
Water parameters		
Treatment flow rate	4 ML/d	About half the average daily flow at Yeodene gauge (233228) (Jacobs, 2018b).
Acidity	500 mg/L $CaCO_3$	Based on May-17 and August-17 surface water quality data (Jacobs, 2018b).
Acidity load	2,000 kg/d	Product of treatment flow rate and acidity.
Total Iron	28 mg/L	Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b).
Fe^{3+} / Fe^{2+}	Variable	Both ferrous and ferric iron are soluble in water at low pH (<3.5). Relative proportion depending on water redox conditions, with reducing conditions leading to an increase of ferrous iron (Fe^{2+}) and oxidising conditions leading to an increase of ferric iron (Fe^{3+}).
Aluminium	75 mg/L	Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b).
Sulfate as SO_4	700 mg/L	Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b).
Manganese	0.15 mg/L	Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b).
Dissolved oxygen	7 mg/L	Based on Austral surface water monitoring results (site 5 and site 5.5, October 2019) (Austral, 2019).
pH	4 units	Based on Jacobs' Big Swamp report (Jacobs, 2018b).

7.2 Methodology for Estimate of Relative Costs

The methodology adopted to estimate relative costs of the preferred remediation options is summarised below.

- Use of the AMDTreat software (USA written) to assist in developing sizing parameters and cost estimate. The software uses a 3-step approach to calculate a treatment cost:
  - The user enters water quality and quantity data (Table 7-1)

  - The user enters an active and/or passive treatment system by selecting the applicable treatment components from the software menu. Cost components include capital costs, ancillary costs (i.e. settling ponds, roads, land access, engineering costs) and annual costs (i.e. sampling, maintenance, pumping, chemical and sludge removal).
  - The user customises each treatment system to site-specific conditions by controlling the size, quantity, and unit cost of treatment system components.
- Because only **relative cost estimates** are required for the purpose of the ROA, several cost unit rates were maintained as per software default values to maintain consistency. However, specific cost unit rates were adjusted to Australian conditions in case they represented a significant component of the total cost (for example sludge disposal costs).
- Cost unit rates not provided in the AMD treat software (i.e. soil disposal cost) were assumed based on our understanding of local market conditions.
- Engineering cost (typically including cost for detailed design) were assumed to be as 20% of capital costs and baseline O&M cost were assumed to be as 3.5 % of capital costs. Budgetary allocations in addition to baseline O&M allowance were also included for some remediation options (i.e. installation of an active groundwater system) where it was considered that additional O&M expenditures were likely to be required.
- Sampling costs were estimated only in relation to activities specifically associated with implementation of each remediation option (i.e. they did not include broader surface water and groundwater monitoring activities already being undertaken as part of the Section 78 Notice requirements).
- No estimate was included for additional works such as tendering, construction quality assurance/quality control, permitting and principal contracting.
- No cost estimate was included for provision of supplementary flows as part of contingency measures (2 ML/d), building of roads to improve access at the site and delivery of infrastructures (i.e. power, water, etc.).
- Additional specific cost assumptions and exclusions are detailed in the description of each of the preferred remediation options.
- An exchange rate of 1.45 USD/AUD (current as of 5 December 2019) was assumed to convert cost outputs from AMDTreat (provided in US dollars) to Australian dollars.

7.3 Concept Designs of Retained Options

The following sections provide additional detail on concept designs for the retained remediation options, including the following:

- Review of the principle of operation of the selected remediation option.
- Envisaged approach for implementation approach.
- Assessment of expected technology performance.
- Inputs from groundwater/surface water and geochemical modelling works by Monash University, Jacobs and GHD (where relevant).
- Estimate of relative costs for technology implementation.
- Assessment of the technology ability to meet the project objectives.

The concept designs have been undertaken based on a range of assumptions and a review of draft reports from Jacobs, Monash University, GHD and Eco Logical. These reports are based on a limited set of soil, surface water and groundwater data, leading to use of conservative assumptions and considerable uncertainty in the predicted results, particularly with respect to temporal variability of the hydrogeochemical system.

Consequently, the information provided in the following sections should be used with caution and only to inform relative decisions on the preferred remediation options (or combination of options) required to achieve the project objectives. Planning, design and budgeting of the preferred remediation option (or combination of options) should be reviewed and updated as more relevant information on site conditions and technology performance are obtained.

7.3.1 Wetland Liming

7.3.1.1 Principles

The principles for surface application of pelletised lime ($CaCO_3$) to Big Swamp include the following:

- Neutralise acidity and increase alkalinity of surface water discharging from Big Swamp into Boundary Creek. This would be accomplished by dissolution of lime deposited in permanently wet areas of Big Swamp as well as dissolution of lime deposited on dry areas of Big Swamp during rain events (i.e. dissolution by runoff water).
- Neutralise acidity in the upper portion of the soil profile as alkalinity from lime is progressively dissolved and transported at increased depths. Depending on rates of precipitation, limestone dissolution rates and soil properties, alkalinity may migrate downwards in the soil profile at a rate of 5-10 cm every 2-3 years.

7.3.1.2 Implementation

Implementation of this remediation option could be realised using a fixed wing aircraft or helicopter (Figure 7-1) to spread pelletised lime across the entire extent of Big Swamp (11 ha). This solution would overcome logistical issues associated with accessing highly vegetated portions of Big Swamp as well as reducing the impacts of heavy machinery typically required for land applications. Based on a literature review of watershed liming projects, a liming rate in the range of 3 t/ha has been adopted to develop the concept design and costing.

Figure 7-1 Helicopter application

7.3.1.3 Expected Performance

Case studies indicate that a dosage of 5 t/ha applied to discharge areas was enough to produce stable pH levels above 6.0 in water quality control sites (Rotteveel, 2018). However, there also have been cases where the increase of pH in surface streams following liming was only marginal (i.e. <0.5 pH units).

Depending on liming rate, soil type and precipitation, improvements of water quality are reported by literature within the first year of liming application, with the effects lasting for several years (between 2 and 10 years) following application.

7.3.1.4 Geochemical Considerations

Results from soil samples collected from Big Swamp (Jacobs, 2019a) indicate that high concentrations of existing and/or potential acidity are present in Big Swamp to maximum investigation depths of 6.0 m bgl.

Based on review of technology performance, it is considered unlikely that wetland liming would reach and neutralise significant portions of the actual or potential ASS at depths greater than 0.5 m below ground level, with ongoing production of acidity requiring multiple applications over time to maintain effectiveness.

The ability of the technology to reduce acid releases into Boundary Creek and improve water quality will depend on several factors, including the rate of lime dissolution compared to the rate of acid mobilisation/production, the potential for armouring of lime surfaces, rainfall patterns and the actual implementation (i.e. total lime mass, lime distribution, etc.) of each lime application.

7.3.1.5 Cost Estimate

Design inputs, cost assumption and estimated costs (for a 10 year period) are summarised in Table 7-2 and Table 7-3.

Table 7-2 Wetland Liming - Design Inputs and Cost Assumptions

Design inputs	Cost assumptions	O&M Assumptions
Area: 11 ha Liming rate: 3t/ha Pellet lime use	Fixed costs: $ 6,000 Spreading cost: $ 400/t Pellet lime cost: $ 150/t Spreading rate: 7/t hour	Annual vegetation survey: $ 5,000 Monthly water sampling, four samples per event O&M cost 3.5% of capital cost for consistency with AMDTreat

Table 7-3 Wetland Liming - Cost Estimate (10 years operation)

Cost item	Estimate (AUD)	Notes
Capital	$ 25,000	
Engineering	$ 5,000	20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc.
O&M per year	$ 6,000	3.5% of capital cost plus vegetation survey.
Sampling per year	$ 20,000	
Total 10 years	$ 350,000	Assumed three applications in total.

7.3.1.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low to Medium.**

The ability of the technology to reduce acid releases into Boundary Creek will depend on several factors, including the rate of lime dissolution compared to the rate of acid production, the potential for armouring of lime surfaces, rainfall patterns and the parameters (i.e. total mass, distribution, etc.) of each lime application.

When mobilisation of existing and retained acidity in the soil profile occurs at a higher rate than lime dissolution rate, pH increase in Boundary Creek surface waters is likely to be limited. However, as the existing and retained acidity are flushed from the system pH is likely to start to increase because the lime dissolution rate is likely to be higher than ASS oxidation rate (GHD, 2019).

- **Manage secondary precipitates: Potentially Worse.**

  Formation of iron/aluminium precipitates following pH increase is likely. These precipitates, if not captured within Big Swamp, have the potential to be carried downstream and settle in Boundary Creek and/or Barwon River.

- **Maintain Boundary Creek minimum flow: No effect**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: Not known.**

  The effect on vegetation is unknown, although it is possible that aerial application of lime could cause harm to vegetation that has adapted to acidic conditions.

- **Reduce fire risk in Big Swamp: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.3.2 Soil Mixing

7.3.2.1 Principle

The principle of this remediation option is to achieve a thorough mixing of suitable alkaline materials into the soil, with the aim of reducing export of acid and acidification products downstream of Big Swamp. The amount of neutralising agent added must be sufficient to neutralise all existing acidity that may be present and all potential acidity that could be generated from complete oxidation of the sulfides over time. An appropriate safety factor must be also included in that amount.

7.3.2.2 Implementation

Because of practical constraints and ecological considerations, it is considered that soil mixing would be typically implemented at the site for treatment of selected 'hot spots' rather than the entire extent of Big Swamp. The areas targeted for treatment are likely to be severely disturbed following remediation and will require work to rehabilitate vegetation and general amenity.

Two conventional 30 t excavators (instead of piling rigs) are proposed for transportation and mixing of fine agricultural lime with the in-situ ASS requiring treatment. The use of excavators compared to piling rigs is considered to be more suitable due to the difficult terrain and access conditions at the site.

To realise mixing of lime with the in-situ ASS, one of the excavators would be fitted with a 'rotary blender' attachment, which is capable of maximum treatment depths between 3 m (powder product such as agricultural lime) and 4 m (slurry product) (Figure 7-3).

For costing purposes, an 'average' liming rate for neutralisation has been calculated based on the following formula (Department of Environment Regulation, Western Australia Treatment and management of soil and water in acid sulfate soil landscapes, 2015)

- Lime (kg/tonne soil) = (Net acidity (%S x 30.59) x 1.022 x Safety Factor) / ENV

The resulting liming rate is 390 kg/t based on the following inputs parameters:

- Net acidity: 5% S
- Safety factor: 1.5
- Effective neutralising capacity (ENV): 60%
- Soil density: 1700 kg / m^3

Average liming rates estimated by GHD range between approximately 40 kg of lime per t of soil (low net acidity case) and 480 kg of lime per t of soil (high net acidity case) (GHD, 2019), which is supportive of the liming rate assumed in the ROA for costing purposes.

It is however noted that liming rates in the range of 1000 kg of lime per t of soil can be calculated when considering net acidity concentrations of individual borehole samples collected from the first 2 m of the soil profile rather than average net acidity estimates (Figure 7-2, Monash University, 2019). On-site mixing for application of such liming rates is expected to be practically difficult and would result in higher costs than currently estimated.

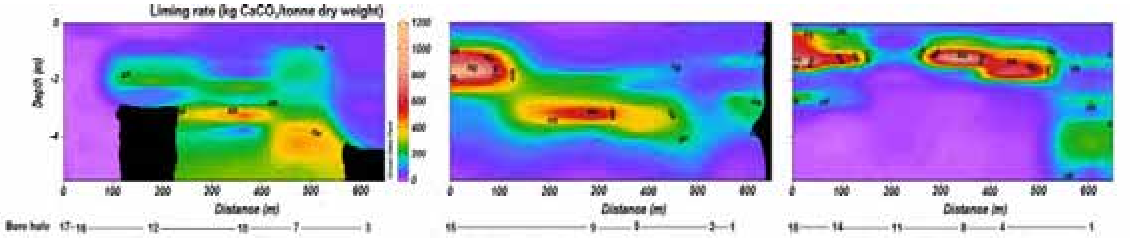

Figure 7-2 Liming rate distribution along three east-west transects across Big Swamp (Monash University, 2019)

In cases where treatment of deeper soil (> 3 m) is required, this remediation option would require the use of piling rigs equipped with specialised mixing devices or through subsurface injection of lime slurries.

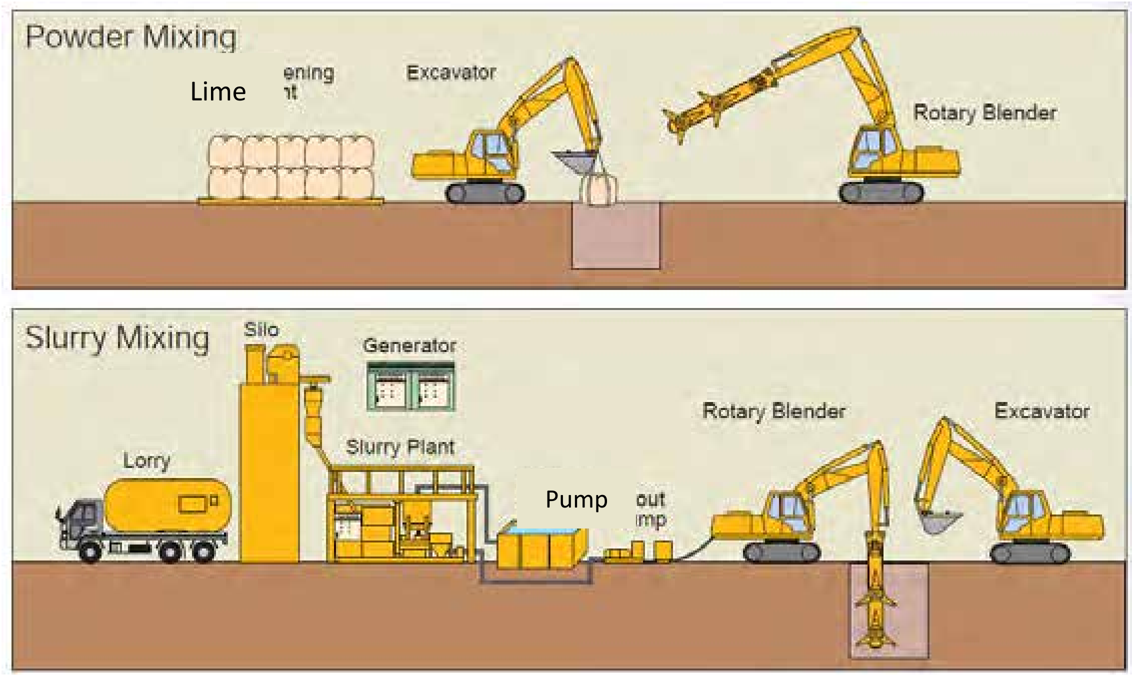

Figure 7-3 Soil Mixing Concept

7.3.2.3 Expected Performance

Application of the appropriate liming rate and effective mixing of the neutralising agent with the ASS to be treated is likely to be effective in neutralising existing and potential acidity within the 'hot spot' areas targeted for remediation.

However, it is considered that this option is unlikely to achieve a significant reduction of the existing and potential acidity stored within Big Swamp and/or a net improvement of the quality of Boundary Creek water. This is because of the overall limited extent of the soil volumes that can practicably treated by this technology versus the significant amounts of existing and potential acidity that will still remain in Big Swamp following remediation.

7.3.2.4 Geochemical Considerations

GHD has estimated that the total volume of sediments in Big Swamp that have the potential generate acidity in the future (depending of the volumes of supplementary flow delivered to Big Swamp and installation of an hydraulic barrier at the eastern end of Big Swamp, as described in Section 7.3.6) to be between 435,000 m^3 and 610,000 m^3 (±50%) (GHD, 2019).

The GHD estimate supports the conclusion the treatment of limited 'hot spot' volumes (i.e. in the range of 20,000 m^3 per day as assumed for costing purposes) in unlikely to significantly reduce the volume of ASS sediments in Big Swam [and the mass of acidity exported from Big Swamp to Boundary Creek].

7.3.2.5 Cost Estimate

Cost estimates for this option have been developed considering a total treatment area of 1 ha and an average treatment depth of 2.0 m. Design inputs, cost assumption and estimated costs (per ha) are summarised in Table 7-4 and Table 7-5.

Table 7-4 Soil Mixing - Design Inputs and Cost Assumptions

Design inputs	Cost assumptions	Validation sampling assumptions
Area: 1 ha Treatment depth: 2 m Treatment volume: 20,000 m^3 Soil net acidity: 5% S Liming rate: 390 kg/t Soil density: 1.7 t/m^3 Soil treatment rate: 300 m^3/d (treatment period of 70 days)	Excavation rate: $ 20/m^3 (two machines) consistent with AMDTreat Clearing and replanting rate: $ 18,000/ha consistent with AMD treat Environmental scientist rate: $ 1500/d Fine Aglime rate: $ 90/t	15 cores/ha Sample depth 3.5 m One sample every 0.5 m 3 days/ha

Table 7-5 Soil Mixing – Treatment Cost per ha

Cost item	Estimate (AUD)	Notes
Mixing	$ 400,000	
Clearing and replanting	$ 18,000	
Lime	$ 1,200,000	
Engineering	$ 84,000	20% of capital cost. Excludes cost of modelling, treatability studies, pilot trials, etc.
Supervision	$ 105,000	Assumed 70 days required to treat 1 ha to an average depth of 2 m
Validation	$ 25,000	Assumes portable push tube sampler used
Total per ha	$ 1,833,000	

7.3.2.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Because of the limited extent of ASS volumes that can be practicably treated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.

- **Manage secondary precipitates: No effect.**

  No effect on secondary precipitates is expected from implementation of this technology

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology

- **Improve vegetation: Potentially Worse.**

  Vegetation across 'hot spots' targeted for treatment will require to be cleared prior to the works. Replanting will be required after remediation with reestablishment of vegetation expected within a few years from completion of the site works.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.3.3 Soil Excavation, Disposal and Rehabilitation

7.3.3.1 Principle

This remediation option is essentially a variation of soil mixing, however the soil is removed and disposed off-site as a waste. Compared to soil mixing, this option has the advantage of removing the source of acidity from the site without the risk of incomplete treatment, which may be a result of inefficient mixing.

7.3.3.2 Implementation

Because of practical constrains and ecological considerations, it is considered that excavation and disposal would be typically implemented at the site for treatment of selected 'hot spots' rather than the entire extent of Big Swamp.

One conventional 30 t excavator will be employed to excavate the soil across the targeted 'hot spot' areas, and several trucks will be required to ensure that the soil can be removed from the site without interruptions (Figure 7-4). The excavated areas will then require reinstatement with clean imported fill before being revegetated.

Figure 7-4 Soil Excavation and Disposal

7.3.3.3 Expected Performance and Geochemical Consideration

Similar considerations for soil mixing apply (refer to Sections 7.3.2.3 and 7.3.2.4).

7.3.3.4 Cost Estimate

For consistency, the same assumption on treatment extent and depth have been adopted for estimating the relative costs of this option. While excavation and disposal does not incur costs for lime (except for a small layer of lime to be spread at the base of the excavation), additional costs are associated with transport/disposal of ASS at a suitable facility (an ASS Environmental Management Plan must be developed and approved) and import of clean fill material.

Design inputs, cost assumption and estimated costs (per ha) are summarised in Table 7-6 and Table 7-7.

Table 7-6 Soil Excavation, Disposal and Rehabilitation - Design Inputs and Cost Assumptions

Design inputs	Cost assumptions	Validation sampling assumptions
Area: 1 ha Excavation depth: 2 m Excavation volume: 20,000 m^3 Soil density: 1.7 t/m^3 Soil excavation rate: 350 m^3/d (period of 57 days) Soil backfilling and compaction rate: 700 m^3/d (period of 29 days)	Excavation rate: $ 10/m^3 (one machine) Backfill and compaction rate: $ 5/m^3 (one machine) Truck and trailer rate: $ 2,880/day (three machines) Clearing and replanting rate: $ 18,000/ha consistent with AMD treat Environmental scientist rate: $ 1500/d ASS loading, transport and disposal rate: $ 65/t Fill material rate: $ 35/t	15 cores/ha Sample depth 3.5 m One sample every 0.5 m 3 days/ha

Table 7-7 Soil Excavation, Disposal and Rehabilitation – Treatment Cost per ha

Cost item	Estimate (AUD)	Notes
Excavation	$ 210,000	
Backfilling	$ 105,000	Excludes compaction testing
Soil disposal	$ 2,210,000	
Fill Material	$ 1,190,000	
Clearing and replanting	$ 18,000	
Engineering	$ 65,000	20% of excavation, backfilling and replanting costs. Excludes cost of modelling, treatability studies, pilot trials, etc.
Supervision	$ 130,000	Assumed 86 days required to excavate/backfill 1 ha to an average depth of 2 m
Validation	$ 25,000	Assumes portable push tube sampler used
Total (per ha)	$ 3,953,000	

7.3.3.5 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Because of the limited extent of ASS volumes that can be excavated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.

- **Manage secondary precipitates: No effect.**

  No effect on secondary precipitates is expected from implementation of this technology.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: Potentially Worse.**

  Vegetation across 'hot spots' targeted for excavation will require clearing prior to the works. Replanting will be required after remediation with reestablishment of vegetation expected within a few years from completion of the site works.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.3.4 Aerobic Wetland

7.3.4.1 Principle

This remediation option, implemented alone, would not be suitable for treatment of the water released from Big Swamp (low pH, net acidity and high metal concentrations). However, an aerobic wetland could be employed as a polishing step after other remediation options have removed the bulk of the impacts from the water. Treated water flowing from the aerobic wetland would then be directed to Boundary Creek.

7.3.4.2 Implementation

Development of the concept design and cost estimate of the aerobic wetland has been undertaken using AMDTreat software, a design removal rate for iron of 10 $g/m^2\ d^{-1}$ and a water inflow rate of 4 ML/d (refer to Table 7-1 for details on other relevant parameters). Flow in excess of the design treatment capacity would have to by-pass the wetland and be discharged directly in Boundary Creek.

The resulting wetland has an area of 1.2 ha, dimension (assuming a 2:1 length to width ratio) of 160 m x 80 m and a water retention time of 10 hours. Depth of water in the wetland is 0.15 m and depth of organic layers is 0.6 m, in accordance with general design guidance.

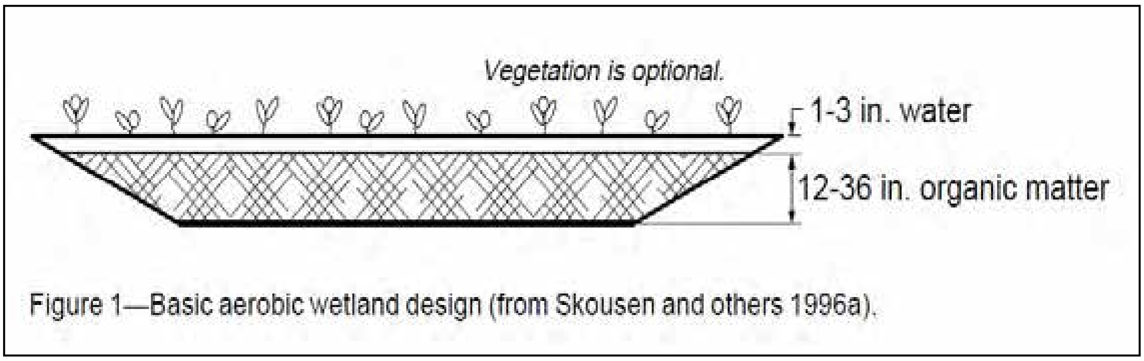

Figure 7-5 Typical Aerobic Wetland Cross Section

7.3.4.3 Expected Performance

As mentioned in the previous sections, an aerobic wetland is not considered to be suitable for effectively treating Boundary Creek water (based on the water quality assumptions supporting the ROA).

However, if the water prior to the aerobic wetland is treated as part of previous steps, then a properly designed and operated aerobic wetland is considered likely to assist in aeration/precipitation of residual metals prior to discharge in Boundary Creek.

Compared to other aeration/precipitation options (such as settling ponds), an aerobic wetland would offer the advantage of supporting ecological values and be more visually pleasing.

7.3.4.4 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-8 and Table 7-9 .

Table 7-8 Aerobic Wetland - Design Inputs and Cost Assumptions

Design inputs	Cost Assumptions	O&M and sampling assumptions
Fe treatment: 10 $g/m^2\ d^{-1}$ Mn treatment: 0.5-1.0 $g/m^2\ d^{-1}$	No management cost (i.e. pre-classification and disposal) for soil volumes (8,730 m^3) excavated for wetland construction No land acquisition costs (included as part of pre-wetland system) No sludge removal cost (included as part of pre-wetland system)	Monthly water sampling, four samples per event O&M cost 3.5% of capital cost for consistency with AMDTreat

Table 7-9 Aerobic Wetland – Treatment Cost per 10 years operational time

Cost item	Estimate (AUD)	Notes
Capital	$ 460,000	
Engineering	$ 95,000	20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc.
O&M per year	$ 16,000	
Sampling per year	$ 20,000	
Total 10 years	$ 905,000	

7.3.4.5 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Unlikely to be able to treat the acid load in Boundary Creek water unless coupled with other treatment technologies.

- **Manage secondary precipitates: Medium.**

  As a polishing step, an aerobic wetland will provide additional retention time to assist with oxidation and precipitation of residual metals prior to final release of water into Boundary Creek.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology

- **Improve vegetation: No Effect.**

  Construction of a vegetated wetland is expected to sustain a range of vegetation and ecosystems. However, this will have no impact on the vegetation across Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.3.5 Reducing and Alkalinity Producing Systems (RAPS)

7.3.5.1 Principle

The principle of operation of a RAPS is passive treatment of acidic water discharges from Big Swamp in a system that establishes reducing conditions and increased pH/alkalinity. The RAPS must be followed by a settling pond (and/or aerobic wetland) to oxidise the reduced water and facilitate precipitation of metals. Treated water flowing from the settling pond would then be directed to Boundary Creek.

7.3.5.2 Implementation

Development of the concept design and cost estimate of the RAPS has been undertaken using AMDTreat software, a design removal rate for acidity of 35 $g/m^2\ d^{-1}$ and a water inflow rate of 4 ML/d (refer to Table 7-1 for details on other relevant water quality parameters). Flow in excess of the design treatment capacity would have to by-pass the RAPS and be discharged directly in Boundary Creek.

The resulting RAPS has an area of 6.3 ha, dimensions (assuming a 2:1 length to width ratio) of 180 m x 360 m and a water retention time of 130 hours. Depth of water in the wetland is 0.9 m, depth of organic layers is 0.3 m and depth of limestone bed is 0.8 m, in general accordance to general design guidance Figure 7-6.

Dimension of the settling pond are 57 m wide, 110 m long and 3 m deep, ensuring a residence time of 48 hours and removal of sludge every year.

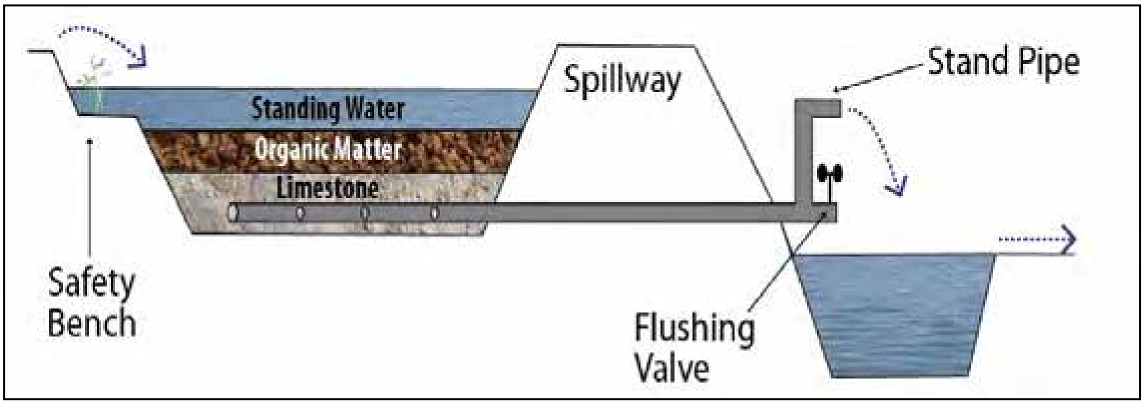

Figure 7-6 Typical RAPS Cross Section

7.3.5.3 Expected Performance

Amongst the passive systems for treating of acidified waters, RAPS are usually presented as the ones having the highest treatment efficiencies and expected lifetime.

Acidity removal rates are generally higher during the first year of operation (40-60 g/m^2/day) when the compost layer has high reactivity and high permeability. Long term removal rates are reported in the range of 20-40 g/m^2/day which would be adequate to treat a water flow of up to 4 ML/d under the design assumptions in Table 7-1.

The effect of the system on Boundary Creek water quality is likely to be variable and depending on seasonal variations of streamflow values, acidity loads and RAPS acidity removal rates, as summarised below:

- When Boundary Creek flow rates fall within the RAPS design treatment capacity (i.e. 4 ML/d as assumed in the ROA), it is expected that water into the creek would be of good quality, with a pH greater than 5 units and low concentration of dissolved iron and aluminium.
- Flow rates in excess of the design treatment capacity would have to by-pass the RAPS and water quality in Boundary Creek would be a result of the mixing of the treated and untreated streams.
- Periods of higher acidity loads (which could happen at any flow rate) have the potential to upset the microbiological conditions within the RPAS and cause progressive decrease of treatment efficiency.

It should be also noted that, compared to other passive systems, RAPS require more intensive maintenance, including flushing of aluminium precipitates in the piping system and removal of sludges from the settling pond. Lack of proper maintenance is likely to results in progressive decrease of system performance and degradation of water quality in Boundary Creek.

7.3.5.4 Geochemical Considerations

The results of the geochemical assessment (GHD, 2019) are summarised below.

- Precipitate clogging of the organic layer of the RAPS is not anticipated to be significant.
- Formation of aluminium precipitates in response to the increase in pH is predicted in the limestone layer, with the potential for clogging and armouring of the limestone reducing the effectiveness of this treatment layer and decreasing the efficiency and effectiveness of the treatment system.

7.3.5.5 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-10 and Table 7-11.

Table 7-10 RAPS - Design Inputs and Cost Assumptions

Design inputs	Cost Assumptions	O&M and sampling assumptions
Acidity treatment: 35.0 g/m^2 d^{-1} Settling pond retention time >48 hrs Sludge removal events: one per year Sludge generation rate: 0.0046 m^3 sludge / m^3 water Sludge solid content: 5%	No management cost (i.e. pre-classification and disposal) for soil volumes excavated for RAPS construction (114,000 m^3) and settling pond construction (14,530 m^3) Land acquisition cost: $ 20k / ha Sludge removal rate: $ 50/m^3	Monthly water sampling, four samples per event O&M cost 3.5% of capital cost for consistency with AMDTreat

Table 7-11 RAPS – Treatment Cost per 10 years operational time

Cost item	Estimate (AUD)	Notes
Capital	$ 4,600,000	
Engineering	$ 920,000	20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc.
Land Acquisition	$ 200,000	Assumed 10 ha and $20,000 per ha
O&M per year	$ 160,000	O&M (3.5% of capital). Routine O&M, no major reconstruction work.
Sludge removal per year	$ 335,000	
Sampling per year	$ 20,000	
Total 10 years	$ 10,870,000	

7.3.5.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Medium to High.**

  Subject to proper design and maintenance, a RAPS would have the ability to treat the acid load in Boundary Creek water. However, Boundary Creek flow rates above the design capacity of the system will not be treated by the RAPS.

- **Manage secondary precipitates: High.**

  Secondary precipitates will be captured in the settling pond.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: No effect.**

  Construction of a vegetated RAPS is expected to sustain a range of vegetation and ecosystems, as well as improving downstream ecological values. However, it will have no effect on the vegetation across Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.3.6 Managed groundwater levels and wetland flooding

7.3.6.1 Principles

The principles supporting flooding of portions of Big Swamp are to provide supplementary flow and install surface water retention structures (‘hydraulic barriers’) to achieve the following:

- Minimise further oxidation of ASS sediments by maintaining saturated conditions within the alluvium aquifer beneath Big Swamp.
- Promote acid neutralising reactions (iron and sulfate reduction) in permanently flooded areas of Big Swamp that will results from the combined effect of delivering supplementary flows and installing hydraulic barriers.

7.3.6.2 Implementation

Implementation of this option will require Barwon Water to deliver supplementary flow upstream of McDonalds Dam, monitoring of effective release of the supplementary flow from McDonalds Dam and construction of one (or multiple) hydraulic barriers within Big Swamp.

Implementation could be progressed in stages, so that the effect of installing one barrier can be monitored to calibrate modelling results, support design of additional barriers and assess potential side-effects associated with the technology (i.e. increased production of soluble ferrous iron than could be mobilised downstream Big Swamp, impact on vegetation, etc.).

Water release control structures (such as weirs) could be integrated in the barriers to control the level of inundation, adapt to higher rainfall periods and allow future integration with in-stream water treatment systems.

The design presented by Jacobs (2018b) consisting of installation of one hydraulic barrier at the eastern end of Big Swamp has been adopted in this ROA, for the following reasons:

- The design is considered adequate to represent, at a conceptual level, the effect of barrier installation of surface water flow and groundwater levels.
- Considerable surface water and groundwater modelling work has been developed to support assessment of the design presented by Jacobs. Results of this modelling work can be extrapolated to draw a range of conclusions on the general ability of this option to meet the project objectives.

7.3.6.3 Expected Performance

Expected performance of this option has been assessed based on a review of draft reports summarising the results of surface water/groundwater models (Jacobs, 2019b), incubation testing (Monash University, 2019), geochemical model (GHD, 2019) and vegetation study (Eco Logical, 2019).

7.3.6.3.1 Surface Water and Groundwater

Jacobs’ modelling was aimed at assessing surface water and groundwater responses to increased supplementary flow volumes (from a minimum of 2 ML/d to a maximum of 20 ML/d) with or without the influence of the hydraulic barrier installed at the eastern end of Big Swamp (barrier elevation set at 142.5 m AHD, Figure 7-7).

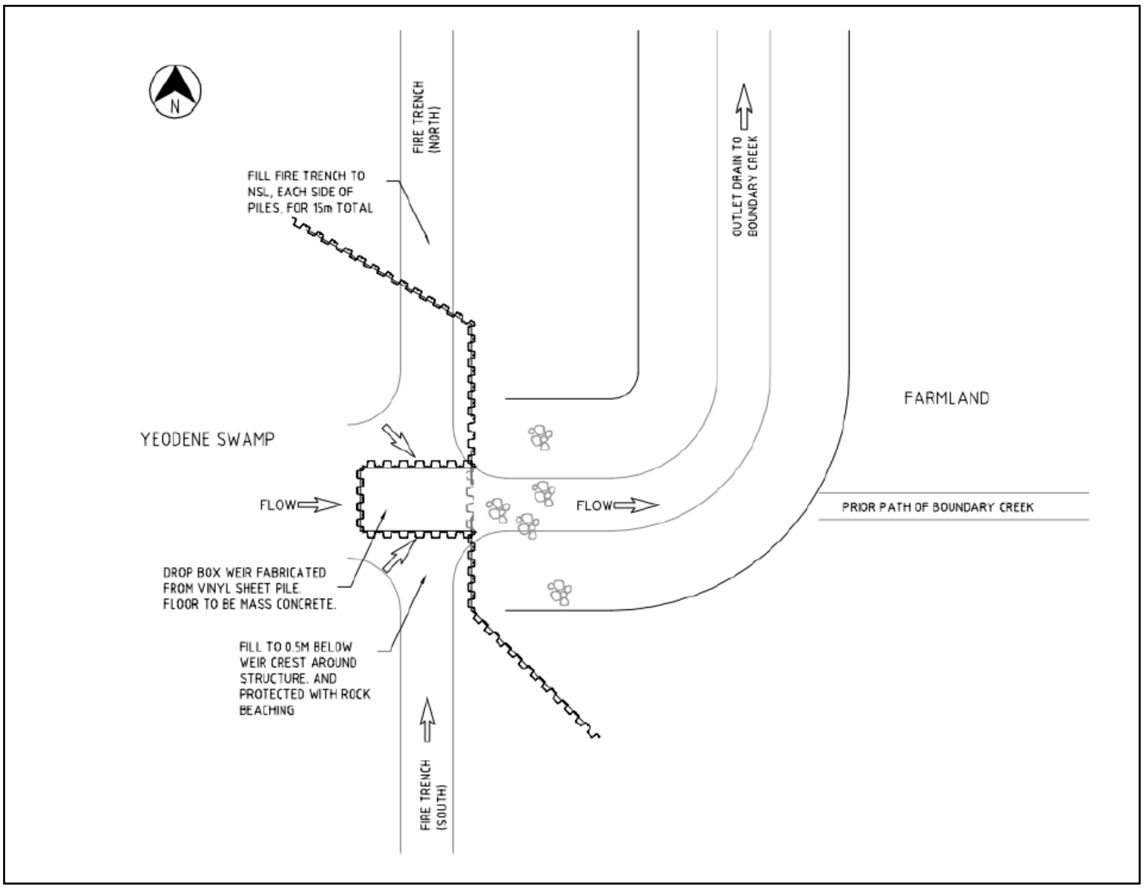

Figure 7-7 Location of Hydraulic Barrier (Jacobs, 2018b)

Interpretation of preliminary results from Jacobs' modelling work is provided below.

Surface Water

- The barrier is set at an elevation of 142.5 m AHD. Surface water levels are below the top of the barrier for each of the scenarios modelled (i.e. supplementary flows of 2 – 5 – 10 – 20 ML/d, refer to Figure 7-8).

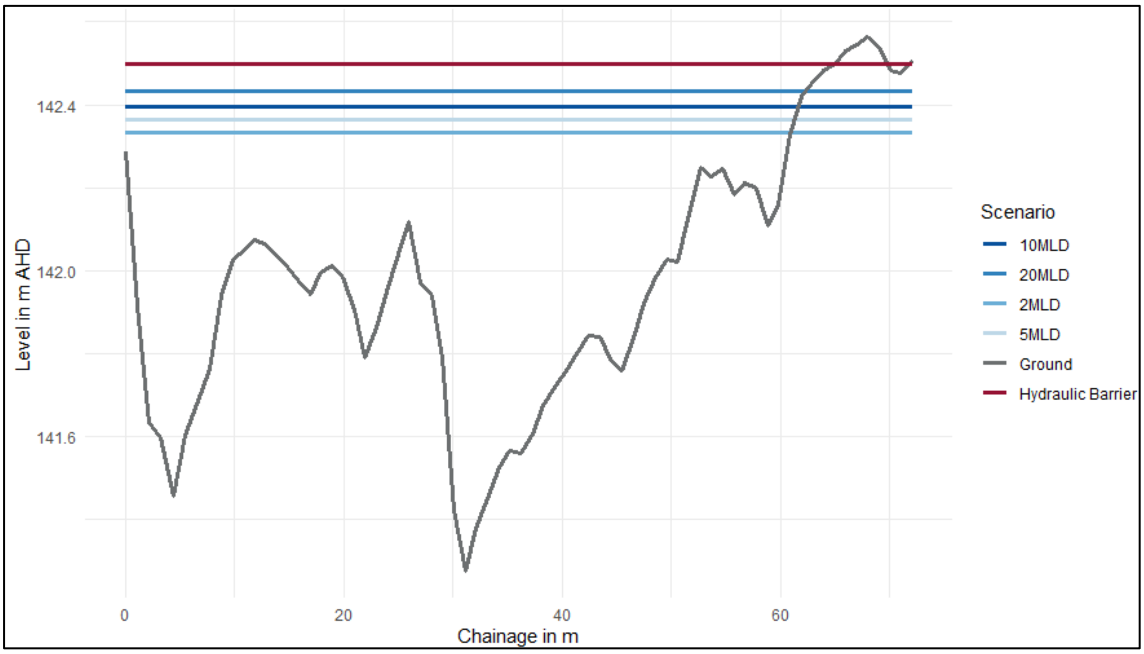

Figure 7-8 Peak water levels immediately adjacent to the hydraulic barrier for various release flows (Jacobs, 2019b)

- Modelled surface water flow across Big Swamp appears to primarily develop through a defined channel along the northern boundary. As supplementary flow rate increases, a range of secondary flow channels appear to develop in the upper-central portion of the swamp (Figure 7-9).

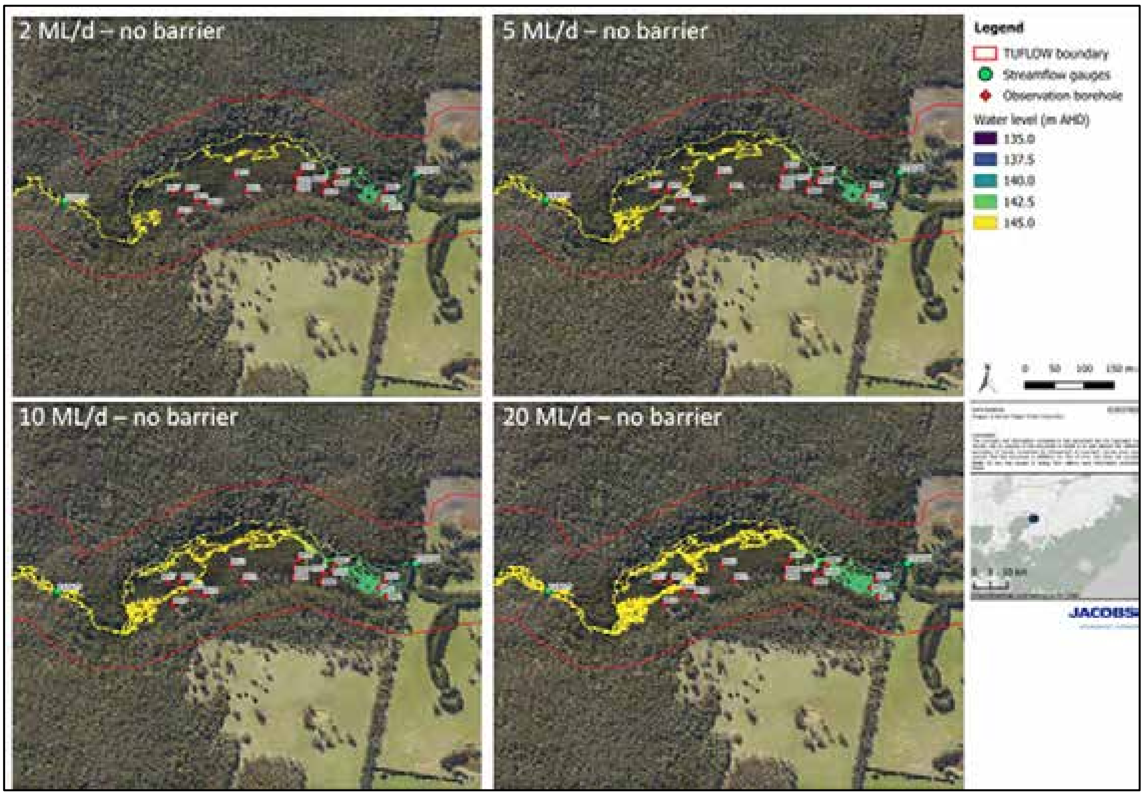

Figure 7-9 Modelled Surface Water Levels (2 – 5 -10 – 20 ML/d release flow, no barrier (Jacobs, 2019b))

- The effect of installing a hydraulic barrier at the eastern end of the Big Swamp is to increase the area of inundation immediately upstream of the barrier. As indicated in Figure 7-16, the additional area of inundation due to the hydraulic barrier is diminished with higher supplementary flows. The effect of these supplementary flow appears to be mostly associated with generation of flow paths upstream of the barrier.

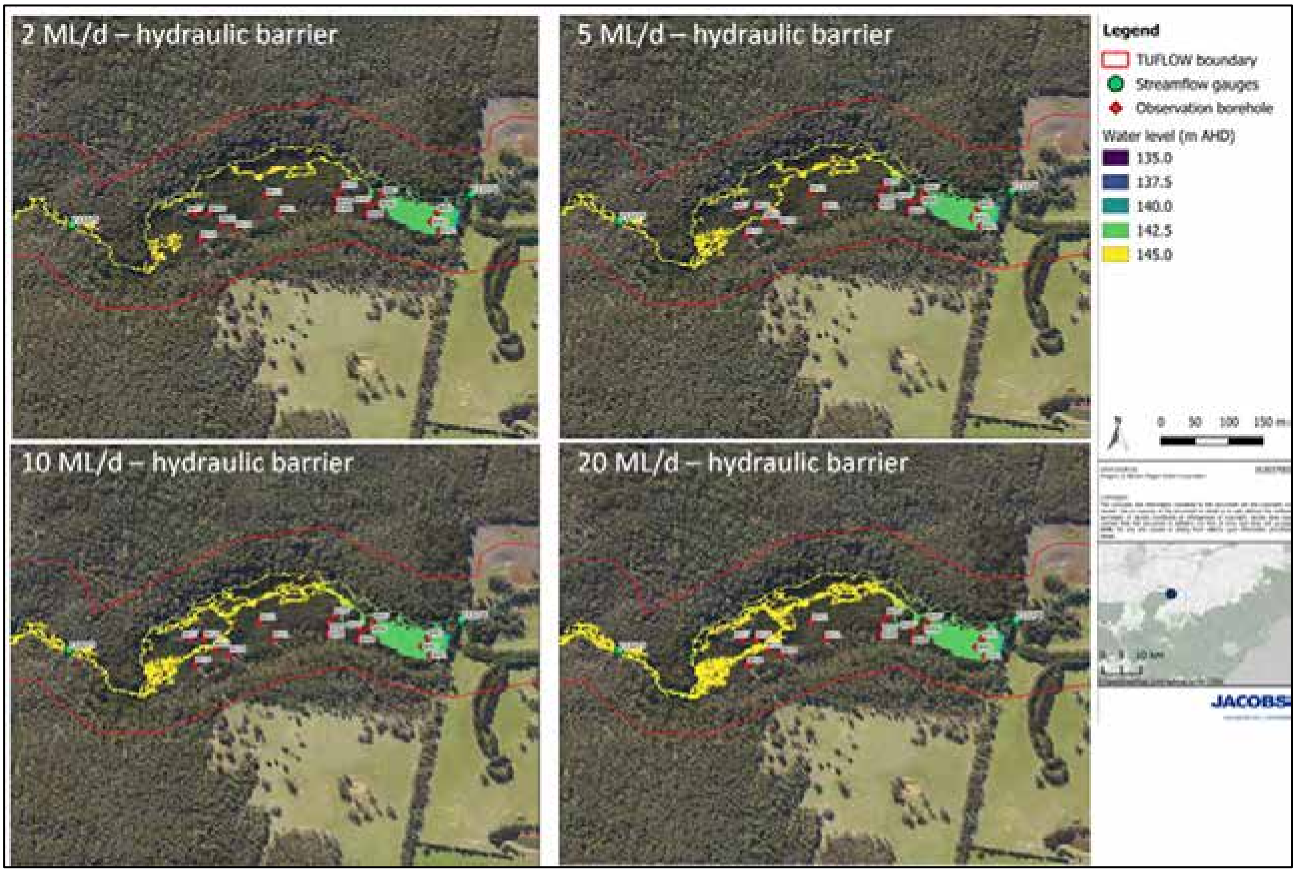

Figure 7-10 Modelled Surface Water Levels (2 – 5 -10 – 20 ML/d release flow, hydraulic barrier (Jacobs, 2019b)

- Calculated areas of inundation for each scenario are summarised in Table 7-12 (Jacobs, 2019b). The results indicate that a supplementary flow of 5 ML/d results in an increase in inundation extent of 40% over the 2 ML/d supplementary flow. A supplementary flow of 10 ML/d results in an increase in inundation extent of 85% and a supplementary flow of 20 ML/d results in an increase in inundation extent of 130% compared to the 2 ML/d supplementary flow.

Table 7-12 Area of inundation over each scenario (Jacobs, 2019b)

Supplementary Flow(ML/d)	Area of inundation under existing model structure (m^2)	Area of inundation with the inclusion of the hydraulic barrier (m^2)
2 ML/d	17,800	27,500
5 ML/d	25,100	34,100
10 ML/d	33,300	41,100
20 ML/d	41,700	48,500

- Predicted streamflow rates at the Yeodene gauge for each of the modelled scenarios (Figure 7-11) indicate that a minimum flow of at least 0.9 ML/d is maintained in Reach 3 of Boundary Creek.

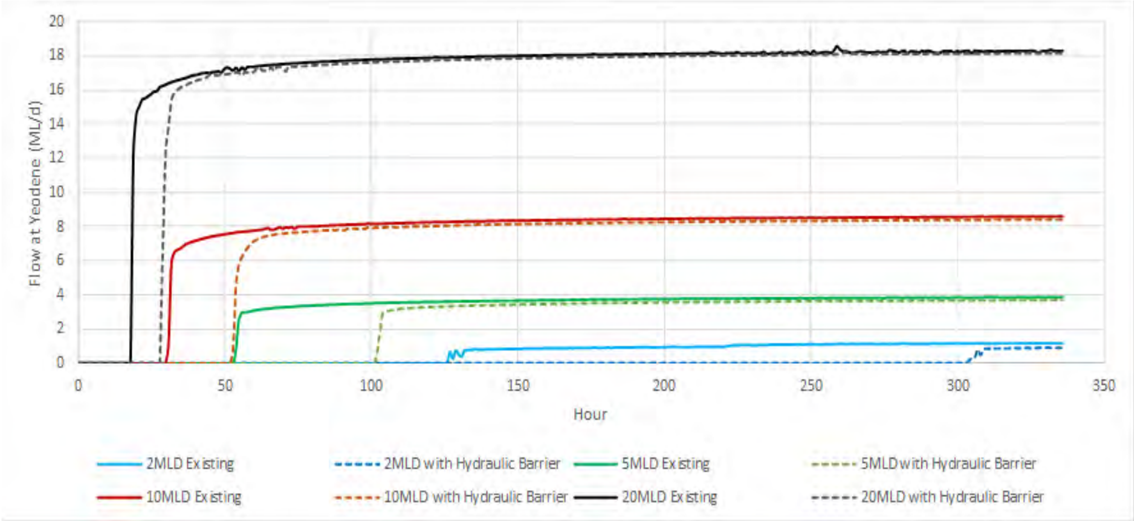

Figure 7-11 Modelled stream flow under each scenario at the Yeodene gauge 233228

- **In summary**, surface water modelling results indicate the following:
  - The introduction of supplementary flow increases the inundation extent of the swamp. Installation of a hydraulic barrier at the eastern end of the swamp is effective in increasing extent of inundation, particularly in the areas immediately upstream of the barrier.
  - When the barrier is in place, the area of inundation immediately upstream of the barrier appears to be relatively independent from increasing supplementary flows, which have the main effect of activating additional flow paths in the upper-central portion of Big Swamp, upstream of the barrier.
  - A supplementary flow of 2 ML/s is effective in maintain a streamflow of 1.1 ML/d (no hydraulic barrier) and 0.9 ML/d (hydraulic barrier) in Reach 3 of Boundary Creek.
  - Construction of additional barriers should be considered to achieve more effective inundation of the swamp and target areas where reflooding is considered beneficial (i.e. areas of higher existing and/or potential acidity).

Groundwater

- Six predictive scenarios have been formulated and run by Jacobs to assess future surface water and groundwater flow regimes:
  - Scenarios 1 to 4 are short term (150 days) simulations that assume a dry period in which the creek flow is entirely supported by supplementary flow (2 ML/d and 20ML/d, with or without hydraulic barriers).
  - Scenarios 5 and 6 are longer term (10 years) simulations that assume an arbitrary flow regime in Boundary Creek (Figure 7-12) to evaluate groundwater level response in Big Swamp, with or without barrier.

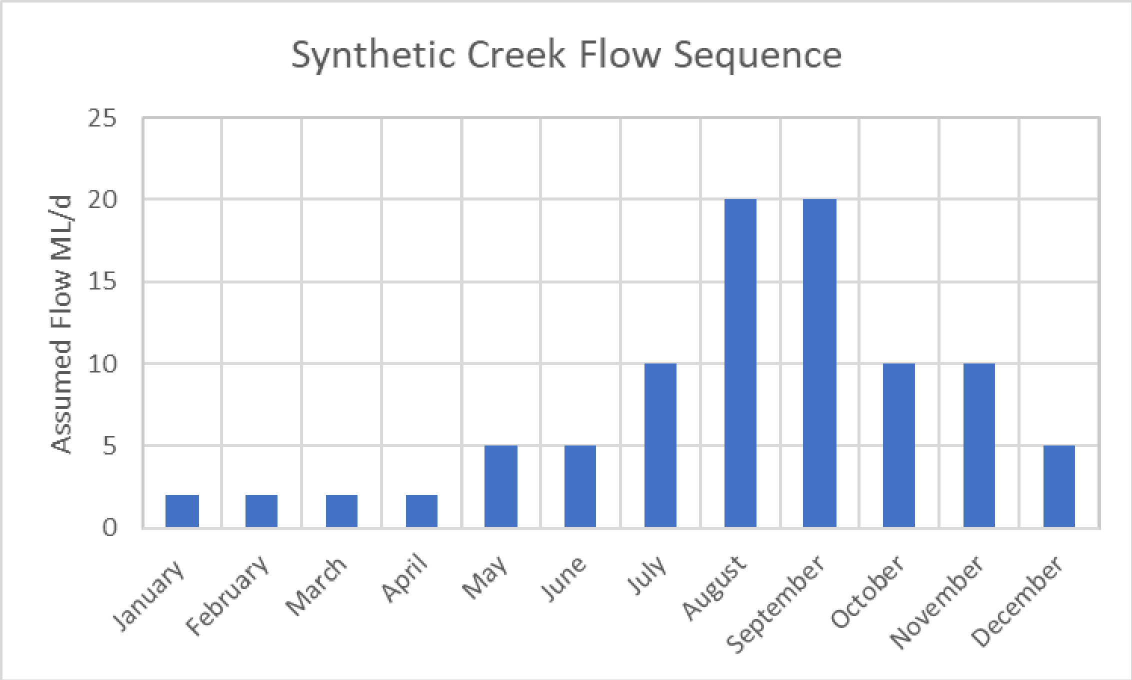

Figure 7-12 Assumed Boundary Creek flow (Jacobs, 2019b)

- Contour maps of the predicted change in head across the swamp for scenario 1 (2 ML/d supplementary flow, no hydraulic barrier) and scenario 3 (20 ML/d supplementary flow, no hydraulic barrier) are presented in Figure 7-14. The head change is calculated after 150 days of constant flow release from the modelled September 2019 groundwater levels, which are considered to represent typical winter (i.e. high) levels.

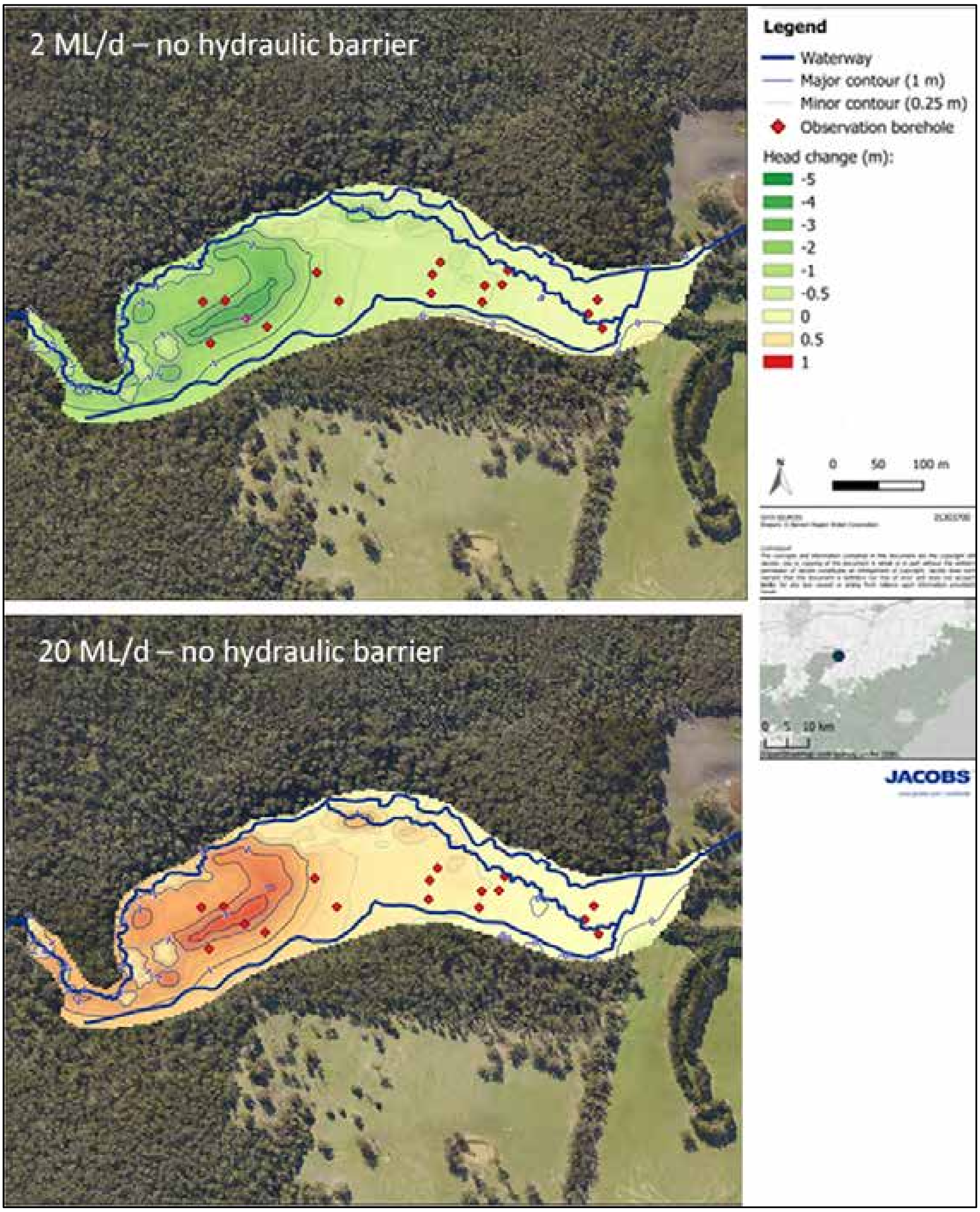

Figure 7-13 Predicted head changes across Big Swamp after 150 days of supplementary flow release, scenario 1 and scenario 3 (Jacobs, 2019b)

- Analysis of Figure 7-14 indicates that a supplementary flow of 2 ML/d does not maintain groundwater levels at typical winter levels, particularly at the western part of the swamp. Instead, a supplementary flow 20 ML/d is effective in raising groundwater levels throughout the swamp.
- Contour maps of the predicted change in head across the swamp for scenario 2 (2 ML/d supplementary flow, with hydraulic barrier) and scenario 4 (20 ML/d supplementary flow, with hydraulic barrier) are presented in Figure 7-14. The head change is calculated after 150 days of constant flow release from the modelled September 2019 groundwater levels, which are considered to represent typical winter (i.e. high) levels.

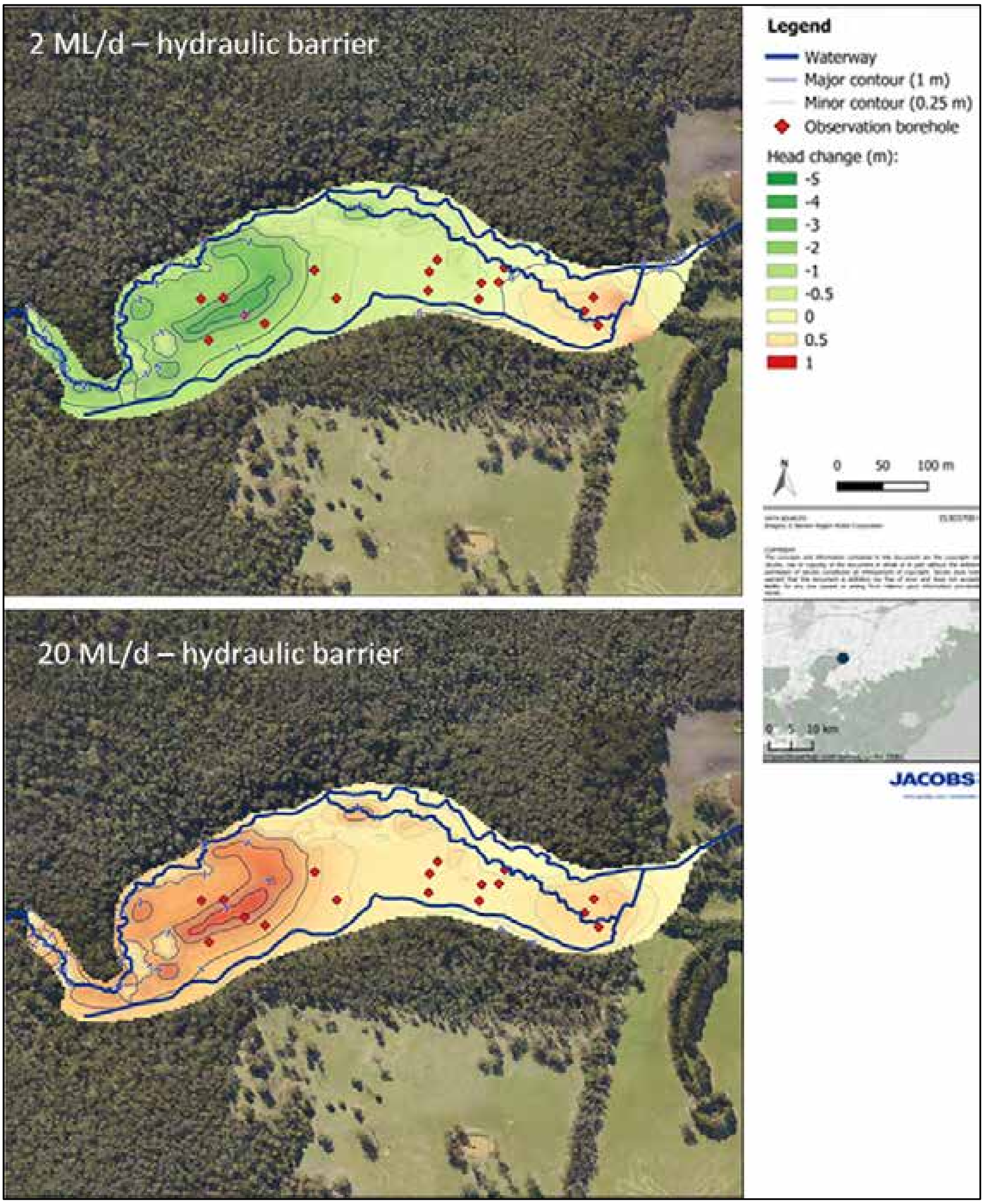

Figure 7-14 Predicted head changes across Big Swamp after 150 days of supplementary flow release, scenario 2 and scenario 4 (Jacobs, 2019b)

- Analysis of Figure 7-14 indicates that incorporation of a hydraulic barrier is effective in raising groundwater levels in the areas in close proximity of the barrier, with limited effect on groundwater levels further upstream.
- Results of scenarios 5 and 6 (Figure 7-15) indicate the absence of long-term trends in groundwater heads, which appear to fluctuate seasonally around a long-term average condition. The magnitude of the seasonal head fluctuations is expected to be much greater in the upper reaches of the swamp than the lower reaches. The predicted impacts of the hydraulic barrier are constrained to the downstream part of the swamp and the increases in groundwater head caused by the barrier are not predicted to be propagated upstream of monitoring bores BH7, BH8 and BH9.

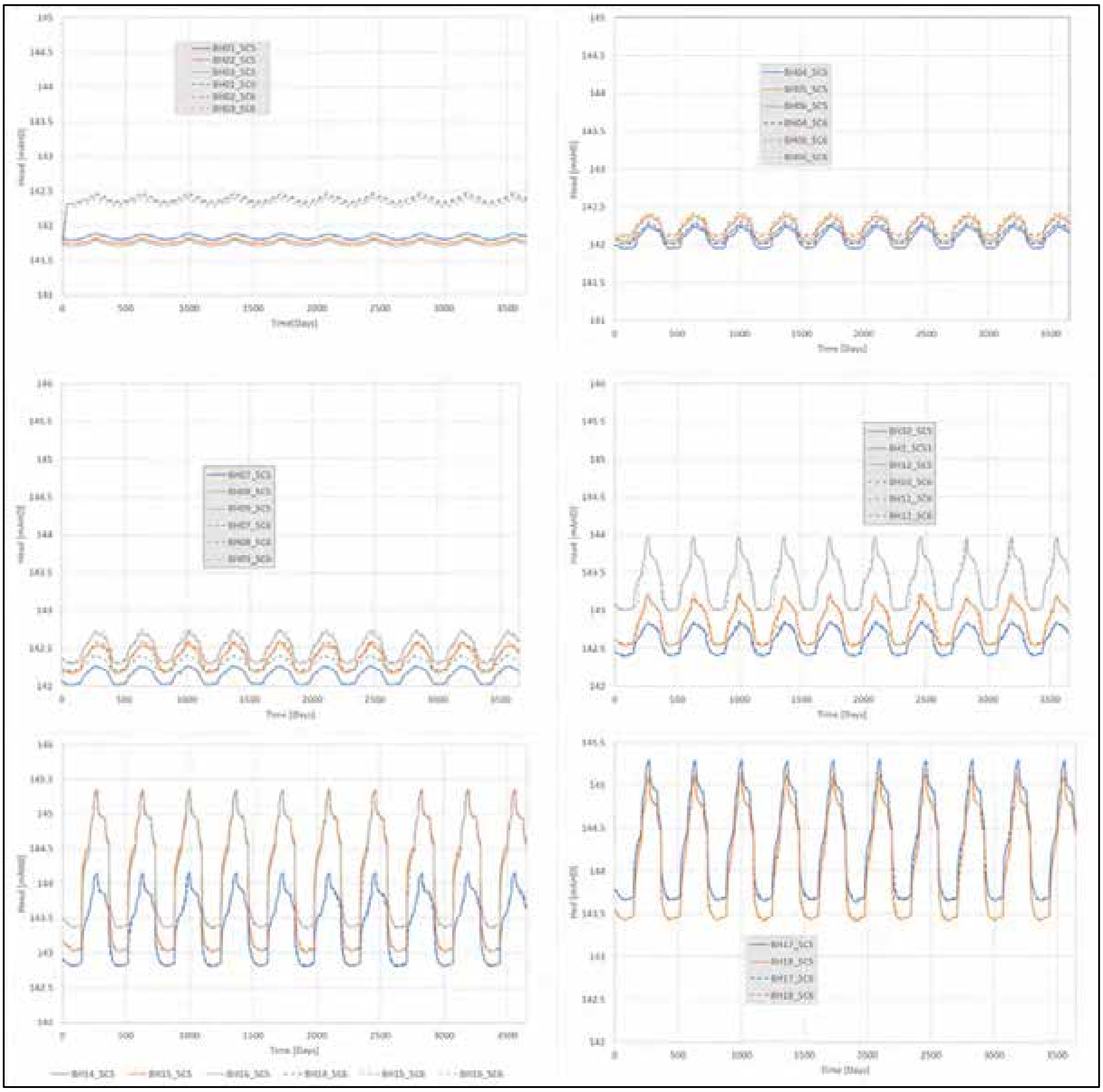

Figure 7-15 Predicted long-term head changes across Big Swamp under a synthetic flow sequence (Jacobs, 2019b)

- **In summary**, groundwater modelling results indicate the following:
  - A combination of providing supplementary flow and installation of a hydraulic barrier at the eastern end of the swamp can be effective in maintaining or increasing groundwater levels across Big Swamp and in ensuring a minimum flow in Boundary Creek during the year.
  - The effect of the hydraulic barrier on groundwater levels appears to be localised and is not predicted to propagate to the central and upstream parts of Big Swamp. Similarly, to surface water levels, installation of multiple hydraulic barriers is likely to require less supplementary flow and be more effective in managing groundwater levels across Big Swamp when compared to a single barrier.
  - A supplementary flow of 2 ML/d does not appear maintain groundwater levels at typical winter levels (i.e. at the end of September) throughout the swamp, whereas a supplementary flow 20 ML/d raise groundwater levels throughout the swamp. No information is provided by Jacobs on the effect of intermediate supplementary flows (i.e. 5 and 10 ML/d) on groundwater levels.

  - Long-term (10 years) simulations indicate that groundwater heads are not expected as the groundwater system equilibrates quite rapidly with changing flows in the creek (Figure 7-15). Higher groundwater level fluctuations are predicted across the western end of Big Swamp (as indicated by predicted long-term groundwater changes in groundwater monitoring wells BH14 to BH18) compared to the eastern end of Big Swamp (as indicated by predicted long-term groundwater changes in groundwater monitoring wells BH01 to BH06).

7.3.6.3.2 Incubation Testing

Incubation testing results (Monash University, 2019) relevant to the implementation of this option are summarised as follows:

- The main reaction observed in the incubation testing is iron reduction, which neutralises 8 equivalents of H^+ for each mole of carbon oxidised.
- No sulfide accumulation has been observed in the incubation testing, indicating sulfate reduction is not taking place to any significant extent.
- Based on the neutralisation rates associated with iron reduction reaction, it was estimated that the net acidities in the soil samples where this reaction was occurring could be neutralised within 1-2 years, assuming steady state reaction rates and continued availability of bioavailable iron and organic carbon.
- The soluble ferrous iron (Fe^{2+}) produced by reducing conditions is mobile and has the potential to be exported downstream of Big Swamp to Boundary Creek and Barwon River. This ferrous iron will generate acidity when exposed to oxygen rich water in Reach 3 of Boundary Creek and/or Barwon River.
- It is unlikely that sulfate reduction reaction will contribute to immobilisation (i.e. precipitation as FeS) of the soluble ferrous iron (Fe^{2+}) produced by reducing conditions. However, recent results do indicate a significant reduction of iron concentration after 128 of testing, indicating that other reactions may be contributing to precipitation of ferrous iron. This matter is subject of further investigations at the time of this ROA.
- The risks associated with mobilisation of existing acidification products within the oxidised sediments in Big Swamp and the potential mobilisation of mobile aqueous ferrous ions are heightened by the current lack of buffering capacity (i.e. alkalinity) both in the Boundary Creek water as well as in the Big Swamp sediments.

7.3.6.3.3 Geochemical Considerations

The results of the draft geochemical assessment (GHD, 2019) are summarised below.

- The time required to flush out the net acid mass that would remain in Big Swamp has been estimated as follows:
  - 2ML Day and no barrier: 100 years ± 50% depending on density assumption and mass flux variance.
  - 2ML Day with barrier: 80 years ± 50% depending on density assumption and mass flux variance.
  - 20ML Day with barrier: 50 years ± 50% depending on density assumption and mass flux variance.
- The swamp sediments contain high amounts of organic carbon, so there should be sufficient carbon source to form and maintain reducing conditions for the foreseeable future.
- The thermodynamic model results support the results of the Monash University study. As reducing conditions dominate, the ferric iron present is reduced to ferrous iron and enters solution, while sulphate reduction does not appear to occur to any level of significance. The only removal of sulphate from solution, as suggested in the model, is precipitation of Aluminium Sulphate. Figure 7-16 shows the changes predicted by the model.
- The thermodynamic modelling also demonstrated that iron is removed from solution through the precipitation of iron oxides and hydroxides irrespective of the Eh conditions (anoxia is not required). The precipitation is pH controlled; it occurs when the pH is above 3.5 units. These finding as corroborated by the Monash University column studies where it was demonstrated that iron is removed from solution when the pH is above 3.5 units.

The Monash University study also demonstrated that the precipitation of the iron does not affect the concentration of dissolved inorganic carbon (DIC). Although the thermodynamic modelling has not used the water quality form the columns as input, it is likely that there will be sufficient readily available neutralising capacity to manage the areas with acidic conditions or the potential to generate acidic conditions.

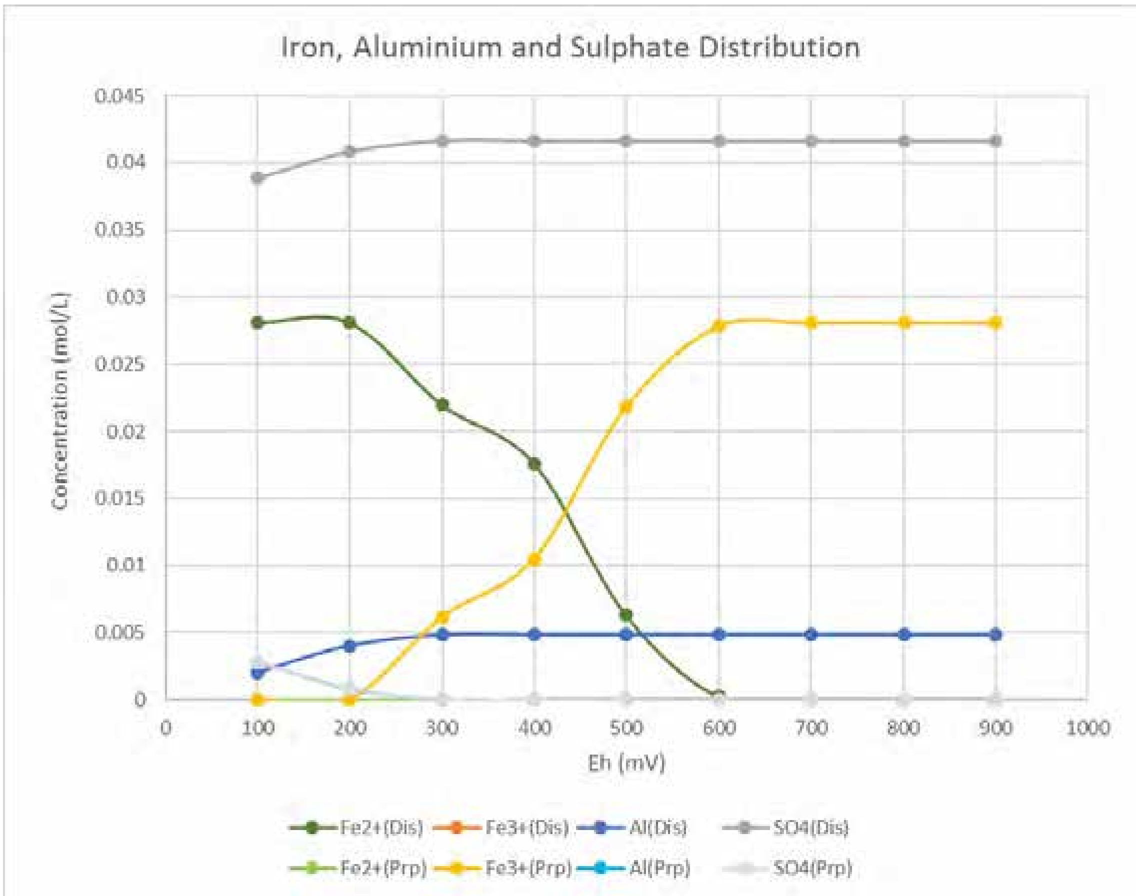

Figure 7-16 Changes in concentration of various compounds due to a return to reducing conditions predicted by the thermodynamic modelling (GHD, 2019)

- The system deficiencies identified through the geochemical modelling can be described as follows:
  - The most significant limitation is a lack of sulphate, which will limit the attenuation of acid through sulphide mineral precipitation. The Monash University incubation studies and geochemical assessment suggest that the reduction will proceed to the iron reduction stage, leading to ferrous iron in solution and transport out of the swamp, resulting in the export of acidity.
  - No kinetic data is available for the complete oxidation / reduction cycle, and therefore the reliability of predictions of geochemical processes is limited.
- The most significant benefit of re-flooding would be the increase of groundwater levels in the swamp, limiting the potential for further oxidation of the re-saturated PASS that may be present within Big Swamp.
- The following should be noted with regards to acid flushes:
  - The re-flooding is likely cause an initial increase of acidity being flushed downstream of Big Swamp, which will then abate once the retained and actual acidity is removed from the system.
  - Interpretation of historic stream flow and pH at Yeodene gauge in Reach 3 of Boundary Creek supports this conclusion. At this location, pH was found to be below the long-term average 84% of the time prior to the

release of the 2 ML/d supplementary flow, and 97% of the time after release of the 2 ML/d supplementary flow.

  - This indicates that the supplementary flow is likely to lead to additional acid flushing in the short to medium term but would reduce the overall acid flux in the long term in consideration of decreased potential for oxidation of the saturated ASS sediments.

- In the context of acid flushes in response to storm events, this would be situation dependent. The historic record suggests that in the majority of storm events, pH was higher during high flow, but there are occasional events where this is not the case. By increasing the saturated volume and inundated area of the swamp, there is likely to be an increase in the risk of acid flush events, as the retained and actual acidity enters solution leading to acidic conditions in standing water bodies in the swamp. This acid water could then exist the swamp in a first flush event in response to a localised storm event.

7.3.6.3.4 Vegetation

Eco Logical (2019) provides an assessment of the potential outcomes associated with increasing groundwater levels and creating permanently inundated areas across Big Swamp, as summarised below:

- Establishment of permanently inundated areas will cause in the total loss of all vegetation cover, resulting in similar conditions to those observed in eastern end of Big Swamp, where a small area of ponded water is present (Figure 7-17).

Figure 7-17 Ponded area at the eastern end of Big Swamp

- Restoring saturated conditions within the top first meter of Big Swamp alluvium sediments is a requisite to preserve the Riparian Fern Scrub community and reduce encroachment of the surrounding Lowland Forest into areas historically dominated by damp woodlands.
- Blocking the preferential channels that have developed since the 2010 fires is likely to achieve a broader distribution of surface flows across Big Swamp and promote establishment of a diverse range of vegetation.

7.3.6.4 Cost Estimate

A cost estimate for delivering the contingency flow and installation of up to three hydraulic barriers across Big Swamp is provided in Table 7-13. The capital cost for installation of each hydraulic barrier is based on the figures provided in the Yeodene Swamp Study (Jacobs, 2018b) which is considered adequate for the purpose of this ROA.

The estimate assumes that no amendments will be used to promote sulfate reducing conditions in the reflooded areas.

Table 7-13 Wetland Flooding and Managed Groundwater Levels – Treatment Cost per 10 years operational time

Cost item	Estimate (AUD)	Notes
Capital	$ 1,200,000	From Jacobs report (Jacobs, 2018b). Cost is for three barriers.
Engineering	$ 240,000	20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc.
Land acquisition	$ 220,000	Assumed 11 ha and $20,000 per ha.
O&M per year	$ 42,000	3.5 % of capital costs (excludes cost of water).
Sampling per year	$ 20,000	Monthly water sampling, 4 samples per event.
Total 10 years	$ 2,280,000	

7.3.6.5 Overall Assessment

Based on the above, our assessment on the ability of this remediation option (as described in the modelling work by Jacobs) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: Medium to High.**

  Based on modelling results, when a 2 ML/d supplementary flow is delivered, it does not appear that groundwater levels can be significantly increased (eastern end of the swamp) or maintained (central and western parts of the swamp) with or without the presence of a hydraulic barrier at the eastern end of the swamp.

  Conversely, when a 20 ML/d supplementary flow is delivered, groundwater levels appear to remain steady or increase across most of the swamp. Under this higher supplementary flow scenario, the influence of a hydraulic barrier at the eastern end of the swamp appears localised.

  By extrapolating these results, it is considered that a combination of practically achievable supplementary flows (i.e. in the range of 5ML/d) and strategically placed hydraulic barriers is likely to be effective in maintaining minimum groundwater levels across targeted areas of Big Swamp.

  Additional surface water and groundwater modelling work will be required to progress design of this option and to support cost-benefit analysis.

- **Control acid release: Initially Low then Medium.**

  This will depend on the volume of supplementary flow delivered, the proportion of Big Swamp that will be permanently inundated and the ability of the natural system to establish iron reducing and sulfate reducing conditions.

  GHD (2019) indicates that, initially, the delivery of supplementary flow has the potential to increase downstream release of actual and retained acidity. However, this process will progressively abate as the acidity is flushed from the system and further aerobic oxidation of ASS sediments is prevented by the establishment of higher groundwater levels.

  The Monash University incubation testing also indicate that, even if the system is unlikely to progress to sulfate reducing conditions, iron reducing conditions also have the ability to neutralise acidity in the permanently flooded areas, within a timeframe estimated in the range of 1-2 years.

  As discussed in Section 8, the risk of increased acid releases will require management in the form of ongoing monitoring and potential implementation of risk mitigation (i.e. contingency) measures. For example, application of neutralising agents could be considered as an effective approach to manage the risk associated with increased export of acidity in Boundary Creek.

- **Manage secondary precipitates: Potentially Worse (if unmanaged).**

The soluble ferrous iron generated under reducing conditions in the permanently flooded portions of Big Swamp has the potential to be exported to downstream receiving environments (i.e. Boundary Creek and Barwon River) generating acidity and iron precipitates.

The magnitude of this secondary effect depends on several factors and ongoing monitoring will be required to evaluate the severity of potential impacts. Recent results from the Monash University testing indicate a reduction of soluble iron after 128 days of incubation, indicating the potential for the iron to be retained in Big Swamp rather than exported downstream.

As discussed in Section 8, the risk of increased acid releases will require management in the form of ongoing monitoring and potential implementation of risk mitigation (i.e. contingency) measures. For example, construction of an intermediate settling pond between Big Swamp and Boundary Creek could be considered as an effective approach to manage the risk of formation of acidity and secondary precipitates in Boundary Creek.

- **Maintain Boundary Creek minimum flow: High.**

  Based on surface water modelling results, release of supplementary flow upstream of McDonalds Dam in the range of 2 ML/d appears to be adequate to sustain a flow in the range of 1 ML/d in Boundary Creek at the Yeodene gauge.

- **Improve vegetation: Medium to High.**

  It is considered that an improved hydrological regime across Big Swamp will have a positive effect in restoring some of the ecological values and diversity over time.

  The Big Swamp ecological assessment (Eco Logical, 2019) indicates that creation of permanently inundated areas across Big Swamp will cause a complete loss of non-aquatic vegetation. However, these losses will be offset by the improvements in areas of increased surface flow and higher groundwater levels.

  To mitigate loss of vegetation, Eco Logical suggests that hydraulic barriers are realised so that a dynamic regime of inundation and drying is established over the year. This could be realised, for example, by incorporating weirs and gates as part of the hydraulic barrier design to allow a degree of control on the level and duration of inundation.

  It is noted that, while a seasonal regime would be beneficial for vegetation, it may not be practical to implement and also have the adverse consequences of increasing acid release downstream of Big Swamp and limit the ability to promote reducing conditions required for neutralisation of acidity.

- **Reduce fire risk: Medium to High.**

  Increasing groundwater levels and maintaining a more permanent surface water coverage across Big Swamp is likely to reduce fire risks, depending on the portion of the Big Swamp that will be permanently inundated.

7.3.7 Active Treatment System

7.3.7.1 Principle

This option relies on installing an active treatment system immediately downstream of Big Swamp to increase alkalinity/pH and remove metals (as precipitates) prior to releasing the treated water into Boundary Creek.

Based on a design treatment flow rate of 4 ML/d and water quality parameters summarised in Table 7-1, the proposed solution involves the installation of an in-stream system (water or electric powered) dispensing pebble quicklime (CaO) directly into Boundary Creek (such as the Aquafix system in Figure 7-18).

The in-stream system will be followed by a settling pond (and/or aerobic wetland) to oxidise water and facilitate precipitation of metals. Treated water flowing from the settling pond would then be directed to Boundary Creek.

The advantages of an in-stream system over a fixed plant are reduced capital costs, low O&M intensity and small footprint. However, in-stream systems are suitable within a certain acid load range (i.e. treatment flow rate multiplied by water acidity) and input parameters will require to be properly considered when developing system design to assess which option would be more suitable.

Figure 7-18 Aquafix Quicklime Dispensing System

7.3.7.2 Implementation

Possible implementation and cost estimate of the system has been progressed using AMDTreat software for a reference design flow rate of 4 ML/d and water quality parameters in Table 7-1. Flow in excess of the design treatment capacity would have to by-pass the in-stream system and be discharged directly in Boundary Creek.

Based on AMDTreat estimates, the consumption of quicklime to neutralise acidity is in the range of 1.45 t/day (for a treatment pH of 6) and sludge production in the range of 15-30 m^3/day (depending on various parameters including water quality, quicklime mixing efficiency, target pH and sludge density). The Aquafix system would have a storage capacity of 50 t, allowing for one refilling of quicklime per month.

Dimensions of the settling pond are 57 m wide, 110 m long and 3 m deep, ensuring a residence time of 48 hours and allowing for removal of sludge every year.

It is noted that the above figures on chemical consumption and sludge production are based on limited data and need to be verified by laboratory and field trials that would be required to progress design of this option.

7.3.7.3 Expected Performance

Use of pebble quick lime is a consolidated approach for treatment of water impacted by acidity and metals, and systems like the Aquafix have been successfully employed in the United States for treatment of high acidity/high flow situations.

The effect of the system on Boundary Creek water quality is likely to be variable and depending on seasonal variations of streamflow values and acidity loads, as summarised below:

- When Boundary Creek flow rates fall within the in-stream design treatment capacity (i.e. 4 ML/d as assumed in the ROA), it is expected that water into the creek would be of good quality, with a pH greater than 6 units and low concentration of dissolved iron and aluminium.
- Flow rates in excess of the design treatment capacity would have to by-pass the in-stream system and water quality in Boundary Creek would be a result of the mixing of the treated and untreated streams.
- Depending on finals system design, periods of higher acidity loads (which could happen at any flow rate) could be managed by increasing the pebble quicklime dosing rates, until the maximum system neutralising capacity is reached. Any acidity load above the system capacity will not be treated by the in-stream system.

7.3.7.4 Geochemical Considerations

The main geochemical consideration associated with this option (GHD, 2019) are summarised below:

- Stream flows at Yeodene gauge in excess of the 4ML/d treatment capacity (as assumed in the ROA) occurred around 27% of the time over the monitoring period post January 2000.
- Acidity concentrations at Yeodene gauge in excess of 500 mg/L (based on automated pH data collected by the Yeodene monitoring station) occurred around 50% of the time over the monitoring period post January 2000.
- Modelled reagent dosing rate (assuming the use of lime and a target pH of 6 units) are estimated in the range of 300 kg/d, which is considerably less than the pebble quicklime dosing rate provided by the AMDTreat software.
- Modelled sludge generation rates are in the range of 2,500-25,000 m^3 per year (depending of acidity loads) which is considered to be consistent with the sludge generation rate provided by the AMDTreat software.

This analysis indicates that there is potential for the system capacity assumed in the ROA to be undersized during periods of high flow and/or high acidity, which would result in decreased water quality in Boundary Creek.

Additional data and studies will be required to select system performance requirements as well as to inform and refine the current estimates on chemical dosing rates and sludge production.

7.3.7.5 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-14 and Table 7-15.

Table 7-14 In-stream treatment - Design Inputs and Cost Assumptions

Design inputs	Cost Assumptions	O&M and sampling assumptions
Flow rate: 4 ML/day Acidity: 500 mg/L Sludge volume: 6,700 m^3/year (at 5% solids) Sludge removal events: one per year Sludge generation rate: 0.0046 m^3 sludge / m^3 water CaO dosing rate: 1.45 t/day $^{-1}$	• No management cost (i.e. pre-classification and disposal) for soil volumes excavated for settling pond construction (14,530 m^3) • Land acquisition cost: $ 20k/ha • Sludge removal rate: $ 50/m^3 • Chemical cost with delivery: $ 200/t	Monthly water sampling, 4 samples per event O&M cost 3.5% of capital cost for consistency with AMDTreat

Table 7-15 In-stream treatment – Treatment cost per 10 years operational time

Cost item	Estimate (AUD)	Notes
Capital	$ 550,000	
Engineering	$ 110,000	20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc.

Cost item	Estimate (AUD)	Notes
Land Acquisition	$ 100,000	Assumed 5 ha
Chemical cost per year	$ 110,000	
Sludge removal per year	$ 335,000	
Sampling per year	$ 20,000	
O&M per year	$ 20,000	O&M (3.5% of capital). Routine O&M, no major reconstruction work.
Total 10 years	$ 5,610,000	

7.3.7.6 Overall Assessment

Based on the above, our assessment of the ability of this remediation option (in the implementation described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: High.**

  This technology has a high potential to control the acid discharge from the swamp, assuming that adequate design parameters are selected using additional data from Boundary Creek monitoring (flow rates and water quality), geochemical modelling, treatability studies and pilot trials.

- **Manage secondary precipitates: High.**

  Secondary precipitates will be captured in the settling pond.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: No effect.**

  Implementation of this technology will have no effect on vegetation in Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

7.4 Ability to Meet Project Objectives

Our assessment of the ability of each technology to meet the project objectives is described in Section 7.3 and summarised in Table 7-16.

Table 7-16 Ability to Meet Objectives

Option / Objective	Maintain minimum GW levels in Big Swamp	Control acid release	Manage secondary precipitates	Maintain Boundary Creek Minimum Flow	Increase Melaleuca/Swamp Ovata ratio	Reduce Peat Fire Risk
Aerial liming	No effect	Low to Medium	Pot. Worse	No effect	Not known	No effect
Soil Mixing	No effect	Low(1)	No effect	No effect	Pot. Worse	No effect
Excavation and disposal	No effect	Low(1)	No effect	No effect	Pot. Worse	No effect
Aerobic Wetland	No effect	Low	Medium(2)	No effect	No effect	No effect
RAPS	No effect	Medium to High	High	No effect	No effect	No effect
Managed Groundwater Levels and Wetland Flooding	Medium to High(3)	Low to Medium(4)	Pot. Worse (if unmanaged)(5)	High(6)	Medium to high(7)	Medium to high
In-Stream dosing	No effect	High	High	No effect	No effect	No effect

Notes:

(1): Assuming only targeted treatment of 'hot spots' is practicably achievable.

(2): Assuming the aerobic wetland is integrated as part of other remediation options.

(3): Depending on detailed design, including actual volumes of supplementary flow and number/location/levels of hydraulic barriers.

(4): The 'low' ability assessment is related to the potential risk of increased export of acidity by increased volumes of supplementary flow and the formation of soluble/mobile ferrous iron under reducing conditions in the permanently inundated areas of Big Swamp.

Both processes will be ongoing until existing and retained acidity is present in Big Swamp and available organic carbon and ferric iron are present, so these side effects are expected to last for several years.

The 'medium' ability assessment acknowledges that above processes may be mitigated by several factors, including:

- *progressive reduction of exported acidity as the actual and retained acidity is flushed away from the system and higher groundwater levels minimising further aerobic oxidation of ASS sediments*
- *neutralisation of acidity as part of iron reduction reactions*
- *precipitation of ferrous iron, as indicated in the Monash University incubation testing*

Management of the above risks will require collection of additional data to improve the current understanding of the significance and temporal/spatial variability of the above processes as well as ongoing monitoring. Depending on the results of these additional studies and data collection, risk mitigation (i.e. contingency) measures will require to be implemented so that the risks are reduced to acceptable levels.

(5): It is recognised that export of ferrous iron in Boundary Creek has the potential to generate acidity as well as precipitation of insoluble iron compounds.

Management of the above risks will require collection of additional data to improve the current understanding of the significance and temporal/spatial variability of the above processes as well as ongoing monitoring. Depending on the results of these additional studies and data collection, risk mitigation (i.e. contingency) measures will require to be implemented so that the risks are reduced to acceptable levels.

(6): Assuming supplementary flow is effectively released downstream of McDonalds Dam.

(7): Depending on the ability to achieve a workable solution that balances the need to increase surface water flow and extent of permanently inundated areas with the goals of promoting higher ecological values and minimising loss of vegetation across Big Swamp.

7.5 Technology Scoring

Ranking of each indicator for the shortlisted remediation options, based on information provided in the previous sections, is presented in Table 7-17.

Table 7-17 Technology Scoring

Indicators	Aerial liming	Soil Mixing	Excavation and disposal	Aerobic Wetland	RAPS	In-stream dosing	Flooding and GW levels
A1 - Ability to meet project objectives	2	1	1	1	3	4	4
A2 - Technology development status	3	4	5	4	4	4	4
A3 - Track record of success in similar conditions	3	4	4	1	2	4	3
A4 - Amount of additional data required for detailed design	5	4	4	3	2	2	2
A5 - Potential side effects of remediation	3	2	1	4	4	3	2
A6 - Potential for residual risks following remediation	2	2	2	1	3	4	3
B1 - Footprint and infrastructure requirements	5	2	2	2	2	4	4
B2 – O&M intensity	4	4	4	3	2	1	4
B3 - Availability of equipment and supplies	4	3	4	4	4	3	5
B4 - Health and safety	3	3	3	4	2	3	5
C1 – Estimated fixed costs	5	3	2	4	1	4	3
C2 – Estimated ongoing costs	5	4	4	4	2	1	4
C3 - Potential for cost overruns	2	2	2	3	2	3	3
D1 - Regulatory acceptance	4	3	3	4	4	4	5
D2 - Community acceptance	4	2	1	4	3	4	4
D3 – Licensing and permits	4	3	3	3	3	4	4
D4 - Impacts on surrounding users and environment	3	2	2	3	2	3	4
D5 - Potential for legacy impacts following remediation	2	3	3	4	3	4	3
E1 - Timeframe for design and construction	5	3	3	3	3	4	3
E2 - Timeframe to meet remediation objectives	4	1	1	1	4	4	3
E3 – Longevity of treatment	2	2	2	2	2	2	3
F1 – Natural resource use	5	2	1	4	3	3	3

Indicators	Aerial liming	Soil Mixing	Excavation and disposal	Aerobic Wetland	RAPS	In-stream dosing	Flooding and GW levels
F2 – Chemical resource use	4	2	5	4	3	2	5
F3 - Waste generation and recycling potential	5	4	1	3	2	2	5
F4 – Emissions	4	3	3	4	2	3	4

7.6 Technology Ranking and Weighting

The score for each category has been totalled and normalised before a total score is calculated. The total score for each category has been set at 50, with a potential total score of 300 (six categories). This provides an unweighted score, where each category has equal weighting. The total category scores, total unweighted score and ranking of technologies is presented in Table 7-18.

During the first Technical Workshop it was identified that the scores could be weighted, depending on which category the stakeholders and Barwon Water deem to be most important. The weightings used in the weighted assessment were suggested by Darren Baldwin (Technical Expert for the RWG) on behalf of the technical panel and comprise:

- A - Technical = 40%
- B - Logistical = 10%
- C - Financial = 10%
- D - Stakeholders = 30%
- E - Timing = 5%
- F - Sustainability = 5%

The weighted score and ranking are shown in Figure 7-19 Table 7-19. 'Aerial liming' ranks highest in the unweighted scoring with 'managed groundwater levels and wetland flooding' ranking highest in the weighted assessment. The 'aerobic wetland' option and 'in-stream dosing' rank equal third in the unweighted assessment, but when technical aspects are prioritised in the weighting, the 'aerobic wetland' option drops to fourth, with 'in-stream dosing' scoring much higher and ranking third.

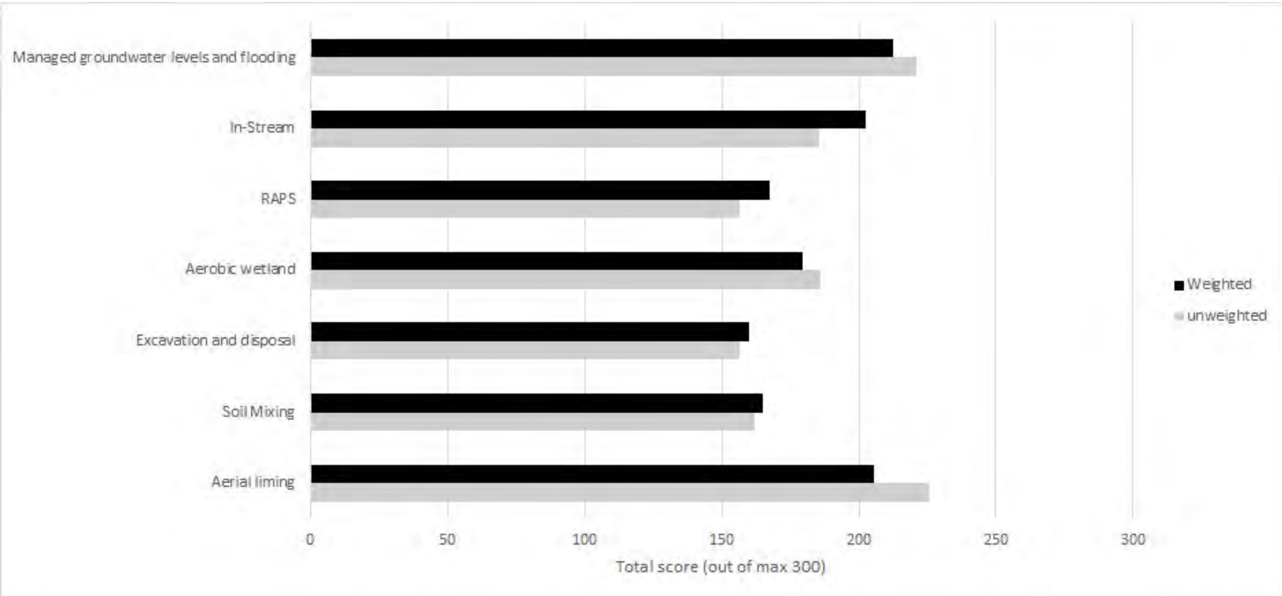

Figure 7-19 Results of scoring and ranking (weighted and unweighted) for the technologies for detailed assessment

Table 7-18 Category scores, total scores and ranking, weighted and unweighted

Option	A - Technical	B - Logistical	C- Financial	D - Stakeholders	E - Timing	F - Sustainability	Total unweighted score	Unweighted Rank	Total weighted score	Weighted Rank
Aerial liming	30	40	40	34	37	45	226	**1**	206	**2**
Soil Mixing	28	30	30	26	20	28	162	**5**	165	**6**
Excavation and disposal	28	33	27	24	20	25	157	**7**	160	**7**
Aerobic Wetland	23	33	37	36	20	38	186	**3**	180	**4**
RAPS	30	25	17	30	30	25	157	**6**	168	**5**
In-Stream dosing	35	28	27	38	33	25	186	**3**	202	**3**
Managed Groundwater Levels and Wetland Flooding	30	45	33	40	30	43	221	**2**	213	**1**

7.6.1 The Effects of Weightings

In order to test the effect of different weightings on the overall scores and rankings, a sensitivity analysis was undertaken. This consisted of varying the weightings one by one so that one category had a weighting of 75% whist the remaining had a weighing of 5%. The results are shown in Figure 7-20 and Table 7-19.

As can be seen, managed groundwater levels and wetland flooding score highest where logistical or stakeholders are prioritised, whereas aerial liming ranks highest for financial, timing and sustainability weighted assessments. Where technical considerations are prioritised, in-stream dosing ranks highest. In stream dosing scores highly across most categories, with the exception of logistical (intense ongoing operating requirements), financial and sustainability (large amounts of chemical use).

Soil mixing and excavation score consistently low across all categories as these technologies are very expensive and are unlikely to meet the project objectives. A standalone aerobic wetland scores low technically (unlikely to meet remediation objectives) and when timing is prioritised but relatively well for logistical, financial and sustainability due to the inactive style of treatment requiring little ongoing operation and cost. RAPS score consistently low as this technology is difficult to implement, expensive and produces hydrogen sulphide, which is both an environmental issue and unlikely to be acceptable to stakeholders due to the odour issues.

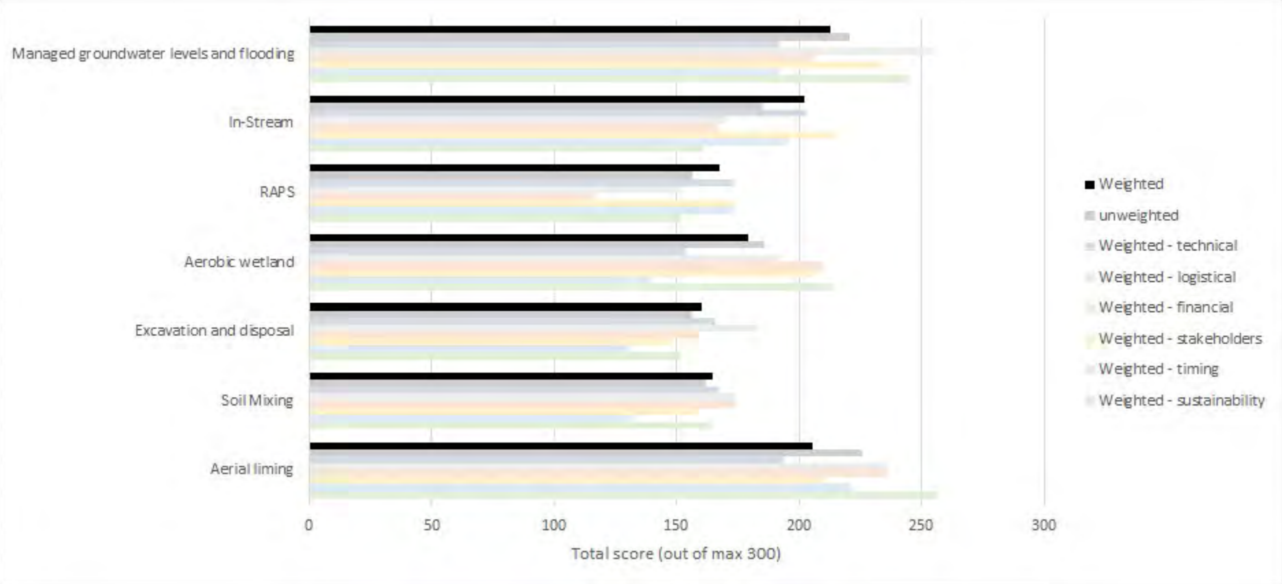

Figure 7-20 Sensitivity analysis for category weightings

Table 7-19 Results of sensitivity analysis of weightings on ranking and overall score

Option	Weighted Category											
	A - Technical		B - Logistical		C – Financial		D - Stakeholders		E - Timing		F - Sustainability	
	Total weighted score	Weighted Rank	Total weighted score	Weighted Rank	Total weighted score	Weighted Rank	Total weighted score	Weighted Rank	Total weighted score	Weighted Rank	Total weighted score	Weighted Rank
Aerial liming	195	3	237	2	279	1	212	3	195	5	258	1
Soil Mixing	181	4	181	5	195	4	164	6	209	3	171	4
Excavation and disposal	178	5	189	4	164	6	153	7	206	4	157	6
Aerobic Wetland	157	7	195	3	227	3	210	4	171	7	216	3
RAPS	175	6	154	7	133	7	175	5	189	6	154	7
In-Stream dosing	204	2	172	6	169	5	216	2	211	2	162	5
Managed Groundwater Levels and Wetland Flooding	211	1	260	1	253	2	239	1	211	1	250	2

Section 8 **Risk Assessment**

The following sections present methodology and results of a risk assessment undertaken on the proposed controls and actions that can be practically implemented for remediation of Big Swamp and Boundary Creek, in accordance to a requirement of the Section 78 Notice.

8.1 Identification of Practical Remediation Options

Through the technology identification process (Section 6.1), a total of 17 remediation option have been considered as potentially applicable for remediation of Big Swamp and Boundary Creek. Following preliminary screening (Section 6.2), seven remediation options were then retained for detailed assessment and relative ranking of technologies.

The result of the detailed assessment (Section 7) has indicated that three of the retained remediation options can be practically implemented at the site and include 'managed groundwater levels and flooding', 'in-stream dosing' and 'aerial liming'. Also 'aerobic wetland' has been included in the risk assessment because, while not suitable to be implemented in isolation, it could be considered as a final treatment step of other remediation options for the management of precipitates.

The other three retained options ('RAPS', 'soil mixing' and 'soil excavation/disposal) are considered unlikely to be practicably implemented at the site because of technical, logistical and financial considerations or the overall assessment on their ability to meet the project objectives. Therefore, they have not been included in the risk assessment.

As part of the risk assessment process, the 'managed groundwater levels and flooding' and 'in-stream dosing' remediation options have been broken down in their basic components to assist with identification and assessment of potential risks, as follows:

- 'Managed groundwater levels and flooding' assessed as a combination of the following components:
  - Infilling of fire trench and drains
  - Provision of supplementary flow
  - Installation of hydraulic barriers
- 'In-stream dosing' assessed as a combination of the following components:
  - Dosing system and handling of neutralising agent
  - Settling pond and sludge management

In addition, the 'aerial liming' option has been assessed as a more generic 'surface application of neutralising agents' so that the risks associated with potential implementation of this technology using terrestrial application methodologies.

Lastly, the 'in-stream limestone sand' option, that was not retained following preliminary screening, has also been included in the risk assessment. As discussed further in (Section 9), this technology is basically a simpler version of the 'In-stream dosing' remediation option, and has been included in the risk assessment because it that could be considered as part of a set of contingency measures to manage some of the potential side effects of remediation.

8.2 Scope of Risk Assessment

The risk assessment process carried out in the ROA comprised the following tasks:

- Identification of a set of risk groups considered applicable categories for project risk considerations.

- Based on the current understanding of the project context (summarised in the RCM, (Section 3) and the characteristic of the proposed practical remediation options, identification of the potential risks events associated with each option.
- Qualitative evaluation of the potential significance of project risks (risk analysis), based on assessment of likelihood of occurrence and adverse impacts of occurrence.
- Identification of mitigation measures that could be implemented to address project risks and evaluation of residual risks.

Additional details on the risk assessment steps are provided in the following sections.

8.3 Risk Group Identification

The following risk groups were considered relevant for the risk assessment:

- **Health and safety**: the potential for the remediation option to impact on human health of worker, operators, visitors and members of the public during construction and operation.
- **Environment**: the potential for the remediation option to cause detrimental effects on the environment, including generation dust, vibration, noise, air emission and impacts on soil, groundwater or surface water quality.
- **Financial**: the potential for the remediation option to incur additional capital or ongoing costs, as well as additional potential costs associated with remediation of detrimental side effects or financial impacts to third parties
- **Community**: the potential for the remediation option to cause negative feedback or concerns from the community.
- **Regulatory**: the potential for the remediation technology to cause concern, delays or litigation by the relevant Regulatory Authorities or fail to meet Section 78 Notice requirements.
- **Technical Performance**: the potential for the remediation technology to not perform as expected because of insufficient site characterisation, site complexity, inadequate technology selection, design or construction, lack of maintenance or inappropriate remediation objectives.
- **Logistical, infrastructure and planning**: the potential for the remediation technology to be constrained by difficult access, lack or resources, damage to infrastructure, local zoning or long-term land use plans.

8.4 Risk Identification

This task was undertaken as an internal workshop exercise that involved undertaking of a systematic review of each selected remediation options against the risk groups defined in the previous section to identify project-specific risk events to be analysed.

8.5 Risk Analysis

Risk analysis involves assessment of the likelihood of a certain risk event occurring and the potential consequences of the event. Project-specific likelihood criteria, consequence framework and risk matrix, developed in consultation with Barwon Water and in general accordance with AS/NZS ISO 31000:2009 Risk management – Principles and guidelines, are provided in Table 8-1 to Table 8-3.

Table 8-1 Likelihood Rating Criteria

Scale	Likelihood Descriptor
Almost Certain – E	Event is expected to occur in most circumstances
Likely - D	Event would probably occur in most instances
Possible - C	Event could occur at some time
Unlikely - B	Event is not expected to occur
Rare - A	Event will only occur in exceptional circumstances

Table 8-2 Consequence Framework

Risk Group / Level	Health and safety	Environment	Financial	Community	Regulatory	Technical (performance)	Logistical / infrastructure
Extreme 5	Death or permanent disability	Environment suffers harm for 20+ years	Very serious financial loss	Very serious public outcry	Regulatory approval withheld	Technology causes a worsening of conditions in Big Swamp and Boundary Creek	Constraint causes project to stop
Severe 4	Extensive or permanent injury	Environment suffers harm for 10 to 20 years	Major financial loss	Serious adverse public attention	Regulatory approval dependant on significant additional work over long period	Technology fails to provide any improvement of conditions in Big Swamp and Boundary Creek	Constraint causes significant delay and cost
Major 3	Injury requiring hospitalisation	Environment suffers harm for 5 to 10 years	Significant financial loss	Adverse localised negative public attention	Regulatory approval dependant on major additional work over medium time period	Technology fails to provide significant improvement of conditions in Big Swamp and Boundary Creek	Constraint causes major delay or cost
Moderate 2	Minor injuries requiring hospital treatment	Reversible short term environmental harm	Minor financial loss	Adverse localised public attention	Regulatory approval dependant on some additional work which is already ongoing	Technology provides limited improvement to Big Swamp and Boundary Creek conditions	Limited delay or cost associated with constraint
Minor 1	Injury requiring first aid	Minor effect on the environment	Minor and localised financial loss	Very limited public interest	Regulatory approval dependant on minor additional work	Technology provides minor improvement to Big Swamp and Boundary Creek conditions	No delay or cost associated with constraint

Table 8-3 Risk Matrix

Likelihood	Consequence				
	Minor (1)	**Moderate (2)**	**Major (3)**	**Severe (4)**	**Extreme (5)**
Almost Certain (E)	Low (1E)	Medium (2E)	High (3E)	Critical (4E)	Critical (5E)
Likely (D)	Low (1D)	Medium (2D)	High (3D)	Critical (4D)	Critical (5D)
Possible(C)	Insignificant (1C)	Low (2C)	Medium (3C)	High (4C)	Critical (5C)
Unlikely (B)	Insignificant (1B)	Insignificant (2B)	Low (3B)	Medium (4B)	High (5B)
Rare (A)	Insignificant (1A)	Insignificant (2A)	Insignificant (3A)	Low (4A)	Medium (5A)

8.6 Mitigation Measures and Residual Risks

Project risk mitigation involves planning and executing a response or mitigation strategy to address project risks. Mitigation efforts reduce the impact of a project risk or decrease its likelihood of occurrence (residual risk). Some project risks may be unavoidable; others may not warrant mitigation if they are low-level risks.

Common risk mitigation measures, generally applicable for remediation projects, include the following:

- Employing redundant systems or processes.
- Considering alternative technologies.
- Conducting treatability studies to better assess technology and remedy performance.
- Setting interim performance goals to identify conditions.
- Communicate to stakeholders that the final objectives may not be met as planned.
- Adopting a simpler process.
- Adding or reallocating resources.
- Negotiating project scope or compliance requirements with regulatory agencies.
- Adjusting schedules; implementing early starts to activities.
- Performing aggressive cost control.

8.7 Risk Register

The results of the risk assessment are presented in a risk register as Appendix A. The risk events that resulted in a high or medium residual risk are presented in Table 8-4. No critical residual risks were identified.

Table 8-4 Risk Register (Medium Residual Risks Only)

Risk ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measure	Residual Risk			
				Consequence		Likelihood		Risk Ranking			Consequence	Likelihood	Risk Ranking	
R031	Environment	Provide supplementary flow	Change in vegetation communities in eastern part of the swamp due to increased extent of permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Certain	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with increased surface flow. Establish supplementary flow so that the extent of the permanently inundated areas is kept to a minimum. Allow seasonal variability of supplementary flow to minimise potential loss of vegetation. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	2 - Moderate	E - Almost Certain	2E	Medium
R037	Environment	Install hydraulic barriers	Change in vegetation communities across the swamp due to the creation of additional permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Certain	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with installation and operation of hydraulic barriers. Design hydraulic barriers so that the extent of the permanently inundated areas is kept to a minimum. Design hydraulic barriers so that inundation levels cab be seasonally adjusted. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	2 - Moderate	E - Almost Certain	2E	Medium
R056	Environment	Settling pond and sludge management	Loss of vegetation for construction of settling pond	3 - Major	Environment suffers harm for 5 to 10 years	E – Almost certain	Event could all the time	3C	High	Locate settling pond in an area of low ecological value. Consider construction of an aerobic wetland as part of the settling pond to offset loss of vegetation.	2 - Moderate	E – Almost certain	2E	Medium
R060	Environment	Aerobic wetland	Change in vegetation type associated with permanently inundated conditions	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Locate aerobic wetland in an area of low ecological value. Design aerobic wetland to incorporate areas of different water depth so that diverse vegetation and ecosystem will establish.	3 - Major	C - Possible	3C	Medium
R102	Community	Install hydraulic barriers	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	Medium
R128	Community	In stream treatment – Boundary Creek	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	Medium
R137	Community	Settling pond and sludge management	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	Medium
R142	Community	Aerobic wetland	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 - Major	C - Possible	3C	Medium
R155	Regulatory	Settling pond and sludge management	Approval for waste disposal or onsite storage of generated sludge required	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Include planning for waste disposal early in the design process and engage with potential receivers. Test any sludge developed during pilot trials to inform planning of waste disposal and waste categorisation.	3 - Major	C - Possible	3C	Medium

Risk ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measure	Residual Risk			
				Consequence		Likelihood		Risk Ranking			Consequence	Likelihood	Risk Ranking	
R170	Technical	Install hydraulic barriers	Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions)	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	5C	Critical	Continue to monitor during installation of barriers and inundation to improve understanding of geochemical reactions in the swamp. Consider implementation as a staged approach (one barrier at a time) so that the effects can be assessed on a small scale before wider implementation. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment.	4 - Severe	B - Unlikely	4B	Medium

Section 9 **Preferred Option**

9.1 Process Overview

This report details the results of a ROA for identification of preferred remediation options to address ASS impacts to Big Swamp and Boundary Creek, in response of a Section 78 Notice issued to Barwon Water.

The framework developed to identify the preferred remediation option for management of ASS impacts at the site comprised:

- Technology identification – a comprehensive literature review for initial identification of a broad spectrum of available options for remediation of ASS impacts. The outcome of this task was identification of 17 remediation options.
- Preliminary screening – a screening process to restrict more detailed and site-specific assessment only to those options considered to be potentially feasible for the site. Following preliminary screening, seven remediation options were retained for detailed assessment.
- Detailed assessment – the retained remediation option (developed at a conceptual level) were assessed against a range of weighted criteria and indicators.

A risk assessment was also performed on the selected practically achievable remediation options to identify potential risks and required management measures associated with implementation of each option, in accordance with one of the requirements of the Section 78 Notice.

Inputs and feedback from the RWG technical experts and the community were sought at various stages of the process to assist with development of key aspects of the ROA.

9.2 Summary of Results

Results of the weighted scoring from the detailed assessment of the options retained after preliminary screening provides the following ranking:

1. Managed Groundwater Levels and Wetland Flooding
2. Aerial liming
3. In-stream treatment
4. Aerobic wetland
5. Soil Mixing
6. RAPS
7. Excavation and disposal

These results, being the outcome of a multi-parameter assessment, provide an indication of the remediation options that, overall, are likely to achieve the best outcomes for the project. The following considerations can be made:

- The three highest ranking options aim to neutralise acidity in Boundary Creek by chemical addition/dosing (‘aerial liming’ and ‘in-stream treatment’) or by reducing further oxidation and establishing favourable natural processes (‘managed groundwater levels and flooding’). As the source of acidity (i.e. oxidised ASS sediments) is unlikely to be significantly affected by any of these technologies (with the possible exclusion of ‘managed groundwater levels and flooding’), it is expected that these options would be required to be implemented, monitored and optimised over long periods (i.e. decades).

- The options aimed at addressing the source of acidity ('soil mixing' and 'excavation and disposal') both achieved low scores, mostly because of the financial and logistical difficulties of treating or removing a substantial volume of soil characterised by high levels of net acidity requiring neutralisation.
- Comparison of weighted and unweighted scoring, as well as sensitivity analysis, seems to indicate that the ROA results are relatively robust, with minor reordering of the preferred options occurring when the weighting is intentionally skewed towards a single category, with the effect of exaggerating the advantages of certain options against the others. For example, when timing is highly prioritised in the weighting system, an option that is quick to implement such as aerial liming is found to score substantially better than other options.

9.3 Ability to Meet Project Objectives

Assessment of the ability of each option to achieve the project objectives (Table 7-16) provides additional insights on which options should be preferred, including:

- It is apparent that none of the retained options is capable, in isolation, of meeting the project objectives in the short term. For this reason, a combination of options is likely to be required.
- A range of potential detrimental side effects with respect to the project objectives are associated with each of the options. While some of these are intrinsic to the technology underlying the option (i.e. loss of ecological values caused by soil excavation and disposal) and are difficult to minimise, others can be managed as part of the design/planning stage and/or by implementing a monitoring regime and a range of contingency measures to minimise the impacts of these side effects.
- Of the seven retained options, 'managed groundwater levels and wetland flooding' is the only option that has potential to achieve three of the project objectives ('maintain minimum groundwater levels in Big Swamp', 'maintain Boundary Creek minimum flow' and 'reduce fire risk/threat'). Therefore, it is unlikely that any remediation strategy that does not include this option will be able to achieve the project objectives and vision.
- The 'managed groundwater levels and wetland flooding' is an option that carries some potentially negative side effects, as discussed below:
  - By increasing surface water flow across Big Swamp, it is likely that actual acidity (and to a minor extent retained acidity) will be mobilised and transported to downstream receiving environments (GHD, 2019). This export of acidity is expected to gradually abate over time as actual and retained acidity are flushed from the system, ongoing aerobic oxidation of ASS sediments is minimised and potential acid neutralisation reactions (i.e. iron reduction) occur in the reflooded portions of Big Swamp.
  - The soluble and mobile ferrous iron produced in permanently inundated areas of Big Swamp, if not retained as a stable precipitate, has the potential to migrate in downstream surface water environments (i.e. Boundary Creek and Barwon River) and generate acidity and secondary precipitates. While recent incubation testing data (Monash University, 2019) indicate a reduction of soluble ferrous iron which could mitigate this issue, additional data are required to understand if the same process would occur in Big Swamp, as well as the temporal stability of the precipitated form. Ongoing monitoring and planning for potential implementation of contingency measures (i.e. construction of a settling pond) should be included in remediation planning to mitigate these risks.
  - Eco Logical (2019) indicates that changes (i.e. loss) to vegetation would occur in response to the creation of permanently inundated areas across Big Swamp. This issue will required to be addressed as part of detailed design where the loss of vegetation in some areas of Big Swamp is balanced against improved conditions in other areas of Big Swamp and Boundary Creek. In addition, the loss of vegetation could be mitigated as part of detailed design, where the hydraulic barriers are designed to allow for flooded waters (if of suitable quality) to be released downstream of the barriers during certain periods of the year (for example by providing the barriers with mobile weirs or other means to adjust inundation levels).

  - When compared to other retained options (such as 'aerial liming' and 'in-stream' treatment') this option is likely to require longer timeframes to achieve improvements on Boundary Creek water quality. While estimates of these timeframes is extremely uncertain at the state of current knowledge, no significant improvement to Boundary Creek water quality should be expected in the first 5-10 years of operation, depending on the following factors:
    - The rate of flushing of actual and retained acidity by increased surface water flows across Big Swamp.
    - The effectiveness of higher groundwater levels to prevent further oxidation of ASS sediments.
    - The occurrence of acid neutralising reaction in permanently flooded areas of Big Swamp.
    - The potential for downstream export of the newly generated acidity in the form of soluble ferrous iron.
- Aerial liming is a relatively simple and cost-effective option that offers several advantages compared to more complex options and, as a result, scores particularly well when assessed using a broad range of parameters. However, when assessed against the ability to meet the project objectives (which is only reflected in one of the scoring indicators), aerial liming does not appear as favourable as the total scoring (based on the remaining 24 indicators) would suggest.

9.4 Assessment and Management of Potential Risks

The risk assessment process has identified a total of 223 risk associated with potential implementation of the following practical remediation measures:

- 'Managed groundwater levels and flooding' assessed as a combination of the following components:
  - Infilling of fire trench and drains
  - Provision of supplementary flows
  - Installation of hydraulic barriers
- 'In-stream dosing' assessed as a combination of the following components:
  - Dosing system and handling of neutralising agent
  - Settling pond and sludge management
- 'Aerobic wetland'
- 'Surface application of neutralising agents'
- 'In-stream limestone sand'

For each of the identified risks, a range of potentially applicable mitigation and management measures have been identified and the residual risks determined based on the mitigation proposed.

The outcomes of the risk assessment process, summarised in the risk register (Appendix A), indicates that the risks associated with the practical remediation measures can be adequately managed through implementation of mitigation measures, with only 10 residual risks ranked as 'medium'.

The risk mitigation measures generally include collection of additional data to improve understanding and assessment of risks, undertaking monitoring activities to confirm if the identified risks are present and implementation of contingency measures to treat unacceptable risks.

9.5 Preferred Option and Next Steps

Based on these above considerations, the 'managed groundwater levels and wetland flooding' remediation option is considered to be the preferred remediation option and is to be included as part of the remediation strategy.

The main reason for this outcome is that this option is the only one with the ability to achieve the 'maintain minimum groundwater levels', 'maintain Boundary Creek minimum flow' and 'reduce peat/fire risk' project objectives.

The following steps should be considered as part of remediation planning:

- To assist with successful implementation of the preferred option, address the uncertainties associated with performance and manage its potential side effects, the following provision should be included as part of remediation planning:
  - Collection of additional data on surface water and groundwater (flow, levels and quality).
  - Use the additional data to refine calibration of surface water and groundwater models, as wells running additional modelling scenarios to support design (i.e. groundwater response to a range of intermediate supplementary flows and groundwater/surface water response to installation of multiple barriers).
  - Undertake kinetic testing to support further geochemical reaction to refine assessment of remediation timeframes.
  - Incorporate ecological condition assessment within the preferred remediation option design to inform practical solution to mitigate potential unacceptable changes to vegetation associated with this option.
  - Consider an adaptive approach for implementation of the preferred remediation options, where the critical or more informed elements of each option are prioritised.
- The 'aerial liming' and 'in-stream treatment' remediation options are considered either as contingency measures or in conjunction with the preferred remediation option, depending on the effectiveness of the preferred remediation option in achieving the project objectives and/or the severity of its potential negative side effects.
- The 'limestone sand' remediation option is also retained as part of remediation planning as a contingency measure, considering low cost and ease of implementation.
- The risk assessment undertaken as part of the ROA is periodically reviewed and updated on the base of the new data and available information.
- An adequate monitoring regime, trigger levels and contingency measures are incorporated as part of the design of the preferred remediation option so that the risks associated with its potential detrimental side effects can be addressed in a timely and effective manner.
- Additional data collection and testing to support feasibility of the other contingency or supplementary options ('aerial liming', 'in-stream treatment' and 'limestone sand') is undertaken to facilitate timeline implementation of these technologies, should this be required. This is particularly important for the 'in-stream treatment' option in consideration of its higher complexity and financial implications.

Section 10 **Disclaimer and Limitations**

This report has been prepared by CDM Smith Australia Pty Ltd (CDM Smith) for the sole benefit of Barwon Water for the sole purpose of undertaking a Remediation Option Assessment for technologies to treat ASS at Big Swamp.

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If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

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Appendix A Risk Register

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R001	Health and safety	Infilling fire trench and drainage channels	Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R002	Health and safety	Infilling fire trench and drainage channels	Injury to public and workers associated with increased truck traffic on local roads	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R003	Health and safety	Install hydraulic barriers	Injury to workers associated with operating or being in the vicinity of machinery (e.g. piling)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R004	Health and safety	Install hydraulic barriers	Injury associated with increased truck traffic on local roads	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R005	Health and safety	Install hydraulic barriers	Drowning risk to third parties in standing water	5 - Extreme	Death or permanent disability	A - Rare	Event will only occur in exceptional circumstances	5A	Medium	Limit access of third parties to inundated areas	1 -	A -	1A	Insignificant
R006	Health and safety	Surface application of neutralising agents	Injury to workers associated with operating of being in vicinity of machinery (e.g. helicopters/suspended loads)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R007	Health and safety	Surface application of neutralising agents	Injury to public and workers associated with increased truck traffic on local roads	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R008	Health and safety	Surface application of neutralising agents	Injury to workers associated with inhalation of or contact with neutralising agent	2 - Moderate	Minor injuries requiring hospital treatment	C - Possible	Event could occur at some time	2C	Low	Implement appropriate health and safety planning to reduce access and exposure to neutralising agent	2 -	A -	2A	Insignificant
R009	Health and safety	Surface application of neutralising agents	Injury to workers and third parties associated with contact with highly alkaline water (if over dosed)	2 - Moderate	Minor injuries requiring hospital treatment	B - Unlikely	Event is not expected to occur	2B	Insignificant	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these	2 -	A -	2A	Insignificant
R010	Health and safety	Channel treatment (Big Swamp) – limestone sand	Injury to workers associated with inhalation of or contact with neutralising agent	2 - Moderate	Minor injuries requiring hospital treatment	C - Possible	Event could occur at some time	2C	Low	Implement appropriate health and safety planning to reduce access and exposure to neutralising agent	2 -	A -	2A	Insignificant
R011	Health and safety	Channel treatment (Big Swamp) – limestone sand	Injury to workers and third parties associated with contact with highly alkaline water (if over dosed)	2 - Moderate	Minor injuries requiring hospital treatment	B - Unlikely	Event is not expected to occur	2B	Insignificant	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these	2 -	A -	2A	Insignificant
R012	Health and safety	Channel treatment (Big Swamp) – limestone sand	Injury to workers associated with operating or being in the vicinity of machinery (e.g. tipper trucks)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R013	Health and safety	Channel treatment (Big Swamp) – limestone sand	Injury to public and workers associated with increased truck traffic on local roads	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R014	Health and safety	In stream treatment – Boundary Creek	Injury to workers associated with inhalation of or contact with neutralising agent	2 - Moderate	Minor injuries requiring hospital treatment	C - Possible	Event could occur at some time	2C	Low	Implement appropriate health and safety planning to reduce access and exposure to neutralising agent	2 -	A -	2A	Insignificant
R015	Health and safety	In stream treatment – Boundary Creek	Injury to workers and third parties associated with contact with highly alkaline water (if over dosed)	2 - Moderate	Minor injuries requiring hospital treatment	B - Unlikely	Event is not expected to occur	2B	Insignificant	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these	2 -	A -	2A	Insignificant
R016	Health and safety	In stream treatment – Boundary Creek	Injury to workers associated with construction of plant (general construction site hazards)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R017	Health and safety	In stream treatment – Boundary Creek	Injury to public and workers associated with increased and ongoing truck traffic on local roads	5 - Extreme	Death or permanent disability	C - Possible	Event could occur at some time	5C	Critical	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R018	Health and safety	In stream treatment – Boundary Creek	Injury to operators from electrical hazards associated with the constructed plant	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any electrical accidents	4 -	A -	4A	Low
R019	Health and safety	In stream treatment – Boundary Creek	Injury to operators associated with machinery in operating plant (e.g. rotating machinery)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any plant operation accidents	4 -	A -	4A	Low
R020	Health and safety	Settling pond and sludge management	Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R021	Health and safety	Settling pond and sludge management	Injury associated with increased and ongoing truck traffic on local roads	5 - Extreme	Death or permanent disability	C - Possible	Event could occur at some time	5C	Critical	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R022	Health and safety	Settling pond and sludge management	Drowning risk to third parties in standing water	5 - Extreme	Death or permanent disability	A - Rare	Event will only occur in exceptional circumstances	5A	Medium	Limit access of third parties to settling pond	1 -	A -	1A	Insignificant
R023	Health and safety	Settling pond and sludge management	Injury to workers and third parties associated with contact with contaminated soil or water	3 - Major	Injury requiring hospitalisation	C - Possible	Event could occur at some time	3C	Medium	Limit access of third parties to settling pond. Implement appropriate health and safety measures for operators of the settling pond	3 -	B -	3B	Low
R024	Health and safety	Aerobic wetland	Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators)	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents	4 -	A -	4A	Low
R025	Health and safety	Aerobic wetland	Injury associated with increased truck traffic on local roads	5 - Extreme	Death or permanent disability	B - Unlikely	Event is not expected to occur	5B	High	Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents	4 -	A -	4A	Low
R026	Health and safety	Aerobic wetland	Drowning risk to third parties in standing water	5 - Extreme	Death or permanent disability	A - Rare	Event will only occur in exceptional circumstances	5A	Medium	Limit access of third parties to wetland	1 -	A -	1A	Insignificant
R027	Environment	Infilling fire trench and drainage channels	Impact to vegetation associated with heavy machinery movement in Big Swamp	2 - Moderate	Reversible short term environmental harm	D - Likely	Event would probably occur in most instances	2D	Medium	Plan access routes to areas of infill to minimise vegetation damage. If significant damage occurs, revegetate area	2 -	A -	2A	Insignificant
R028	Environment	Infilling fire trench and drainage channels	Importation of weeds and foreign species via infilled soil	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Conduct soil validation and sampling including weed and seed checks	2 -	B -	2B	Insignificant
R029	Environment	Infilling fire trench and drainage channels	Activation of additional flow patterns in Big Swamp resulting in mobilisation of actual and retained acidity	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Use the topographical data to model predicted flow patterns	2 -	B -	2B	Insignificant
R030	Environment	Provide supplementary flow	Activation of additional flow patterns in Big Swamp resulting in mobilisation of actual and retained acidity	2 - Moderate	Reversible short term environmental harm	D - Likely	Event would probably occur in most instances	2D	Medium	Use the topographical data and geochemical model (distribution of acidity) to predict new flow paths and likely acidity risk	2 -	C -	2C	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R031	Environment	Provide supplementary flow	Change in vegetation communities in eastern part of the swamp due to increased extent of permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Cert	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with increased surface flow. Establish supplementary flow so that the extent of the permanently inundated areas is kept to a minimum. Allow seasonal variability of supplementary flow to minimise potential loss of vegetation. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	2 -	E -	2E	Medium
R032	Environment	Provide supplementary flow	Mobilisation of actual acidity through the soil profile via capillary rise due to increased groundwater levels	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Estimate the additional acidity load via capillary rise and assess whether additional remediation is required or whether the additional load is minor compared to other inputs. If additional remediation is required, consider implantation of additional measures such as soil or water liming within the swamp.	2 -	C -	2C	Low
R033	Environment	Provide supplementary flow	Export of acidity and acidity products associated with reducing conditions in permanently inundated areas	4 - Severe	Environment suffers harm for 10 to 20 years	B - Unlikely	Event is not expected to occur	4B	Medium	Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of acidity export	3 -	B -	3B	Low
R034	Environment	Provide supplementary flow	Generation of groundwater plume of acid and acid products (sulfate and metals) due to inundation of soils	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Use groundwater model to predict potential for a groundwater plume to migrate from the site. Low permeability of sediments is likely to restrict migration of plume	2 -	C -	2C	Low
R035	Environment	Provide supplementary flow	Local destabilisation of waterway banks and channel profile, leading to landslips and increased erosive action on creek banks and bed	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Use surface water model to predict changes in geomorphology and erosion risk. If risk is confirmed, install erosion management measures such as riffles and gabions	2 -	B -	2B	Insignificant
R036	Environment	Provide supplementary flow	Production of hydrogen sulfide and methane due to degradation of organic matter in reducing conditions	1 - Minor	Minor effect on the environment	D - Likely	Event would probably occur in most instances	1D	Low	Use geochemical model to estimate the rates and likelihood of gas production and likely impacts on the environment. If impact is expected, develop and implement an air quality monitoring plan including management measures for exceedances of threshold values.	1 -	B -	1B	Insignificant
R037	Environment	Install hydraulic barriers	Change in vegetation communities across the swamp due to the creation of additional permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Cert	Event is expected to occur in most circumstances	3E	High	Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with installation and operation of hydraulic barriers. Design hydraulic barriers so that the extent of the permanently inundated areas is kept to a minimum. Design hydraulic barriers so that inundation levels cab be seasonally adjusted. Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation.	2 -	E -	2E	Medium
R038	Environment	Install hydraulic barriers	Disturbance of ASS during excavation associated with barrier construction (if required)	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Treat exposed soil with lime during excavations to prevent the generation of acidity during earthworks	2 -	B -	2B	Insignificant
R039	Environment	Install hydraulic barriers	Impact to vegetation associated with heavy machinery movement in Big Swamp	2 - Moderate	Reversible short term environmental harm	D - Likely	Event would probably occur in most instances	2D	Medium	Plan access routes to construction areas to minimise vegetation damage. If significant damage occurs, revegetate area	2 -	A -	2A	Insignificant
R040	Environment	Install hydraulic barriers	Mobilisation of actual acidity through the soil profile via capillary rise due to increased groundwater levels	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Estimate the additional acidity load via capillary rise and assess whether additional remediation is required or whether the additional load is minor compared to other inputs. If additional remediation is required, consider implantation of additional measures such as soil or water liming within the swamp.	2 -	C -	2C	Low
R041	Environment	Install hydraulic barriers	Export of acidity and acidity products associated with reducing conditions in permanently inundated areas	3 - Major	Environment suffers harm for 5 to 10 years	D - Likely	Event would probably occur in most instances	3D	High	Conduct additional data collection and studies to further characterise magnitude and likelihood of acidity export. Implement contingency measures in the form of surface liming, limestone sand application and/or in-stream treatment.	2 -	C -	2C	Low
R042	Environment	Install hydraulic barriers	Generation of groundwater plume of acid and acid products (sulfate and metals) due to inundation of soils	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Use groundwater model to predict potential for a groundwater plume to migrate from the site. Low permeability of sediments is likely to restrict migration of plume	2 -	C -	2C	Low
R043	Environment	Install hydraulic barriers	Local destabilisation of waterway banks and channel profile, leading to landslips and increased erosive action on creek banks and bed	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Use surface water model to predict changes in geomorphology and erosion risk. If risk is confirmed, install erosion management measures such as riffles and gabions	2 -	B -	2B	Insignificant
R044	Environment	Install hydraulic barriers	Production of hydrogen sulfide and methane due to degradation of organic matter in reducing conditions	1 - Minor	Minor effect on the environment	D - Likely	Event would probably occur in most instances	1D	Low	Use geochemical model to estimate the rates and likelihood of gas production and likely impacts on the environment. If impact is expected, develop and implement an air quality monitoring plan including management measures for exceedances of threshold values.	1 -	B -	1B	Insignificant
R045	Environment	Surface application of neutralising agents	Loss of wetland vegetation due to increased alkalinity conditions in surface soil	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Develop and implement a vegetation management plan so that impacts on vegetation can be monitored and any impacts managed. Management may include replanting or remediating impacted vegetation.	2 -	C -	2C	Low
R046	Environment	Surface application of neutralising agents	Precipitation of metal oxy hydroxides in Big Swamp and downstream environments due to neutralising reactions	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of potential export of precipitates. If significant precipitates are predicted to be exported, design and construct a settling pond.	2 -	C -	2C	Low
R047	Environment	Surface application of neutralising agents	Impact on vegetation and aquatic ecology in Big Swamp due to short term generation of local highly alkaline surface waters	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, mix with lower pH water or treat	2 -	B -	2B	Insignificant

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R048	Environment	Surface application of neutralising agents	Generation of dust - airborne neutralising agent	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Plan application for days with low wind to ensure targeted treatment and limited migration of dust	2 -	B -	2B	Insignificant
R049	Environment	Channel treatment (Big Swamp) – limestone sand	Loss of wetland vegetation due to increased alkalinity conditions in surface water	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Develop and implement a vegetation management plan so that impacts on vegetation can be monitored and any impacts managed. Management may include replanting or remediating impacted vegetation.	2 -	C -	2C	Low
R050	Environment	Channel treatment (Big Swamp) – limestone sand	Precipitation of metal oxy hydroxides in Big Swamp and downstream environments due to neutralising reactions	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of potential export of precipitates. If significant precipitates are predicted to be exported, design and construct a settling pond.	2 -	C -	2C	Low
R051	Environment	Channel treatment (Big Swamp) – limestone sand	Impact on vegetation and aquatic ecology in Big Swamp due to short term generation of local highly alkaline surface waters	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, mix with lower pH water or treat	2 -	B -	2B	Insignificant
R052	Environment	Channel treatment (Big Swamp) – limestone sand	Generation of dust - airborne neutralising agent	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Plan application for days with low wind to ensure targeted treatment and limited migration of dust	2 -	B -	2B	Insignificant
R053	Environment	In stream treatment – Boundary Creek	Formation of metal oxy hydroxides downstream of the treatment infrastructure	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Conduct further monitoring and modelling to ensure settling pond is designed to capture precipitates. Monitor the settling pond (or other designed infrastructure) to ensure it has suitable capacity and is regularly emptied	3 -	B -	3B	Low
R054	Environment	In stream treatment – Boundary Creek	Impact on vegetation and aquatic ecology in Boundary Creek due to short term generation of local highly alkaline surface waters	2 - Moderate	Reversible short term environmental harm	C - Possible	Event could occur at some time	2C	Low	Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, modify treatment or mix with lower pH water	2 -	B -	2B	Insignificant
R055	Environment	Settling pond and sludge management	Disturbance of ASS caused by excavation of settling pond	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Presence of ASS and PASS at the location of the settling pond should be assessed prior to excavation. If ASS/PASS is identified, implement an construction plan to treat ASS if disturbed (e.g. liming in excavations)	2 -	B -	2B	Insignificant
R056	Environment	Settling pond and sludge management	Loss of vegetation for construction of settling pond	3 - Major	Environment suffers harm for 5 to 10 years	E - Almost Cert	Event is expected to occur in most circumstances	3E	High	Locate settling pond in an area of low ecological value. Consider construction of an aerobic wetland as part of the settling pond to offset loss of vegetation.	2 -	E - .	2E	Medium
R057	Environment	Settling pond and sludge management	Failure of settling pond (or other on site waste storage/facilities) resulting in uncontrolled release of sludge	4 - Severe	Environment suffers harm for 10 to 20 years	B - Unlikely	Event is not expected to occur	4B	Medium	Conduct further surface water and geochemical modelling to inform detailed design of the settling pond so that catastrophic failures are unlikely	4 -	A -	4A	Low
R058	Environment	Settling pond and sludge management	Reduced fish migration due to fish barrier associated with treatment system (i.e. settling pond)	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Conduct ecological survey to assess the requirement for a fish ladder past the treatment infrastructure. If required, construct a fish ladder.	1 -	A -	1A	Insignificant
R059	Environment	Aerobic wetland	Disturbance of ASS caused by construction of wetland	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Presence of ASS and PASS at the location of the wetland should be assessed prior to excavation. If ASS/PASS is identified, implement an construction plan to treat ASS if disturbed (e.g. liming in excavations)	2 -	B -	2B	Insignificant
R060	Environment	Aerobic wetland	Change in vegetation type associated with permanently inundated conditions	3 - Major	Environment suffers harm for 5 to 10 years	C - Possible	Event could occur at some time	3C	Medium	Locate aerobic wetland in an area of low ecological value. Design aerobic wetland to incorporate areas of different water depth so that diverse vegetation and ecosystem will establish.	2 -	C -	2C	Low
R061	Financial	Infilling fire trench and drainage channels	Additional costs caused by unexpected logistical difficulties and potential requirement for revegetation	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R062	Financial	Provide supplementary flow	Additional costs associated with providing supplementary flow or upgrading infrastructure	3 - Major	Significant financial loss	B - Unlikely	Event is not expected to occur	3B	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	3 -	A -	3A	Insignificant
R063	Financial	Provide supplementary flow	Cost of requirement to remediate indirect impacts from delivery of supplementary flow (e.g. erosion)	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation	1 -	A -	1A	Insignificant
R064	Financial	Provide supplementary flow	Additional cost for implementation of contingency measures should they be required	3 - Major	Significant financial loss	C - Possible	Event could occur at some time	3C	Medium	Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation	3 -	A -	3A	Insignificant
R065	Financial	Install hydraulic barriers	Additional costs associated with installation of multiple barriers (i.e. more than designed)	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R066	Financial	Install hydraulic barriers	Additional costs associated with unexpected logistical constraints or bad weather	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R067	Financial	Install hydraulic barriers	Cost of increased monitoring requirements to assess and manage the technology's side effects	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R068	Financial	Install hydraulic barriers	Additional cost for implementation of contingency measures should they be required	3 - Major	Significant financial loss	C - Possible	Event could occur at some time	3C	Medium	Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation	3 -	A -	3A	Insignificant
R069	Financial	Install hydraulic barriers	Cost of replacement of barrier due to loss of barrier/integrity due to natural disaster	2 - Moderate	Minor financial loss	B - Unlikely	Event is not expected to occur	2B	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R070	Financial	Surface application of neutralising agents	Additional cost due to a requirement for higher than expected frequency of application and/or higher rates of liming	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R071	Financial	Surface application of neutralising agents	Additional cost to restore damaged vegetation impacted by liming	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R072	Financial	Surface application of neutralising agents	Cost of ongoing monitoring requirements due to higher than anticipated negative side effects	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation	2 -	A -	2A	Insignificant

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R073	Financial	Channel treatment (Big Swamp) – limestone sand	Additional costs due to an increase of required liming rates or frequency	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R074	Financial	Channel treatment (Big Swamp) – limestone sand	Additional costs due to logistical constraints for application	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R075	Financial	Channel treatment (Big Swamp) – limestone sand	Cost of ongoing monitoring requirements due to higher than anticipated negative side effects	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation	2 -	A -	2A	Insignificant
R076	Financial	In stream treatment – Boundary Creek	Cost for additional lime due to an underestimation of liming rates required	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R077	Financial	In stream treatment – Boundary Creek	Cost of replacement of equipment due to loss of equipment caused by fires	4 - Severe	Major financial loss	B - Unlikely	Event is not expected to occur	4B	Medium	Expected costs should be based on detailed design including contingency costs for unexpected overruns	4 -	A -	4A	Low
R078	Financial	In stream treatment – Boundary Creek	Cost of replacement of equipment due to loss of equipment caused by floods	4 - Severe	Major financial loss	B - Unlikely	Event is not expected to occur	4B	Medium	Expected costs should be based on detailed design including contingency costs for unexpected overruns	4 -	A -	4A	Low
R079	Financial	In stream treatment – Boundary Creek	Cost of additional infrastructure/treatment steps into process (e.g. a mixing tank, power upgrades)	3 - Major	Significant financial loss	B - Unlikely	Event is not expected to occur	3B	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	3 -	A -	3A	Insignificant
R080	Financial	In stream treatment – Boundary Creek	Ongoing cost increase due to an increase in the cost of chemicals	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R081	Financial	In stream treatment – Boundary Creek	Ongoing cost increase due to unfavourable exchange rates (if chemicals sourced from overseas)	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R082	Financial	In stream treatment – Boundary Creek	Ongoing cost increase due to requirement to use different chemicals	2 - Moderate	Minor financial loss	C - Possible	Event could occur at some time	2C	Low	Expected costs should be based on detailed design including contingency costs for unexpected overruns	2 -	A -	2A	Insignificant
R083	Financial	Settling pond and sludge management	Additional costs associated with unexpected logistical constraints or bad weather during construction or emptying	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R084	Financial	Aerobic wetland	Additional costs associated with unexpected logistical constraints or bad weather during construction	1 - Minor	Minor and localised financial loss	C - Possible	Event could occur at some time	1C	Insignificant	Expected costs should be based on detailed design including contingency costs for unexpected overruns	1 -	A -	1A	Insignificant
R085	Community	Infilling fire trench and drainage channels	Higher than expected impacts on vegetation	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Make ecological studies and risks available to community.	2 -	B -	2B	Insignificant
R086	Community	Infilling fire trench and drainage channels	Perception that infilling fire trench would increase fire risk	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts. Communicate with local CFA.	1 -	B -	1B	Insignificant
R087	Community	Infilling fire trench and drainage channels	Increased traffic in local area	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant
R088	Community	Infilling fire trench and drainage channels	Loss of usable land due to wetter conditions in previously drained areas	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R089	Community	Infilling fire trench and drainage channels	Requirement to access private land	1 - Minor	Very limited public interest	D - Likely	Event would probably occur in most instances	1D	Low	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	C -	1C	Insignificant
R090	Community	Infilling fire trench and drainage channels	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	C - Possible	Event could occur at some time	1C	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	C -	1C	Insignificant
R091	Community	Infilling fire trench and drainage channels	Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Keep community informed of the process, the risks and the management and mitigation measures.	1 -	C -	1C	Insignificant
R092	Community	Provide supplementary flow	Perception that water is being prioritised for ecological outcomes over water security	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public.	1 -	C -	1C	Insignificant
R093	Community	Provide supplementary flow	Side effects of implementation - potential increase in export of acidity	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	C -	2C	Low
R094	Community	Provide supplementary flow	Modified character of Big Swamp - loss of vegetation	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Make ecological studies, risks and management measures available to community.	2 -	B -	2B	Insignificant
R095	Community	Provide supplementary flow	Hydrogen sulfide and methane produced due to degradation of organic matter and reducing conditions	3 - Major	Adverse localised negative public attention	B - Unlikely	Event is not expected to occur	3B	Low	Maintain open communication with the community, including the RWG technical experts. Provide estimates of gas production and likely impacts on locals.	2 -	B -	2B	Insignificant
R096	Community	Provide supplementary flow	Community opposition to the final design due to differences from the Concept Design on which the community were consulted.	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community.	1 -	B -	1B	Insignificant
R097	Community	Provide supplementary flow	Length of time required for remediation	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community.	2 -	B -	2B	Insignificant
R098	Community	Provide supplementary flow	Disagreement about natural resource use	3 - Major	Adverse localised negative public attention	B - Unlikely	Event is not expected to occur	3B	Low	Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public.	2 -	B -	2B	Insignificant
R099	Community	Install hydraulic barriers	Side effects of implementation - potential increase in export of acidity	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	C -	2C	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R100	Community	Install hydraulic barriers	Modified character of Big Swamp - loss of vegetation and increase of infrastructure	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Make ecological studies, risks and management measures available to community.	2 -	B -	2B	Insignificant
R101	Community	Install hydraulic barriers	Hydrogen sulfide and methane produced due to degradation of organic matter reducing conditions	3 - Major	Adverse localised negative public attention	B - Unlikely	Event is not expected to occur	3B	Low	Maintain open communication with the community, including the RWG technical experts. Provide estimates of gas production and likely impacts on locals.	1 -	B -	1B	Insignificant
R102	Community	Install hydraulic barriers	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 -	C -	3C	Medium
R103	Community	Install hydraulic barriers	Requirement to access private land	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R104	Community	Install hydraulic barriers	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R105	Community	Install hydraulic barriers	Community opposition to the final design due to differences from the Concept Design on which the community were consulted.	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community.	3 -	B -	3B	Low
R106	Community	Install hydraulic barriers	Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site.	3 - Major	Adverse localised negative public attention	B - Unlikely	Event is not expected to occur	3B	Low	Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site.	2 -	B -	2B	Insignificant
R107	Community	Install hydraulic barriers	Length of time required for remediation	4 - Severe	Serious adverse public attention	C - Possible	Event could occur at some time	4C	High	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community.	3 -	B -	3B	Low
R108	Community	Install hydraulic barriers	Disagreement about natural resource use	3 - Major	Adverse localised negative public attention	B - Unlikely	Event is not expected to occur	3B	Low	Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public.	2 -	B -	2B	Insignificant
R109	Community	Surface application of neutralising agents	Side effects of application - dust	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	B -	2B	Insignificant
R110	Community	Surface application of neutralising agents	Side effect of application - secondary precipitates	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	C -	2C	Low
R111	Community	Surface application of neutralising agents	Increased traffic in local area	2 - Moderate	Adverse localised public attention	B - Unlikely	Event is not expected to occur	2B	Insignificant	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant
R112	Community	Surface application of neutralising agents	Requirement to access private land	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R113	Community	Surface application of neutralising agents	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	C - Possible	Event could occur at some time	1C	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R114	Community	Surface application of neutralising agents	Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site.	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site.	3 -	B -	3B	Low
R115	Community	Surface application of neutralising agents	Length of time required for remediation	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community.	2 -	B -	2B	Insignificant
R116	Community	Channel treatment (Big Swamp) – limestone sand	Side effect of application - dust	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	B -	2B	Insignificant
R117	Community	Channel treatment (Big Swamp) – limestone sand	Side effect of application - secondary precipitates	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	C -	2C	Low
R118	Community	Channel treatment (Big Swamp) – limestone sand	Increased traffic in local area	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant
R119	Community	Channel treatment (Big Swamp) – limestone sand	Requirement to access private land	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R120	Community	Channel treatment (Big Swamp) – limestone sand	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R121	Community	Channel treatment (Big Swamp) – limestone sand	Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site.	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site.	3 -	B -	3B	Low
R122	Community	In stream treatment – Boundary Creek	Amenity impact of treatment infrastructure (visual and noise)	4 - Severe	Serious adverse public attention	C - Possible	Event could occur at some time	4C	High	Maintain open communication with the community, including the RWG technical experts. Make detailed design plan available for public comment.	3 -	B -	3B	Low
R123	Community	In stream treatment – Boundary Creek	Increased and ongoing traffic in the local area	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R124	Community	In stream treatment – Boundary Creek	Side effect of application - secondary precipitates	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community.	2 -	B -	2B	Insignificant
R125	Community	In stream treatment – Boundary Creek	Perception of waste (sludge) generated by technology	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by technical studies, including sludge volume predictions and management plans.	2 -	C -	2C	Low
R126	Community	In stream treatment – Boundary Creek	Perception of cost of treatment (rate increases or financial viability)	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts. Ensure budget for the implementation of this technology is secured, including contingency costing.	2 -	C -	2C	Low
R127	Community	In stream treatment – Boundary Creek	Residential property owners subject to acquisition or in proximity to construction areas postpone or reconsider their plans for their properties.	2 - Moderate	Adverse localised public attention	C - Possible	Event could occur at some time	2C	Low	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R128	Community	In stream treatment – Boundary Creek	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 -	C -	3C	Medium
R129	Community	In stream treatment – Boundary Creek	Land use changes that would result in minor inconsistencies with local planning policies and current planning scheme provisions	1 - Minor	Very limited public interest	C - Possible	Event could occur at some time	1C	Insignificant	Maintain open communication with Local Council including development of plans and design requirements.	1 -	B -	1B	Insignificant
R130	Community	In stream treatment – Boundary Creek	Community opposition to the final design due to differences from the Concept Design on which the community were consulted.	4 - Severe	Serious adverse public attention	C - Possible	Event could occur at some time	4C	High	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community.	3 -	B -	3B	Low
R131	Community	In stream treatment – Boundary Creek	Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site.	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site.	3 -	B -	3B	Low
R132	Community	Settling pond and sludge management	Increased traffic in local area	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant
R133	Community	Settling pond and sludge management	Requirement to access private land	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R134	Community	Settling pond and sludge management	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R135	Community	Settling pond and sludge management	Loss of usable land due to settling pond construction	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R136	Community	Settling pond and sludge management	Community opposition to the final design due to differences from the Concept Design on which the community were consulted.	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community.	3 -	B -	3B	Low
R137	Community	Settling pond and sludge management	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 -	C -	3C	Medium
R138	Community	Aerobic wetland	Increased traffic in local area	3 - Major	Adverse localised negative public attention	C - Possible	Event could occur at some time	3C	Medium	Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes.	2 -	B -	2B	Insignificant
R139	Community	Aerobic wetland	Requirement to access private land	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R140	Community	Aerobic wetland	Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes)	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R141	Community	Aerobic wetland	Loss of usable land due to wetland construction	1 - Minor	Very limited public interest	B - Unlikely	Event is not expected to occur	1B	Insignificant	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	1 -	B -	1B	Insignificant
R142	Community	Aerobic wetland	Acquisition of titles for the project	3 - Major	Adverse localised negative public attention	D - Likely	Event would probably occur in most instances	3D	High	Maintain open communication with the community, including the RWG technical experts and relevant landholders.	3 -	C -	3C	Medium
R143	Regulatory	Infilling fire trench and drainage channels	Opposition of infilling of fire trench by CFA	1 - Minor	Regulatory approval dependant on minor additional work	C - Possible	Event could occur at some time	1C	Insignificant	Engage CFA early to discuss the fire risk benefits of infilling the fire trenches (i.e. a wetter swamp)	1 -	A -	1A	Insignificant
R144	Regulatory	Provide supplementary flow	Delivery of supplementary flows above 2 ML/d opposed by regulator under Water Act	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional groundwater and surface water modelling to refine the likely volume of supplementary flow required for rewetting and present as a risk/benefit analysis with respect to water supply requirements	2 -	B -	2B	Insignificant
R145	Regulatory	Provide supplementary flow	Regulatory approval required due to potential side effects (exporting of acidity)	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	C -	2C	Low
R146	Regulatory	Provide supplementary flow	Regulatory approval required due to potential side effects (acid groundwater plume) and impact under SEPP	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R147	Regulatory	Install hydraulic barriers	Regulatory approval required due to potential side effects (exporting of acidity)	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	C -	2C	Low
R148	Regulatory	Install hydraulic barriers	Regulatory approval required due to potential side effects (acid groundwater plume) and impact under SEPP	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant
R149	Regulatory	Surface application of neutralising agents	Regulatory approval required due to potential side effect (precipitates in Boundary Creek)	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	C -	2C	Low
R150	Regulatory	Surface application of neutralising agents	Regulatory approval required due to potential side effect (vegetation impacts)	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant
R151	Regulatory	Channel treatment (Big Swamp) – limestone sand	Regulatory approval required due to potential side effect (precipitates in Boundary Creek)	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	C -	2C	Low
R152	Regulatory	Channel treatment (Big Swamp) – limestone sand	Regulatory approval required due to potential side effect (vegetation impacts)	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant
R153	Regulatory	In stream treatment – Boundary Creek	Regulatory approval required due to potential side effect (precipitates in Boundary Creek)	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	C -	2C	Low
R154	Regulatory	In stream treatment – Boundary Creek	Planning approval required for infrastructure	1 - Minor	Regulatory approval dependant on minor additional work	D - Likely	Event would probably occur in most instances	1D	Low	Follow planning approval procedures and undertaken detailed design of the treatment infrastructure	1 -	D -	1D	Low
R155	Regulatory	Settling pond and sludge management	Approval for waste disposal or onsite storage of generated sludge required	4 - Severe	Regulatory approval dependant on significant additional work over long period	C - Possible	Event could occur at some time	4C	High	Include planning for waste disposal early in the design process and engage with potential receivers. Test any sludge developed during pilot trials to inform planning of waste disposal and waste categorisation.	3 -	C -	3C	Medium
R156	Regulatory	Settling pond and sludge management	Regulatory approval required due to potential side effect (vegetation impacts)	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant
R157	Regulatory	Aerobic wetland	Regulatory approval required due to potential side effect (vegetation impacts)	3 - Major	Regulatory approval dependant on major additional work over medium time period	B - Unlikely	Event is not expected to occur	3B	Low	Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan	2 -	B -	2B	Insignificant
R158	Technical (performance)	Provide supplementary flow	Selection of inappropriate remediation technology	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	B - Unlikely	Event is not expected to occur	2B	Insignificant	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling.	2 -	A -	2A	Insignificant
R159	Technical (performance)	Provide supplementary flow	Remediation technology improperly designed	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling.	2 -	B -	2B	Insignificant
R160	Technical (performance)	Provide supplementary flow	Inappropriate remediation objectives	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	B - Unlikely	Event is not expected to occur	2B	Insignificant	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling.	2 -	A -	2A	Insignificant
R161	Technical (performance)	Provide supplementary flow	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	D - Likely	Event would probably occur in most instances	2D	Medium	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update modelling to incorporate additional data.	2 -	C -	2C	Low
R162	Technical (performance)	Provide supplementary flow	Supplementary flows do not raise the groundwater levels as expected	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Continue to monitor during delivery of supplementary flows and update modelling to improve understanding of how the groundwater levels react to inundation. If groundwater levels are not rising as expected, consider contingencies such as increasing flow rates or modifying flow through the swamp.	2 -	C -	2C	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R163	Technical (performance)	Provide supplementary flow	Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions)	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	D - Likely	Event would probably occur in most instances	2D	Medium	Continue to monitor during delivery of supplementary flows to improve understanding of geochemical reactions in the swamp. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment.	2 -	C -	2C	Low
R164	Technical (performance)	Provide supplementary flow	Failure to deliver minimum flow at Boundary Creek (Yeodene gauge) due to higher than expected losses to groundwater	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	3B	Low	Continue to monitor during delivery of supplementary flows and update modelling to improve understanding of streamflow losses. If losses are significant and minimum flow requirements are not met, increase the supplementary flow volumes.	1 -	B -	1B	Insignificant
R165	Technical (performance)	Install hydraulic barriers	Selection of inappropriate remediation technology	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	5B	High	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test.	3 -	B -	3B	Low
R166	Technical (performance)	Install hydraulic barriers	Remediation technology improperly designed	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test.	3 -	B -	3B	Low
R167	Technical (performance)	Install hydraulic barriers	Inappropriate remediation objectives	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test.	2 -	B -	2B	Insignificant
R168	Technical (performance)	Install hydraulic barriers	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update modelling to incorporate additional data.	2 -	B -	2B	Insignificant
R169	Technical (performance)	Install hydraulic barriers	Hydraulic barriers do not raise the groundwater levels as expected	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Continue to monitor during implementation and update modelling to improve understanding of how the groundwater levels react to inundation. If groundwater levels are not rising as expected, consider contingencies such as increasing flow rates or modifying flow through the swamp / install additional barriers.	2 -	B -	2B	Insignificant
R170	Technical (performance)	Install hydraulic barriers	Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions)	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	5C	Critical	Continue to monitor during installation of barriers and inundation to improve understanding of geochemical reactions in the swamp. Consider implementation as a staged approach (one barrier at a time) so that the effects can be assessed on a small scale before wider implementation. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment.	4 -	B -	4B	Medium
R171	Technical (performance)	Surface application of neutralising agents	Selection of inappropriate remediation technology	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	B -	2B	Insignificant
R172	Technical (performance)	Surface application of neutralising agents	Remediation technology improperly designed	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	C -	2C	Low
R173	Technical (performance)	Surface application of neutralising agents	Inappropriate remediation objectives	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	B - Unlikely	Event is not expected to occur	2B	Insignificant	Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application).	2 -	B -	2B	Insignificant
R174	Technical (performance)	Surface application of neutralising agents	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data.	2 -	B -	2B	Insignificant

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R175	Technical (performance)	Surface application of neutralising agents	Liming of soils fails to have measurable impact on Boundary Creek water quality	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	3 -	B -	3B	Low
R176	Technical (performance)	Surface application of neutralising agents	Excessive coating of lime by metal precipitates	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Consider pilot scale application or laboratory testing to understand the timing and severity of armouring. Plan for armouring by using an appropriate chemical and application rate/frequency.	3 -	B -	3B	Low
R177	Technical (performance)	Surface application of neutralising agents	Uneven surface application due to inappropriate delivery method	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Use existing understanding of topography and streamflow to ensure reagent is applied at the appropriate scale and location. Use 3D geochemical model (updated to include any additional data) to plan extent of application and appropriate delivery method.	3 -	B -	3B	Low
R178	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Selection of inappropriate remediation technology	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Use existing geochemical data and any further data collected to plan targeted application and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	B -	2B	Insignificant
R179	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Remediation technology improperly designed	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Use existing geochemical data and any further data collected to plan targeted application and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	3 -	B -	3B	Low
R180	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Inappropriate remediation objectives	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	B - Unlikely	Event is not expected to occur	2B	Insignificant	Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application).	2 -	B -	2B	Insignificant
R181	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data.	2 -	B -	2B	Insignificant
R182	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Liming in channel fails to have measurable impact on Boundary Creek water quality	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Use existing geochemical data and any further data collected to plan targeted application of limestone sand. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	C -	2C	Low
R183	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Excessive coating of limestone sand by metal precipitates	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Consider pilot scale application or laboratory testing to understand the timing and severity of armouring. Plan for armouring by using an appropriate chemical and application rate/frequency.	3 -	B -	3B	Low
R184	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Uneven surface application due to inappropriate delivery method	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Use existing understanding of topography and streamflow to ensure reagent is applied at the appropriate scale and location. Use 3D geochemical model (updated to include any additional data) to plan target locations	2 -	B -	2B	Insignificant
R185	Technical (performance)	Channel treatment (Big Swamp) – limestone sand	Incorrect placement of limestone (i.e. surface flows not understood)	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Complete further surface water modelling to understand surface flows through the swamp at an appropriate timestep for entrainment of sand into surface flow. Use topographical data and stream flow modelling to plan targeted application of sand to areas of known stream flow.	1 -	B -	1B	Insignificant
R186	Technical (performance)	In stream treatment – Boundary Creek	Selection of inappropriate remediation technology	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	4B	Medium	Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	C -	2C	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R187	Technical (performance)	In stream treatment – Boundary Creek	Remediation technology improperly designed	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	C -	2C	Low
R188	Technical (performance)	In stream treatment – Boundary Creek	Inappropriate remediation objectives	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application).	2 -	B -	2B	Insignificant
R189	Technical (performance)	In stream treatment – Boundary Creek	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data.	2 -	B -	2B	Insignificant
R190	Technical (performance)	In stream treatment – Boundary Creek	Plant infrastructure is undersized for the actual acidity load	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the variability of acidity loads can be planned for. Base calculations on modelled acidity and measured acidity when data is available. Undertake pilot trials to guide appropriate selection of chemical and dosing requirements.	2 -	C -	2C	Low
R191	Technical (performance)	In stream treatment – Boundary Creek	Incorrect choice of neutralising agent	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the variability of acidity loads can be planned for. Base calculations on modelled acidity and measured acidity when data is available. Undertake pilot trials to guide appropriate selection of chemical and dosing requirements.	2 -	C -	2C	Low
R192	Technical (performance)	In stream treatment – Boundary Creek	Inefficient mixing of neutralising agent in stream	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Analyse existing streamflow data to predict mixing of various loads of reagent in the stream immediately downstream of the dosing. Monitor effectiveness of treatment and modify if required (e.g. addition of a mixing tank)	2 -	B -	2B	Insignificant
R193	Technical (performance)	Settling pond and sludge management	Selection of inappropriate remediation technology	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	5B	High	Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	B -	2B	Insignificant
R194	Technical (performance)	Settling pond and sludge management	Remediation technology improperly designed	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	5C	Critical	Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design is oversized to allow for contingency volumes (if pond cannot be emptied at the planned frequency).	3 -	B -	3B	Low
R195	Technical (performance)	Settling pond and sludge management	Inappropriate remediation objectives	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application).	2 -	B -	2B	Insignificant
R196	Technical (performance)	Settling pond and sludge management	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data.	2 -	B -	2B	Insignificant
R197	Technical (performance)	Settling pond and sludge management	Excessive production of sludge	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	5B	High	Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design is oversized to allow for contingency volumes (if pond cannot be emptied at the planned frequency).	3 -	B -	3B	Low
R198	Technical (performance)	Settling pond and sludge management	No formation of sludge in pond due to incorrect pond conditions	5 - Extreme	Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	5B	High	Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design allows for appropriate residence times.	3 -	B -	3B	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R199	Technical (performance)	Aerobic wetland	Selection of inappropriate remediation technology	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	B -	2B	Insignificant
R200	Technical (performance)	Aerobic wetland	Remediation technology improperly designed	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	4C	High	Collect additional water quality data for flows expected to enter the wetland. Base design on estimations from more detailed modelling. Ensure wetland design is oversized to allow for contingency flow rates.	2 -	B -	2B	Insignificant
R201	Technical (performance)	Aerobic wetland	Inappropriate remediation objectives	3 - Major	Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek	C - Possible	Event could occur at some time	3C	Medium	Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application).	2 -	B -	2B	Insignificant
R202	Technical (performance)	Aerobic wetland	Remediation is too slow	2 - Moderate	Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions	C - Possible	Event could occur at some time	2C	Low	Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data.	2 -	B -	2B	Insignificant
R203	Technical (performance)	Aerobic wetland	Wetland provides no measurable improvement to water quality in Boundary Creek	4 - Severe	Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek	B - Unlikely	Event is not expected to occur	4B	Medium	Use existing geochemical data and any further data collected to design wetland, especially water quality data of water expected to enter wetland, such as after other treatments. Monitor effects of application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method.	2 -	B -	2B	Insignificant
R204	Logistical / infrastructure	Infilling fire trench and drainage channels	Access constraints limit the ability to completely infill the trenches	2 - Moderate	Limited delay or cost associated with constraint	C - Possible	Event could occur at some time	2C	Low	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R205	Logistical / infrastructure	Infilling fire trench and drainage channels	Requirements to upgrade access tracks to the swamp and to the trenches requiring filling	2 - Moderate	Limited delay or cost associated with constraint	C - Possible	Event could occur at some time	2C	Low	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R206	Logistical / infrastructure	Provide supplementary flow	Reliability of supplementary water supply	4 - Severe	Constraint causes significant delay and cost	C - Possible	Event could occur at some time	4C	High	Ensure regular maintenance and upgrades of water supply infrastructure so that failures are reduced. Investigate potential back up supplies for the supplementary flow (such as an agreement with the owners of McDonalds Dam)	3 -	B -	3B	Low
R207	Logistical / infrastructure	Provide supplementary flow	Failure of downstream delivery mechanism at McDonalds dam	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Maintain current management measures in place to ensure delivery is maintained. Continue monitoring downstream flow. Establish open communication with the owners/operators of McDonalds Dam	2 -	A -	2A	Insignificant
R208	Logistical / infrastructure	Install hydraulic barriers	Access constraints limit the ability to install barriers at target locations	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R209	Logistical / infrastructure	Install hydraulic barriers	Failure of automated gates/weirs which may be part of the barrier design to periodically release flows	3 - Major	Constraint causes major delay or cost	B - Unlikely	Event is not expected to occur	3B	Low	Assess requirement for gates/weirs in detailed design. If deemed necessary (for ecological health of the swamp), establish a suitable monitoring and maintenance regime for the infrastructure to maintain condition.	1 -	C -	1C	Insignificant
R210	Logistical / infrastructure	Install hydraulic barriers	Loss of barrier integrity	4 - Severe	Constraint causes significant delay and cost	C - Possible	Event could occur at some time	4C	High	Establish a regular maintenance program for the barriers so that potential integrity issues are identified before loss of integrity occurs. Conduct regular monitoring of barrier performance so that failures are identified in a timely manner and can be addressed.	3 -	B -	3B	Low
R211	Logistical / infrastructure	Surface application of neutralising agents	Access constraints limit the ability to deliver the required neutralising agent	2 - Moderate	Limited delay or cost associated with constraint	C - Possible	Event could occur at some time	2C	Low	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R212	Logistical / infrastructure	Channel treatment (Big Swamp) – limestone sand	Access constraints limit the ability to deliver the required neutralising agent	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R213	Logistical / infrastructure	In stream treatment – Boundary Creek	Identification of suitable location for system installation	3 - Major	Constraint causes major delay or cost	D - Likely	Event would probably occur in most instances	3D	High	Early works should include planning for a fixed treatment system so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design.	2 -	C -	2C	Low
R214	Logistical / infrastructure	In stream treatment – Boundary Creek	Requirements to upgrade access tracks to deliver the neutralising agent to the system	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R215	Logistical / infrastructure	In stream treatment – Boundary Creek	Provision and reliability of power/water supply	4 - Severe	Constraint causes significant delay and cost	C - Possible	Event could occur at some time	4C	High	Begin planning for power and water supply to plant as soon as a location is identified (or as part of location identification).	2 -	C -	2C	Low

ID	Risk Group	Practicable measure implemented	Risk Event	Initial Risk						Risk Mitigation Measures	Residual risk			
				Consequence		Likelihood		Risk ranking			C	L	Risk ranking	
R216	Logistical / infrastructure	In stream treatment – Boundary Creek	Reliability of mechanical and electrical components of the system (dosers, mixers instrumentation etc)	3 - Major	Constraint causes major delay or cost	C - Possible	Event could occur at some time	3C	Medium	Ensure regular maintenance is carried out on all system components and develop an infrastructure management plan that includes actions for system failures.	2 -	C -	2C	Low
R217	Logistical / infrastructure	In stream treatment – Boundary Creek	Requirement for adequate storage of chemicals (i.e. environmental conditions)	3 - Major	Constraint causes major delay or cost	B - Unlikely	Event is not expected to occur	3B	Low	Include chemical storage and consideration of environmental controls required for chemicals in the planning stage so that adequate storage is designed.	2 -	B -	2B	Insignificant
R218	Logistical / infrastructure	In stream treatment – Boundary Creek	System loss due to flooding/fire	5 - Extreme	Constraint causes project to stop	B - Unlikely	Event is not expected to occur	5B	High	Include measures in the design to minimise the risk of total system loss, such as fire management measures (vegetation clearing) and flood risk assessment and management.	4 -	A -	4A	Low
R219	Logistical / infrastructure	Settling pond and sludge management	Constraints associated with disposal of potentially high sludge volumes	3 - Major	Constraint causes major delay or cost	C - Possible	Event could occur at some time	3C	Medium	Ensure that design includes development of a sludge management plan, including contingency measures associated with system failure.	3 -	B -	3B	Low
R220	Logistical / infrastructure	Settling pond and sludge management	Identification of suitable location for settling pond	3 - Major	Constraint causes major delay or cost	D - Likely	Event would probably occur in most instances	3D	High	Early works should include planning for a settling pond so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design.	2 -	C -	2C	Low
R221	Logistical / infrastructure	Settling pond and sludge management	Requirements to upgrade access tracks to settling pond location	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant
R222	Logistical / infrastructure	Aerobic wetland	Identification of suitable location for wetland	3 - Major	Constraint causes major delay or cost	D - Likely	Event would probably occur in most instances	3D	High	Early works should include planning for a wetland so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design.	2 -	C -	2C	Low
R223	Logistical / infrastructure	Aerobic wetland	Requirements to upgrade access tracks to wetland location	2 - Moderate	Limited delay or cost associated with constraint	D - Likely	Event would probably occur in most instances	2D	Medium	Ensure that planning stage includes assessment of access and provision for access upgrades if necessary	1 -	B -	1B	Insignificant

Barwon Downs Borefield

Investigation plan for areas of potential high risk

1 | Final

19 December 2019

Barwon Water

Barwon Downs Borefield

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Contents

Executive Summary

Background

Barwon Water received a Section 78 Notice (under the Water Act 1989 (Vic)) and the purpose of the Notice is to ensure that Barwon Water successfully remediate impacts caused by historic groundwater extraction. The Section 78 Notice directs Barwon Water to develop and implement a Remediation Plan for Boundary Creek and Big Swamp and surrounding environment.

The Remediation Plan is divided into two areas with different action plans:

- *Boundary Creek and Big Swamp remediation plan* includes areas where impact has been confirmed by monitoring data and remediation actions have been recommended and
- *Surrounding Environment investigation plan* includes areas where impact has not yet been confirmed due to insufficient monitoring to validate groundwater model predictions and further work is required.

This report documents the recommendations for the Surrounding Environment investigation plan. A key input to the assessment that supports the plan is results from the regional groundwater model. The following description provides context for the results that are utilised in this report.

Regional Groundwater Model

The regional groundwater model has evolved over more than two decades as more information has become available. The most recent groundwater model was completed in 2016-17 when the model was expanded, re-built and re-calibrated. The update of the model includes new layers, new monitoring data and a significant improvement in the conceptual understanding.

Although the regional model has significant improvements in the conceptualisation, there are still several limitations of this model. The regional groundwater model is understood to over-state potential drawdown in regional aquitards and in areas where Quaternary aquifers have been confirmed to be present but have not been included in the model. These layers are known to act as physical constraints, such as clay layers within the formations that restrict groundwater flow from the regional aquifer and therefore may limit groundwater drawdown. As these physical constraints have not been included in the regional groundwater model, the model does not account for the restriction of vertical groundwater flow and subsequent decrease in drawdown observed at these locations.

The regional groundwater model was developed to assess the historical impacts of pumping in terms of drawdown and changes in baseflow to rivers. The model estimates drawdown in all layers, with the exception of the alluvial aquifer as this layer is not represented in the model. For the reasons described above, exclusion of the alluvial aquifer from the model was considered not to limit the assessment of pumping impacts across the regional aquifer. The predicted drawdown and change in baseflow to rivers were used to inform the risk to groundwater dependent ecosystem (GDEs) using the risk assessment framework outlined in the The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015).

Barwon River Catchment

The Barwon River East and West Branches rise in the Otway Ranges around the township of Forrest. The Barwon River East Branch joins the West Branch near Gerangamete Flats, and below the confluence of these two branches, the river becomes the Barwon River. Boundary Creek also joins the Barwon River near Gerangamete Flats.

Three rivers in the Barwon River catchment (outside Boundary Creek) were classified as potential high risk:

- Barwon River East Branch;

- Barwon River West Branch; and,
- Barwon River downstream of the confluence.

The Barwon River East Branch is represented as a gaining river in the regional groundwater model. The model estimated it remained a gaining river until around 2000, when a decline in groundwater level is interpreted to have caused the creek to become a losing river. The potential high risk areas are located near the headwaters of the Barwon River East Branch, immediately upstream of the Bambra Fault (south east) and downstream of the fault. In other areas, the risk to the river is moderate to low due to the predicted drawdown being much less at these locations.

The Barwon River West Branch is represented as a losing river in the regional groundwater model. Where the river flows over the MTD, the model predicts there is no observable difference between the pumping and no pumping scenarios, which indicates that groundwater pumping is not predicted to impact the river in this location. The potential high risk areas are located near the headwaters of the Barwon River West Branch and immediately upstream of the Bambra Fault (south east). In other areas, the risk to the river is moderate to low due to the predicted drawdown being much less at these risk locations.

Downstream of the confluence with Boundary Creek, the Barwon River is represented generally as a gaining river with seasonal variability. During summer months (low flows), the river is predicted to be gaining and during the winter months (high flows), the river is predicted to become losing. The potential high risk area is located downstream of the confluence with Boundary Creek and the risk to the Barwon River is moderate to low in other areas.

Gellibrand River Catchment

The Gellibrand River is located in the south western corner of the LTA extent with tributaries rising in the Otway Ranges and the Barongarook High. Tributaries include Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren. Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

Like the Barwon River catchment, three rivers in the Gellibrand catchment were classified as potential high risk:

- Gellibrand River;
- Ten Mile Creek; and,
- Yahoo Creek.

The Gellibrand River is represented as a gaining river and the volumes of groundwater flux to the river are reasonably large (greater than 50 L/sec), consistent with the conceptualisation that the Gellibrand River is a key discharge site. The regional groundwater model indicates there is a small impact on reduction in baseflow to the river. The potential high risk areas are located downstream of the Bambra Fault further downstream in the middle of the model and near the southern boundary of the model. The risk to the river is moderate in other areas.

Ten Mile Creek is represented as a gaining river and the volumes of groundwater flux to the river is typically less than 10 L/sec. The regional groundwater model predicts that the groundwater contribution to the river declines marginally over the model period (1979 to 2016) in response to climate. However there is also a noticeable difference in groundwater flux to the river predicted between the pumping and no pumping scenarios. The potential high risk areas are located near the headwaters of the creek and further downstream on the LTA outcrop. The risk to the river is low to moderate in other areas.

Yahoo Creek is represented as a losing river and the regional groundwater model predicts there is a difference in groundwater flux to the river between the pumping and no pumping scenarios. The potential high risk areas are located near the headwaters of the creek where the LTA outcrops and the risk to the river is low to moderate in other areas.

Vegetation and PASS

The risk to groundwater dependent vegetation across the catchment was determined using the depth to water table from the regional groundwater model and the drawdown predicted in the water table aquifer as a result of historical groundwater extraction. Vegetation and PASS in some areas is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to water table as a result of historic groundwater pumping.

There are three key (large) areas the model estimates the potential risk to be high. Further investigations may be recommended in other isolated areas of potential high risk based on the outcomes of the investigation plan focussed on the following areas:

- West of the Barwon River to the north of Yeodene;
- East of the Barwon River between Barwon Downs and Yeodene; and,
- Along the Gellibrand River.

The regional aquitard (MTD) outcrops across most of the area to the west of the Barwon River. The LTA outcrops on the Barongarook High located in the south of this area and alluvial sediments are present along the Barwon River. Areas of potential high risk to groundwater dependent vegetation and PASS are located around Barongarook Creek and north east of Yeodene, however there is limited information to inform the accuracy of the assigned risk in these areas.

The area east of the Barwon River around Deans Marsh is bounded by the Bambra Fault to the south east and the Barwon River to the north west. Several tributaries of the Barwon River flow in a north westerly direction from the Otway ranges to the Barwon River, including Mathews Creek, Deans Marsh Creek and Yan Yan Gurt Creek. The regional aquitard (MTD) outcrops across most of the area and the LTA outcrops on the south eastern side of the Bambra Fault. Alluvial sediments are present along the tributaries and the Barwon River and although there are no bores located in the alluvial sediments, these are likely to contain the water table aquifer. Areas of potential high risk to groundwater dependent vegetation and PASS in this area of the catchment is focussed in areas where there are alluvial sediments, for example, around Mathews Creek and Deans Marsh Creek. Other areas of high risk are located in the north east of the area.

Vegetation and PASS in some areas around the Gellibrand River is classified as high risk as there are particular sections considered to have “certain” likelihood of connection to the regional groundwater system and modelling indicates a significant impact on drawdown as a result of historic groundwater pumping (see Appendix A for detail on the risk assessment framework). Areas of potential high risks are expected to be in the areas to the east and close to the Bambra Fault. The risk across the remainder of the area is considered to be moderate and low.

Recommendations for Surrounding Environment Investigation Plan

Currently there is limited data to confirm surface water groundwater connection between the rivers and GDEs with the regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers/aquitards;
- The nature of groundwater-surface water interactions (i.e. are the rivers gaining flow or losing flow to groundwater);
- If there is baseflow contribution from the LTA; and,

- If impacts on baseflow from drawdown are buffered by the presence of the MTD and alluvial aquifers.

Further work is required in all these areas to install additional monitoring assets to inform further investigations. An overview of the recommendations for additional monitoring assets to install as part of the investigation plan, together with the rationale is provided in Table E.1.

After 12 months of data has been collected, it is recommended that the data be reviewed and the risk re-evaluated. The review would confirm the following:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer, LTA or MTD;
- Vertical gradients between aquifers and rivers;
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers); and,
- Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS).

The review of the additional data and hydrological conceptual model could result in one of the following three scenarios:

1. Site specific monitoring data confirms a lower risk than that predicted by the regional groundwater model, presumably based on the following criteria:
    - Regional groundwater model over-predicts impact;
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed upward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or water table decline predicted by model with the observed flow data confirms low risk.
2. Site specific monitoring data confirms the high risk predicted by the regional groundwater model, based on the following criteria:
    - Confirmed absence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer consistent with regional groundwater model predictions; and,
    - Groundwater flux predicted by model confirmed with observed data.
3. Site specific monitoring data confirms a high risk, based on the following criteria:
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed downward gradient exists between LTA and alluvial aquifer; and,

- o Comparison of groundwater flux or watertable flux predicted by regional model with the observed flow data confirms high risk.

If scenario 1 occurs – no further action is required, results presented to Southern Rural Water for consideration

If scenario 2 occurs – it is recommended that the regional groundwater model is used to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for any further action.

If scenario 3 occurs – recommended that a local groundwater model(s) is/are developed for each location to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for further action.

Table E.1: Rationale and recommendations for additional monitoring

Area	Why	What is the information gap	Recommended additional monitoring assets
BARWON RIVER CATCHMENT			
Barwon River east branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River east branch and regional groundwater system / outcropping LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing), if there is baseflow contribution from the LTA and if borefield impacts on baseflow are buffered by the presence of alluvial aquifers.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores PASS 2 and 48249 **Additional Surface water monitoring** Install one stream gauge on the East Branch near Seven Bridges Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. **Survey data** Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction. Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.
Barwon River west branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact	Currently there is limited data to confirm surface water groundwater connection between Barwon River west branch and regional groundwater system / outcropping LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

Area	Why	What is the information gap	Recommended additional monitoring assets
	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 64237 and 108915. **Additional Surface water monitoring** Install one stream gauge on the West Branch near Boundary Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Barwon River downstream of confluence	Rated as high risk as there are particular sections considered to have a possible likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River downstream of the confluence and the regional groundwater system / MTD. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the MTD.	**Additional Groundwater Monitoring** Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 82838. **Additional Surface water monitoring** Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Area	Why	What is the information gap	Recommended additional monitoring assets
GELLIBRAND CATCHMENT			
Gellibrand River	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between the Gellibrand River and the regional groundwater system / LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Ten Mile Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. Survey the stream bed elevation in the vicinity of the gauge and the bores.
Yahoo	Rated as high risk as there are particular sections considered to have a certain	Currently there is limited data to confirm surface water groundwater connection	**Additional Groundwater Monitoring**

Area	Why	What is the information gap	Recommended additional monitoring assets
	likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	between Yahoo Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. **Survey data** Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.
Vegetation and PASS investigations			
Yeodene	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA).	**Additional Groundwater Monitoring** Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level.

Area	Why	What is the information gap	Recommended additional monitoring assets
			Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. Survey the elevation of the creek bed close to the bores and at any gauge locations. **Additional Vegetation monitoring** Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.
Deans Marsh	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA). Vegetation assessments are required to confirm vegetation types and their reliance groundwater.	**Additional Groundwater Monitoring** Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Vegetation monitoring** Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition. Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.
Gellibrand	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling	Currently there is limited data to confirm the depth to watertable and connection with the LTA. This data is required to understand the nature of groundwater dependence from the LTA.	**Additional Groundwater Monitoring** See recommendations for Gellibrand River **Additional Vegetation monitoring**

Area	Why	What is the information gap	Recommended additional monitoring assets
	indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions		Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to outline the required investigations to confirm (or amend) the risk to groundwater dependent features from groundwater pumping in areas identified as high risk. These works have been carried out in accordance with the scope of services as set out in our proposal to investigate areas of potential high risk submitted to Barwon Water on 3rd September 2019.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and concludes as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Barwon Water and DELWP as outlined in this report.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by the law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in another other context.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs' client, Barwon Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Barwon Water. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 Background

Barwon Water received a Section 78 Notice (under the Water Act 1989 (Vic)) and the purpose of the Notice is to ensure that Barwon Water successfully remediate impacts caused by historic groundwater extraction. The Section 78 Notice directs Barwon Water to develop and implement a Remediation Plan for Boundary Creek and Big Swamp and surrounding environment.

In response to the Section 78 Notice, Barwon Water developed a scope of works in consultation with the Boundary Creek Remediation Working Group, their nominated experts and Jacobs, which was submitted to Southern Rural Water in July 2019.

The scope of works used the groundwater model and risk assessment framework outlined in the Ministerial Guidelines for High Value GDEs to assess areas of potential low, moderate and high risk of impact from the Barwon Downs borefield. The risk assessment framework considers the likelihood of a groundwater dependent feature (river, vegetation or PASS) being connected to the regional groundwater system and the consequence of drawdown induced by pumping on the feature. The important part of this assessment is the link to the regional groundwater system, as it is this system which is affected by pumping.

The risk assessment identified several areas of potential high risk. These include some areas in the Boundary Creek catchment and other areas along the Barwon River East Branch, Gellibrand River, Ten Mile Creek and Yahoo Creek. These areas of potential high risk are the focus for the remediation plan.

The remediation plan is divided into areas with different action plans:

- Areas where impact has been confirmed will transition into the *Boundary Creek and Big Swamp remediation plan*.
- Areas where impact has not yet been confirmed due to insufficient monitoring to validate groundwater model predictions will be covered by the *Surrounding Environment investigation plan*.

An overview of the approach taken to prioritise areas for remediation is shown in Figure 1.1.

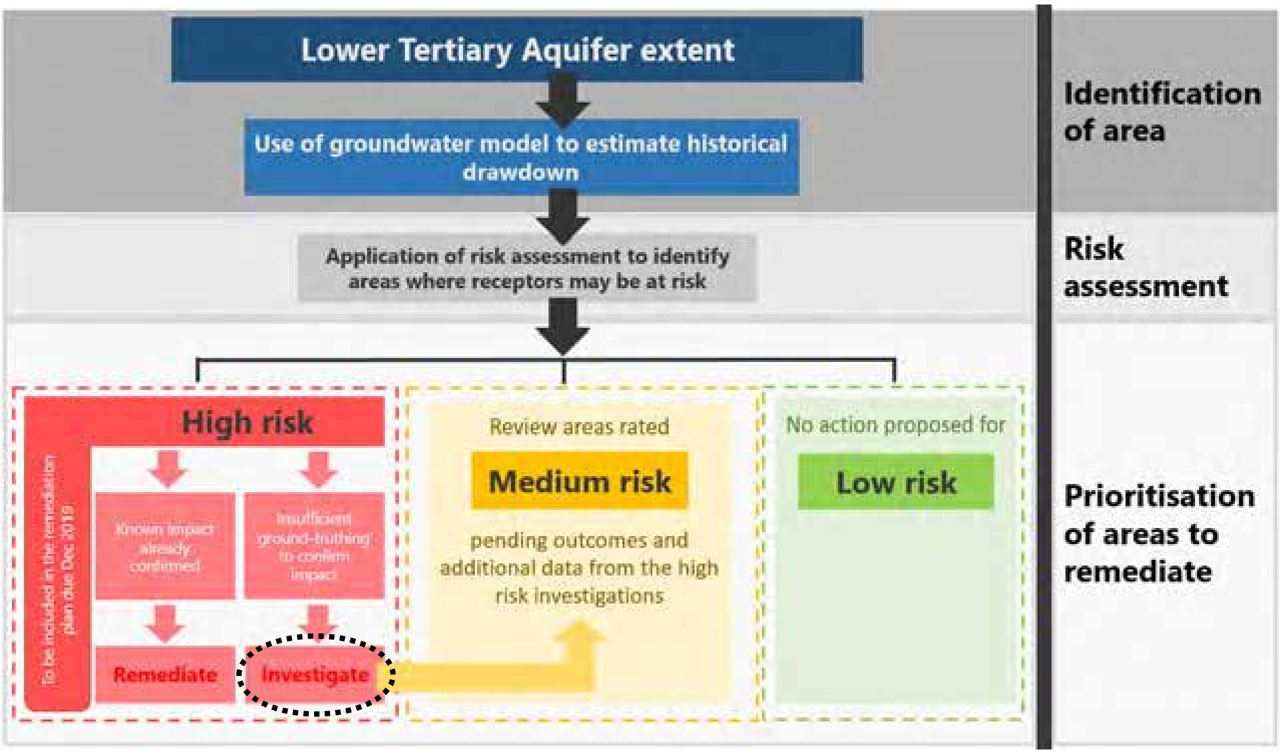
This report outlines the rationale for the recommendations in the *Surrounding Environment investigation plan* for areas of potential high risk that cannot be confirmed with historical monitoring data. Areas with potential moderate risk will be reviewed pending the outcomes of the investigation plan. No further action is recommended for areas classified as low risk.

1.2 Objectives

The objectives of this study are to:

- Review the monitoring data available for areas that have been identified previously through the revised ‘scope of works’ as potential high risk from impact of historical groundwater extraction; and
- Recommend additional monitoring and/or environmental assessments required to confirm if historical groundwater extraction has caused a measurable impact at high risk areas.

Figure 1.1: Approach taken to prioritise areas for remediation



1.3 Areas included in the investigation plan

Areas of potential high risk included in the investigation plan include:

- Barwon River catchment:
  - Barwon River East and West Branches
  - Barwon River downstream of the confluence
- Gellibrand River catchment:
  - Ten Mile Creek
  - Yahoo Creek
  - Gellibrand
- Groundwater dependent vegetation in three areas of the model:
  - West of Barwon River to the north of Yeodene
  - East of Barwon River between Barwon Downs and Deans Marsh and
  - Along the Gellibrand River.

2. Regional groundwater model

The regional groundwater model has been developed and refined over many years to reflect the continual gathering of groundwater data and improved conceptual understanding of the regional aquifer that resulted from ongoing Barwon Water studies. The most recent calibrated model was completed in 2016-17 when the model was expanded, re-built and re-calibrated. The update of the model includes new layers, new monitoring data and a significant improvement in the conceptual understanding. A summary is provided below and more detail on the re-calibration is outlined in Jacobs (2018).

2.1 Regional stratigraphy and model layers

The extent of the Barwon Downs regional groundwater model is determined by the extent of the Lower Tertiary Aquifer (LTA). The model area covers most of the aquifer extent. While the aquifer units that comprise the LTA are widespread and also are found south west of the Gellibrand River, the River provides a strong hydraulic influence on the aquifer, so the numerical model and the limit of interest for this risk assessment is the Gellibrand River in the south west. The LTA is located in a graben, which is a valley defined by escarpments on each side. The LTA outcrops near the edges of the graben and dips down in the centre of the graben, where it is found at around 500 m depth. The areas where groundwater level decline in the LTA in response to pumping has the greatest potential to cause adverse impacts is where the aquifer outcrops around the margins of the graben.

Surficial geology together with the extent of regional groundwater model is shown in Figure 2.2. A cross section through the centre of the aquifer is shown in Figure 2-1 and the location of this cross section is shown in Figure 2.2. The key hydrogeological units and their corresponding layer in the regional groundwater model are outlined in Table 2-1. Due to the relatively very small spatial extent of the Quaternary Alluvium combined with the difficulty of representing this discontinuous unit in a regional groundwater model, this unit was excluded as a layer from the model.

Table 2-1 Hydrogeological units of the Barwon Downs Graben and relationship to model layers in the regional groundwater model

VAF aquifer	Geological Unit	Description	Type	Model layer
Minor surficial sediments	Quaternary Alluvium	Sands, silts and gravels.	**Aquifer (minor)**	Not modelled
Mid Tertiary Aquitard (MTD)	Gellibrand Marl	Calcareous silty clay and clayey silt. Fossiliferous.	**Aquitard**	1
	Clifton Formation	Calcarenite with marine fossils and minor quartz and limonite sands	**Aquifer (minor)**	2
	Narrawaturk Marl	Calcareous mudstone with thin carbonaceous beds, sand beds and fossiliferous beds	**Aquitard**	3
Lower Tertiary Aquifer (LTA)	Mepunga Formation	Medium to coarse grained quartz sand with some carbonaceous clays and silt layers	**Aquifer**	4
	Dilwyn Formation	Carbonaceous, sandy clays and silts, with some quartz sand and silty sand beds, and minor gravel. Coal and carbonaceous clays also occur in this unit.	**Aquifer**	
	Pember Mudstone	Clays, silts and fine grained sand with carbonaceous, micaceous and pyritic horizons.	**Aquitard (minor)**	5
	Pebble Point Formation	Fine-grained sand with carbonaceous silt and quartz pebble beds. This unit is an equivalent to the Moomowroong Sand Member, Wiridjil Gravels that occur in the Gellibrand sub-basin to the south west of the study area.	**Aquifer**	6
Bedrock (BSE)		Sandstone, siltstone and mudstone with feldspar and quartz grains, well-bedded and consolidated.	**Aquitard/Minor aquifer**	7

Figure 2-1 Representative cross section of the Barwon Downs Graben (Alluvial aquifers not modelled in the regional groundwater model)

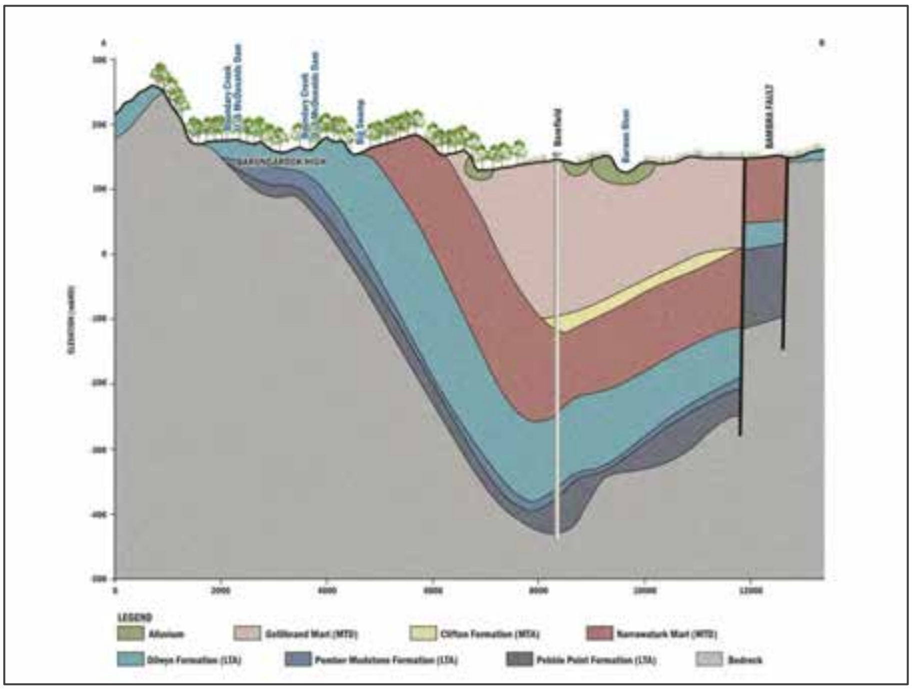
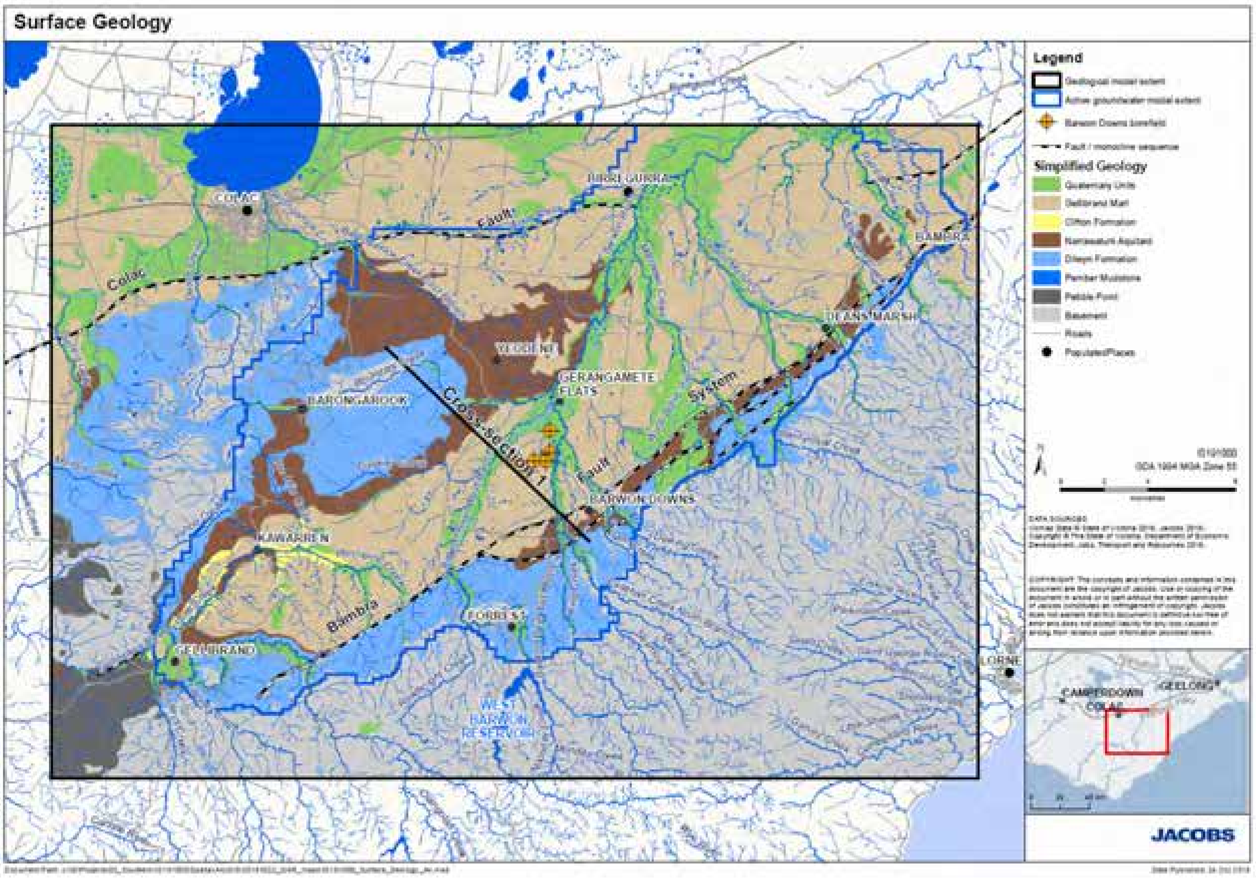


Figure 2.2: Surficial geology in vicinity of the Barwon Downs borefield (cross section 1 is shown in figure above)



The regional groundwater model does not explicitly include the alluvial aquifer as this aquifer is not continuous across the study area and is highly variable where it is present. The exclusion of the alluvial aquifer as a layer in the model limits the ability of the regional groundwater model to represent drawdown propagation to the watertable aquifer in those areas where the alluvial aquifer is significant in controlling water level. This inherently extends to subsequent potential impacts to ecosystems dependent on the shallow groundwater (e.g. rivers, wetlands and vegetation). Where there are alluvial aquifers, the impact to the watertable represented by the regional groundwater model reflects changes in the regional aquitard (MTD) or regional aquifer (LTA), rather than the alluvial aquifer.

2.2 Faults

Faults are hydrogeologically important to the Barwon Downs Graben as they cause discontinuities in groundwater flow. The most important faults are the Colac Fault and Bambra Fault. The Colac Fault restricts the extent of groundwater flow to and from the north. The Bambra Fault causes aquifer units to be upthrown on the southeast side of the fault, resulting in partial or complete discontinuity in the aquifer, aquifer outcrop and termination of the Dilwyn Formation south east of the Fault.

Faults are generally found on the steeply dipping sides of the graben. The Colac Fault was previously used to define the northern model boundary (SKM, 2001 and SKM, 2011). Analysis of observed drawdown responses found that there was limited connectivity across the Colac Fault (Jacobs, 2015), which indicates that the fault acts as a boundary that significantly reduces the migration of groundwater responses to the north of the fault.

The Bambra Fault, or Bambra Fault zone, is characterised by a series of sub-parallel faults that have resulted in the upward displacement of aquifer layers to the southeast of the fault. In a recent review of borefield related groundwater responses in the Lower Tertiary Aquifer, Jacobs (2015) found that the Bambra Fault was best represented in a regional groundwater model by a 95% reduction in aquifer transmissivity to the southeast of the fault. The apparent loss of transmissivity to the southeast of the fault is due to the combined effects of aquifer thinning and displacement related disruption to aquifer continuity. The section of the Bambra Fault located further to the southwest is likely to have an even lower apparent transmissivity and it was concluded that it should be represented as a partial barrier to flow in the regional groundwater model.

2.3 Natural recharge and discharge processes

The LTA, consisting of the Pebble Point, Dilwyn and Mepunga Formations, is the major aquifer in the region. The major recharge process is rainfall infiltration where the aquifer outcrops at the edges of the graben (see Figure 2.2), with the largest area being the Barongarook High in the western part of the graben. Some additional recharge is also received from downward leakage from overlying formations and leakage from some rivers where they cross the aquifer outcrops.

Natural discharge processes include evapotranspiration from shallow groundwater and vegetation, discharge to some rivers and aquifer throughflow to the north and south of the graben. The most significant is discharge process is discharge to rivers including the Gellibrand River, Barwon River East Branch and Ten Mile Creek where the LTA provides baseflow to these rivers.

2.4 Groundwater flow directions

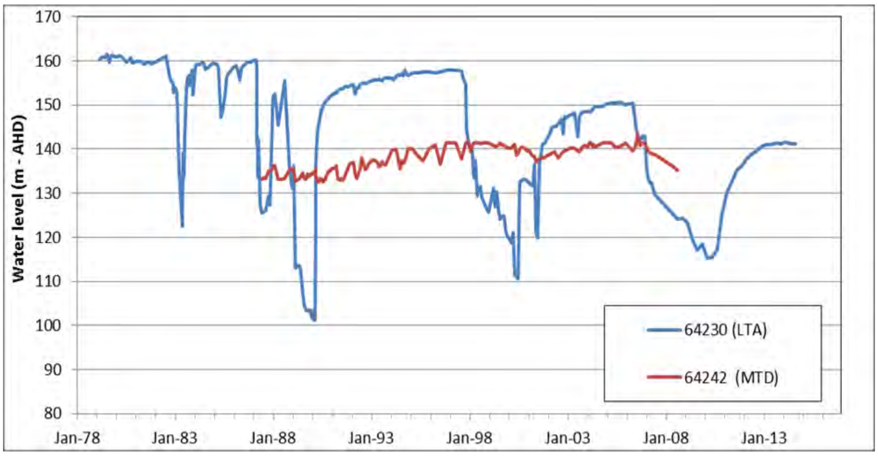
Groundwater levels at the Barongarook High are currently greater than 240 m AHD (at the top of the groundwater system) and this drives horizontal groundwater flow to the east towards the Gerangamete Flats and south towards Gellibrand. Groundwater flow within the graben discharges to the south west (towards Gellibrand) and north east (towards Bambra).

Vertical flow processes also play a key role in groundwater flow in the Barwon Downs graben. Vertical gradients exist within the LTA and between the LTA and the overlying hydrogeological units. It is generally understood that upward hydraulic gradients naturally exist between the Dilwyn and Pebble Point aquifers and the overlying Narrawaturk Marl aquitard through the central portion of the graben. This facilitates upward leakage from the aquifers into the overlying aquitard and is a key discharge process for the aquifer. Groundwater pumping from the LTA has the potential to generate water level declines that induce downward leakage from the overlying MTD. This downward leakage results in reduced groundwater levels in the MTD which has the potential to subsequently result in negative environmental impacts at the surface.

As part of recent investigations between 2014 and 2016, bores were constructed in the Gellibrand Marl above the LTA (Jacobs, 2016). Groundwater monitoring in these bores indicates upward hydraulic gradients from the LTA to the Gellibrand Marl, consistent with those observed by Witebsky (1995).

Groundwater monitoring has identified that groundwater levels in the LTA have fallen below the overlying MTD during periods of pumping (see Figure 2-3). This shows that when groundwater levels in the LTA fall below the groundwater level in the MTD, the water levels in the MTD display a corresponding decline which consequently has the potential to cause adverse environmental impacts at the surface.

Figure 2-3 Bore hydrographs in LTA and MTD near the borefield



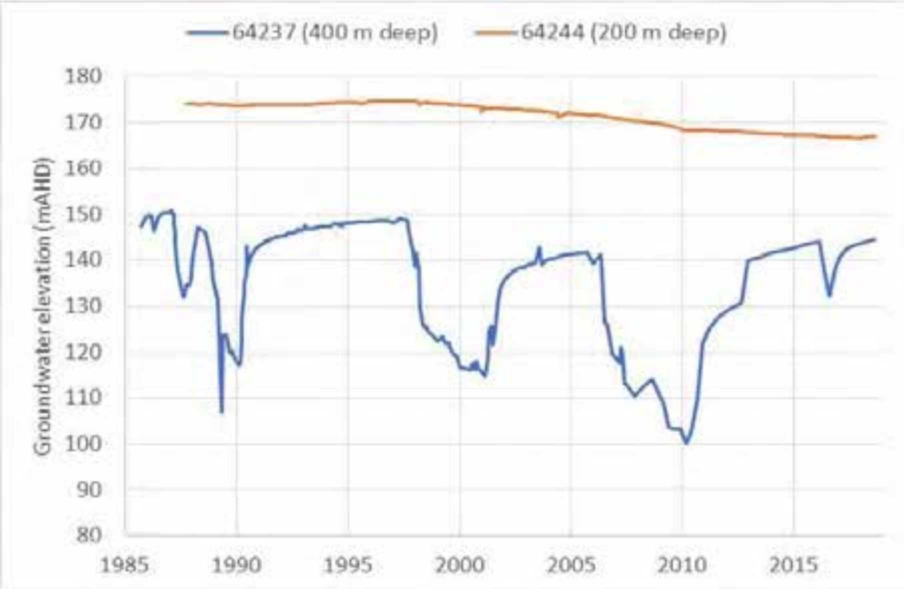
There are also vertical flow gradients present within the LTA. Figure 2-4 shows two hydrographs for bores in the LTA located at the centre of the study area near Seven Bridges Road. In the deeper LTA where the groundwater is extracted, there is a strong response to pumping, whereas shallower bores in the LTA show a much more subdued response to pumping. This is consistent with stratigraphic variability in the LTA and whilst there is a downward gradient within the LTA, the effects of pumping are buffered through the LTA.

Downward trends in the LTA are observed closer to the edges of the graben, while the upwards trends from the LTA to the MTD are observed in the centre of the graben.

In addition to variability in the LTA, the presence of alluvial aquifers and minor perched aquifers have been confirmed on the Barongarook High. Analysis of data collected by Barwon Water from shallow groundwater monitoring bores in this area have confirmed that groundwater levels in these aquifers are more influenced by seasonal climate and have been buffered from drawdown in the LTA (Jacobs, 2017a, 2017b).

The presence and thickness of the alluvial aquifers have not been confirmed outside of Barongarook High. PASS bores 2 and 4 are shallow bores installed by Barwon Water located near the Barwon River East Branch and Yan Yan Gurt Creek in the north east of the study area, respectively. These bores are located in terrace landscapes adjacent to waterways where the alluvial sediments comprise of fine grained silts and clays deposited in a low energy environment. The alluvial aquifers in these locations are not significant aquifers, even at this local scale.

Figure 2-4 Examples of groundwater level trends at different depths in the LTA which demonstrate the vertical gradient (upward pressure potential)



2.5 Limitations of the regional groundwater model

The regional groundwater model is understood to over-state potential drawdown in regional aquitards and in areas where Quaternary aquifers have been confirmed to be present but have not been included in the model. These layers are known to act as physical constraints, such as clay layers within the formations that restrict groundwater flow from the regional aquifer and therefore may limit groundwater drawdown. As these physical constraints have not been included in the regional groundwater model, the model does not account for the restriction of groundwater flow and subsequent decrease in drawdown observed at these locations.

The Technical Works Monitoring Program undertaken by Barwon Water to inform the Barwon Downs licence application has confirmed the presence of many Quaternary alluvial aquifers which are not influenced by pumping (Jacobs 2018). In these areas, monitoring indicates that the model over predicts drawdown caused by pumping and thus also over-predicts the subsequent risk to environmental receptors at the surface. The predicted drawdown in these areas and associated risk will need to be confirmed with further technical site-specific investigations to confirm or amend predicted drawdown and subsequent risk to environmental receptors at the surface. This data can then also be used to help confirm the presence and level of impact at the surface to inform decisions regarding any further actions required.

3. Barwon River Catchment

The Barwon River East and West Branches rise in the Otway Ranges around the township of Forrest. The Barwon River East Branch joins the West Branch near Gerangamete Flats, and below the confluence of these two branches, the river becomes the Barwon River. Boundary Creek also joins the Barwon River near Gerangamete Flats.

Flow in the Barwon River is regulated from its upper reaches through releases from the West Barwon Dam and diversions from some tributaries.

Outcropping geology is shown in Figure 3-1 and Figure 3-2 . Figure 3-1 shows that the East and West branches of the Barwon River originate where the Basement outcrops in the Otway Ranges, and then flow over the outcropping Lower Tertiary Aquifer (LTA) on the south east side of the Bambra Fault. Further downstream (north west of the Bambra Fault), the rivers flow over outcropping Mid Tertiary Aquitard (MTD) towards the Gerangamete Flats. According to the geological mapping, alluvial sediments are present along both rivers, however the presence and thickness of an alluvial aquifer in these sediments has not been confirmed. Alluvial sediments can hold local aquifers that provide an additional source of water which may not be influenced by groundwater pumping from Barwon Downs.

Figure 3-2 shows that downstream of the confluence with Boundary Creek, the Barwon River flows through the centre of the graben over alluvial sediments, which in turn, overlie the regional Mid Tertiary Aquitard (MTD). The alluvial sediments are more extensive downstream (to the north) as the floodplain widens, however the thickness of the alluvium is not known. Monitoring indicates that the MTD is up to 300 meters thick in the centre of the graben.

Figure 3-1 Outcropping geology around the Barwon River East and West Branches

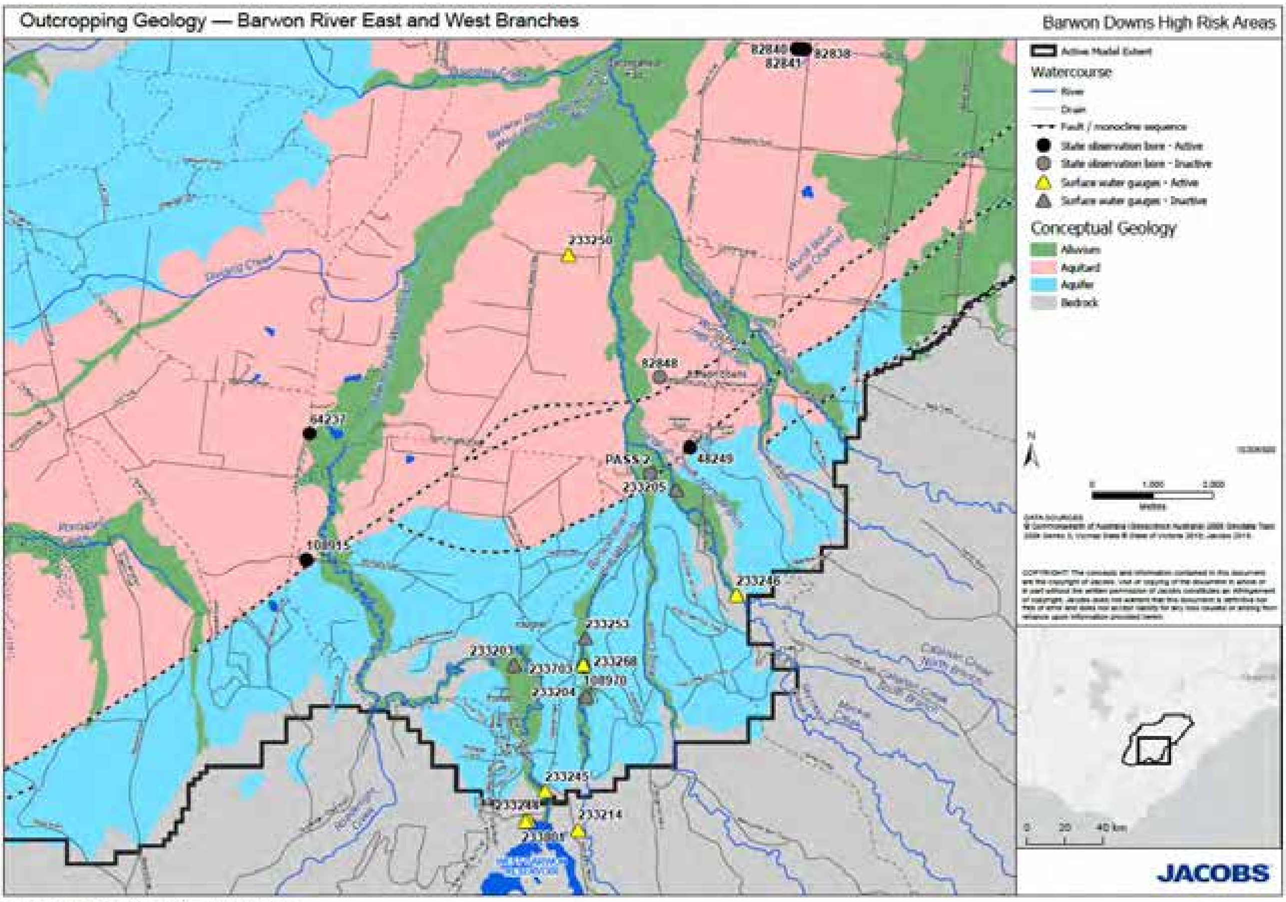
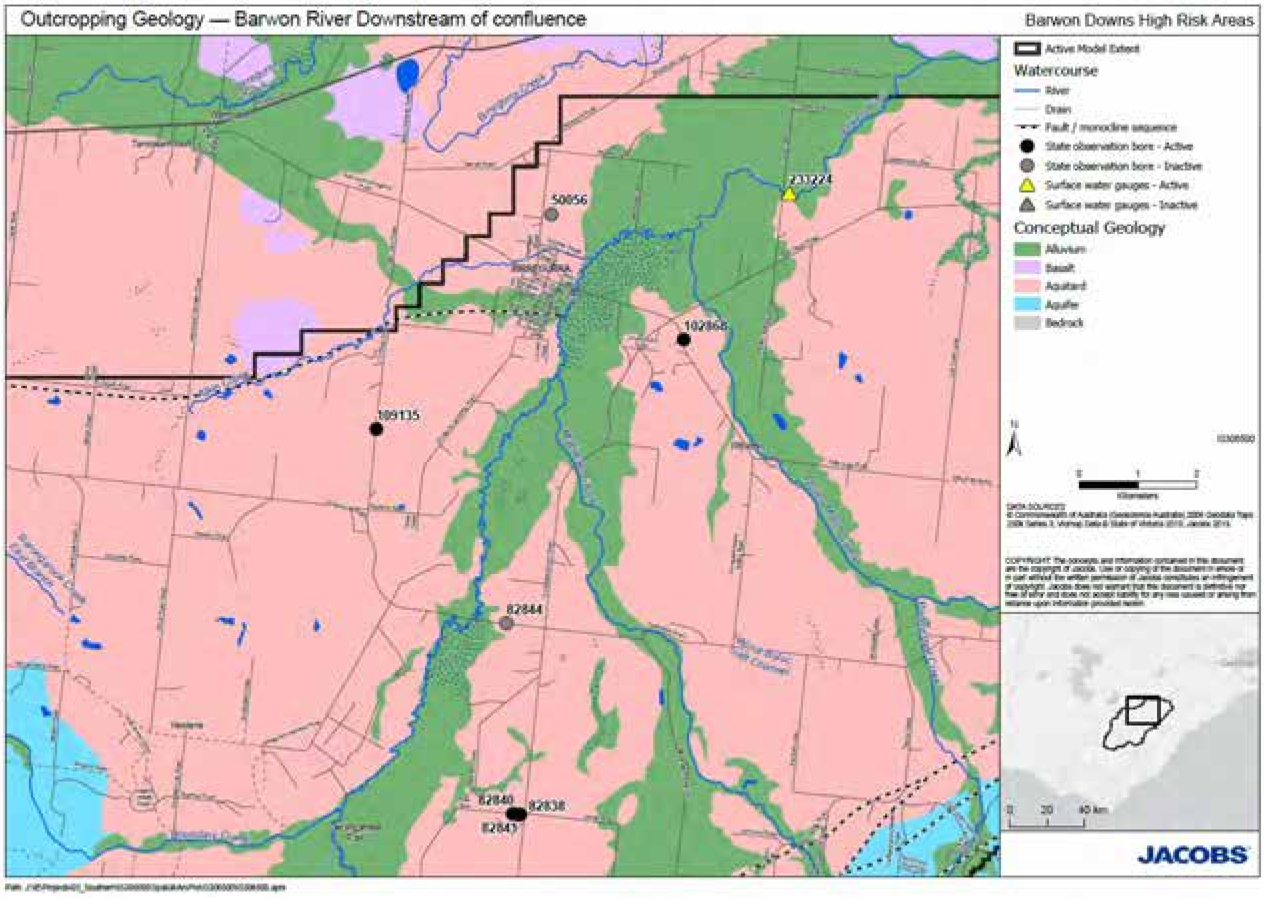


Figure 3-2 Outcropping geology around Barwon River downstream of confluence with Boundary Creek



3.1 Barwon River East Branch

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River East branch. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

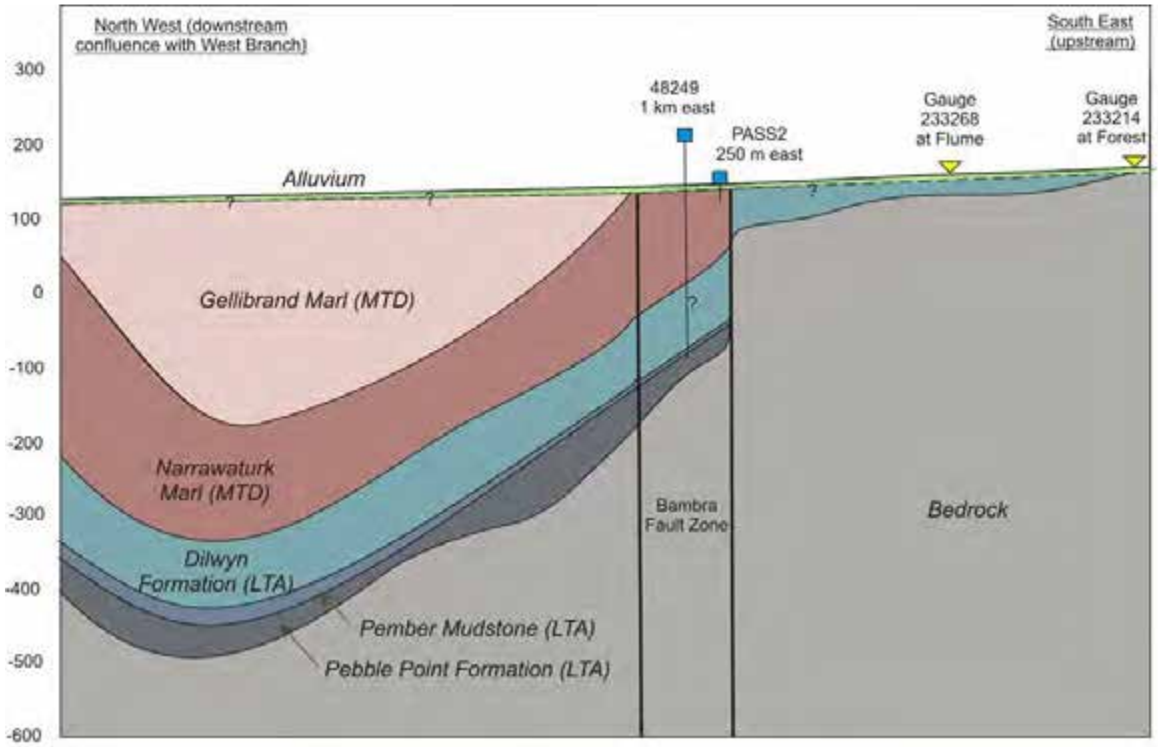
3.1.1 Why it was classified high risk

The Barwon River East Branch is classified as potential high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.3 shows a long section along the East Branch of the Barwon River, which shows the stratigraphy as presented in the regional groundwater model. This highlights that the LTA has the greatest potential to impact the river upstream of the Bambra Fault zone, where the LTA outcrops at the surface. North west of the fault zone (downstream), the MTD overlies the LTA and is between 70 and 100 m thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.3: Long section along Barwon East Branch. Bore 48249 is assumed to be in the LTA based on depth.



Regional groundwater model results

Figure 3.4 and Figure 3.5 shows the estimate of river seepage calculated by the model for the Barwon East Branch where it flows over the LTA and MTD respectively. The East Branch is represented as a gaining river where it flows over the LTA (represented by positive river seepage values). The model estimated it remained a gaining river until around 2000, when a decline in groundwater level is interpreted to have caused the creek to become a losing river.

Where the East Branch flows over the MTD, the river is also represented as a gaining river until about 2000, when groundwater level is interpreted to have declined and the creek becomes losing.

Figure 3.6 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios (from the regional groundwater model). This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 18 L/sec in each river reach (combined total 36 L/sec), at the end of the Millennium Drought.

Figure 3.4: Predicted river seepage from the Barwon River East Branch where it flows over the LTA

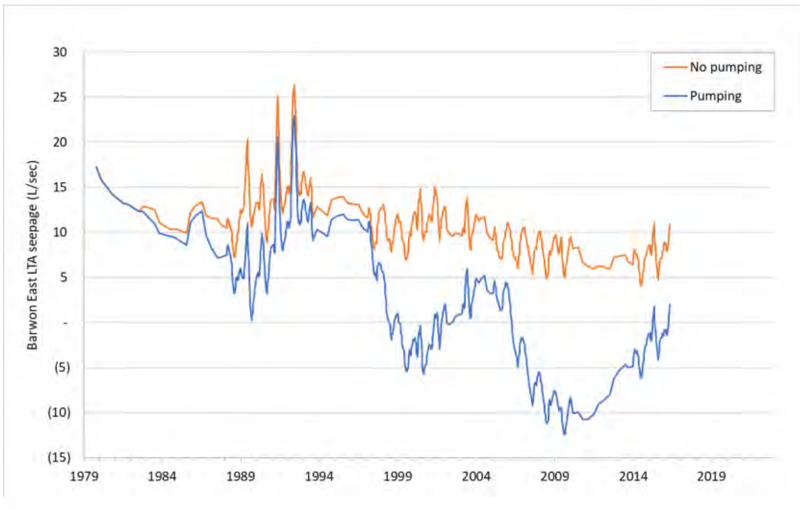


Figure 3.5: Predicted river seepage from the Barwon River East Branch where it flows over the MTD

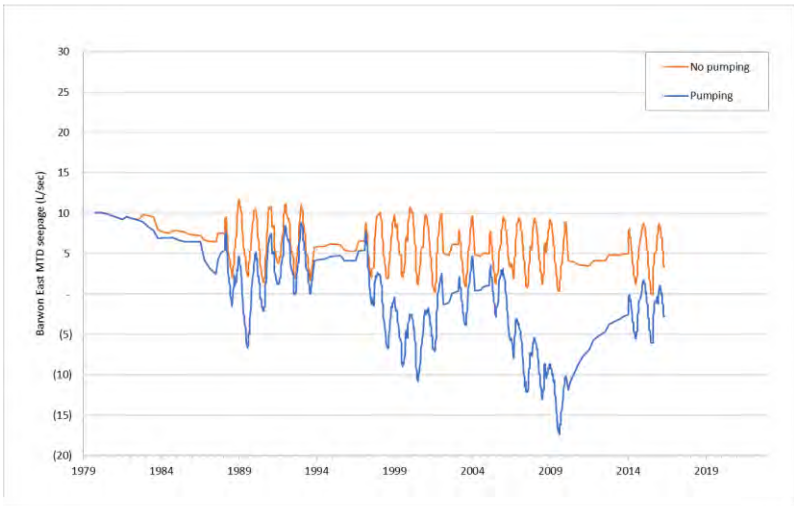
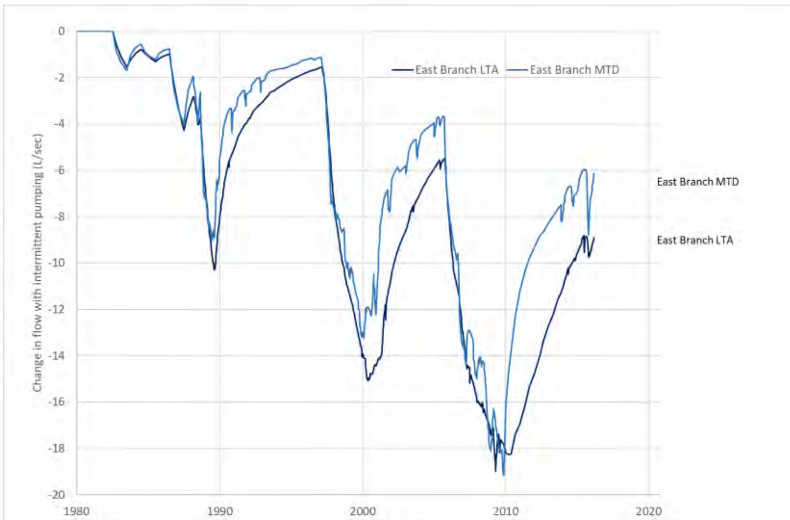


Figure 3.6: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 3-7. This was calculated using the risk assessment framework outlined in Appendix A and using the likelihood defined in Figure A.1 and Table 3.1 and the drawdown predicted by the model.

Figure 3-7 shows the spatial distribution of risk to Barwon River East Branch, which has three areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk area is located near the headwaters of the Barwon River East Branch, immediately upstream of the Bambra Fault (south east) and downstream of the fault. In other areas, the risk to the Barwon River East Branch is moderate to low due to the predicted drawdown being much less at this location.

Along this reach, the Barwon River East Branch flows over outcropping aquifer (LTA) and aquitard (MTD). Where the river flows across outcropping LTA, the likelihood of the river being connected to the regional groundwater system is classified as certain. Where the river flows over the regional aquitard, the likelihood of it being connected is classified as possible.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 3.6).

There are three active streamflow gauge monitoring the Barwon River and the Barwon River East Branch. One gauge is upstream and outside the model domain and another gauge monitors the intake to Wurdee Bullock reservoir. The most relevant active streamflow gauge within the model domain is Site 233224 Barwon River @ Ricketts Marsh, which monitors flow in the Barwon River downstream of the confluence with Boundary Creek. The 10th percentile of flow (Q90) from this gauge is 4.9 ML/day based on monitoring data collected between 1971 – 2017.

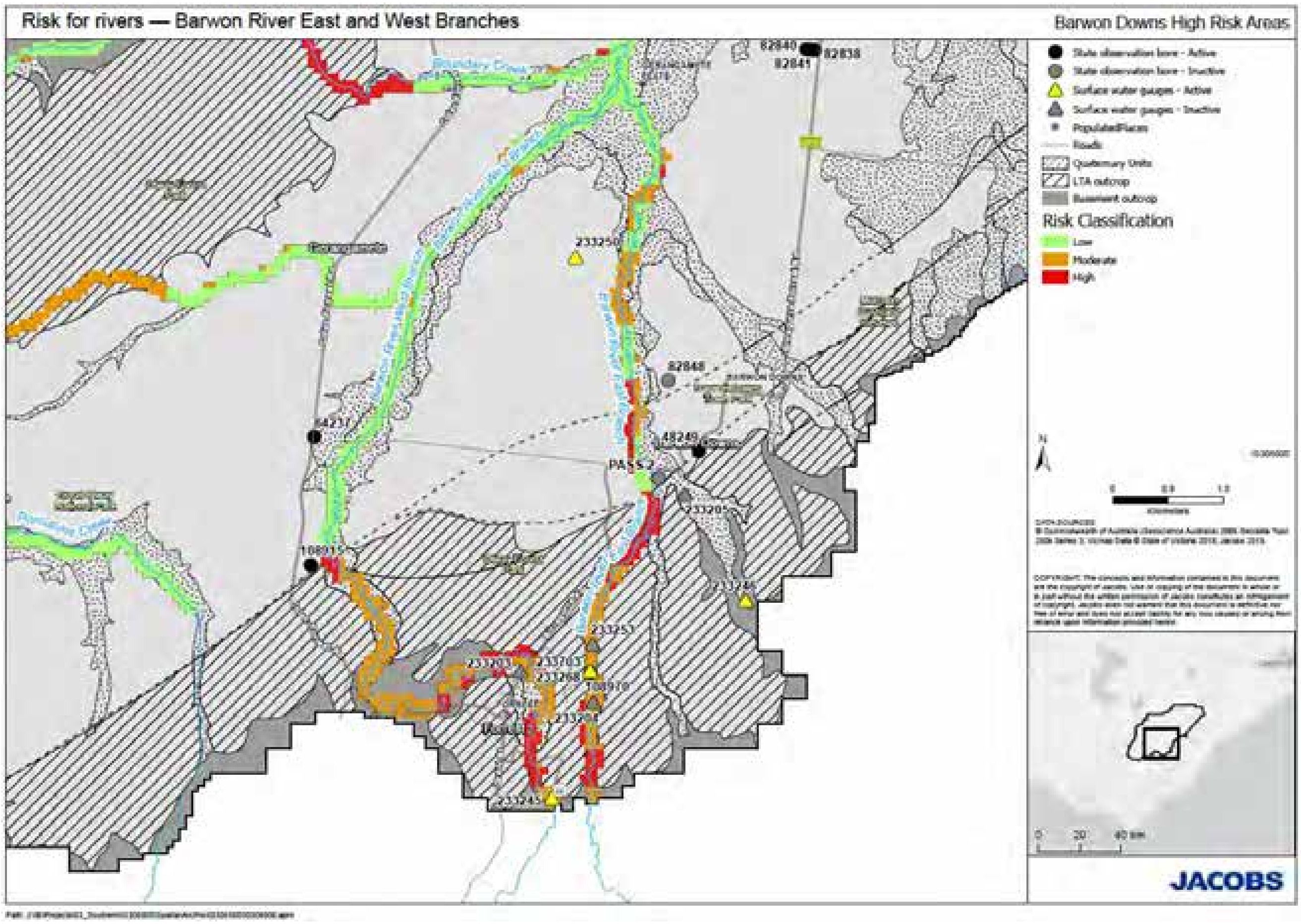
The change in river flux was calculated for reaches that flow over the LTA and the MTD. This shows that the maximum impact predicted by the model is almost 36 L/sec for both reaches (3.3 ML/day total). The maximum predicted impact equates to 33% of low flow for the Barwon River East Branch where it flows over the LTA and 35% of low flow where it flows over the aquitard. The combined total reduction in groundwater contribution to the river is 68% of low flows. The predicted reduction in groundwater contribution is expected to be similar for both as the MTD is thinner along this reach (downstream of the Bambra Fault zone), and the model indicates that the MTD does not provide a significant buffer to drawdown in this location.

Based on the likelihood and consequence (based on change in river flux) classifications, both river reaches are classified as potential high risk (see Table 3.1). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.1: Risk assessment results for Barwon River East Branch

River Reach	Likelihood	Consequence	Risk
Barwon River East Branch LTA	Certain	Significant	High
Barwon River East Branch MTD	Possible	Significant	High

Figure 3-7 Location of areas of potential high risk along the Barwon River East (and West) Branches using drawdown to define the consequence



3.1.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River East Branch and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River East Branch gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix C.

The primary data gaps identified for the Barwon River East Branch relate to information that can be used to determine if the rivers are gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores along the Barwon River East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Bores should be located on the south eastern side of the Bambra Fault.

- Monitoring bores to be installed with a data logger, with a monitoring frequency of at least daily readings. Quarterly manual water level readings are also recommended for a minimum period of 5 years. The datalogger is recommended to be downloaded on a quarterly basis, when the manual readings are collected.

- Ongoing monitoring of existing bores PASS 2 and 48249 to the same frequency as above.

Additional Surface water monitoring

- Install one stream gauge on the Barwon River East Branch near Seven Bridges Road to record all flows (with a priority to accurately measure low flows) and level. Include recording of the elevation of the stream bed.

- The stream gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Survey data

- Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction.

- Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

3.2 Barwon River West Branch

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River West branch. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

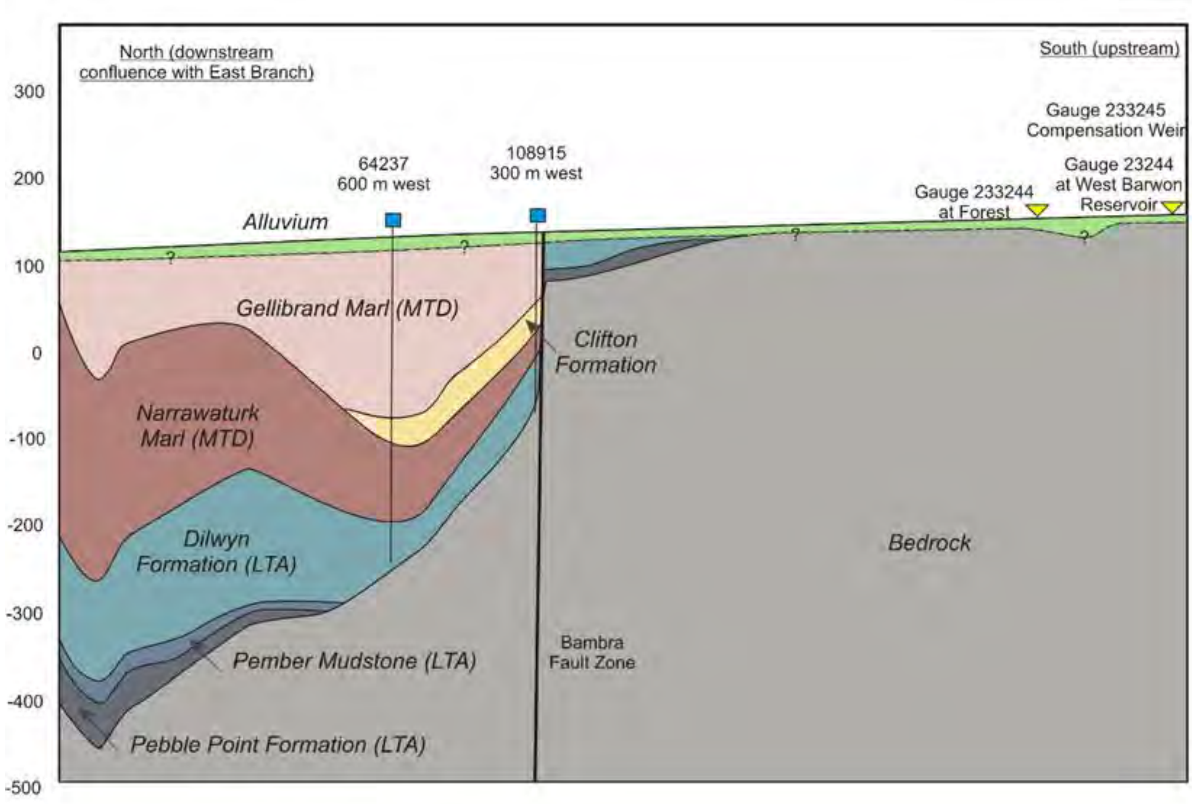
3.2.1 Why it was classified high risk

The Barwon River West Branch is classified as high risk as there are particular reaches considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.8 shows a long section along the West Branch of the Barwon River, which shows the stratigraphy as presented in the regional groundwater model. This highlights that the LTA has the greatest potential to impact the river upstream of the Bambra Fault zone, where the LTA outcrops at the surface. North west of the fault zone (downstream), the MTD overlies the LTA and is between 70 and 100 m thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.8: Long section along Barwon West Branch



Regional groundwater model results

Figure 3.9 and Figure 3.10 shows the estimate of river seepage calculated by the model for the Barwon West Branch where it flows over the LTA and MTD respectively. The Barwon River West Branch is represented as a losing river where it flows over the LTA (represented by negative river seepage values). There is no observable difference between the pumping and no pumping scenarios, which indicates that groundwater pumping is not predicted to impact the river in this location.

Where the Barwon River West Branch flows over the MTD, the river is also represented as a losing river. The regional groundwater model predicts there is a potential impact of around 1-2 L/sec in response to pumping.

Figure 3.6 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model where the river flows over the MTD was an increase in river losses to groundwater of around 1.5 L/sec, experienced at the end of the Millennium Drought.

Figure 3.9: River seepage from Barwon River West Branch where it flows over the LTA (no impact of pumping is predicted at this location and so the two lines in this plot appear as one)

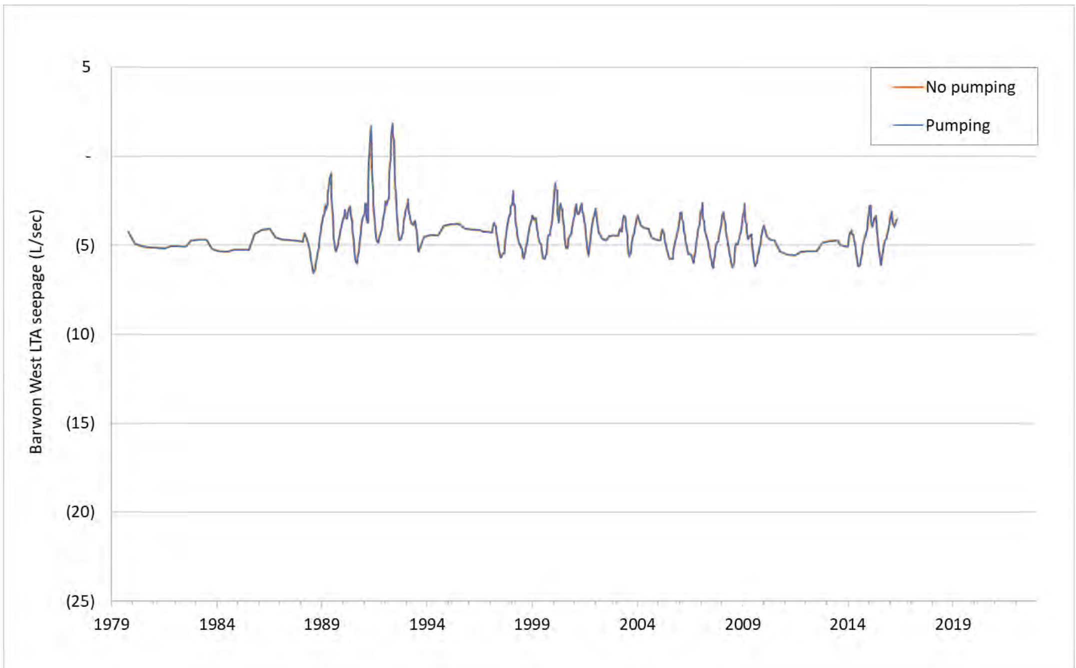


Figure 3.10: River seepage from Barwon River West Branch where it flows over the MTD

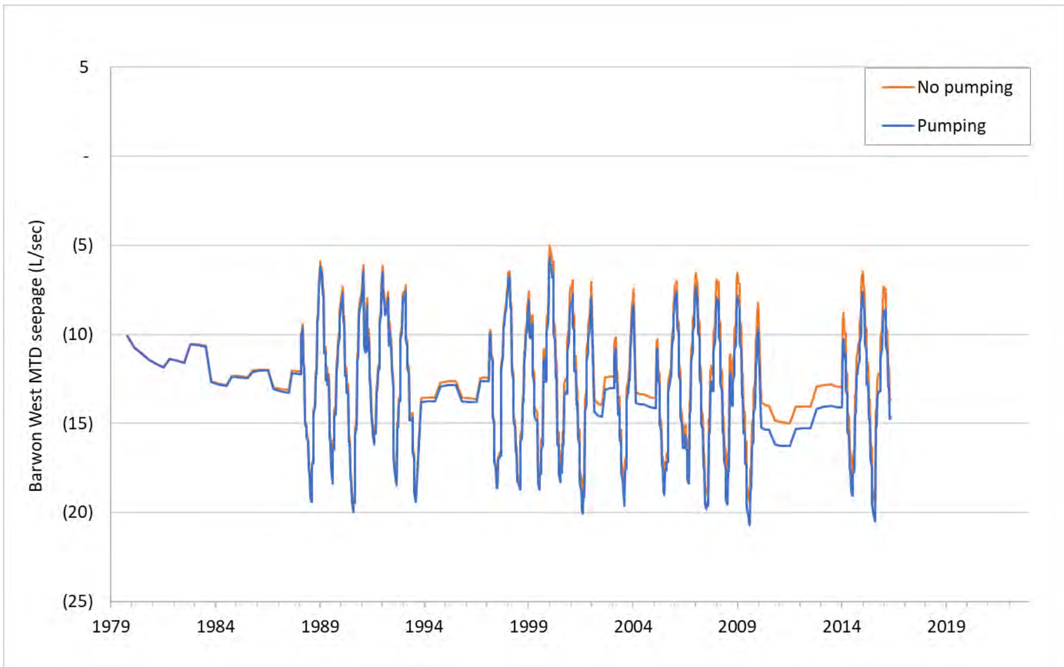


Figure 3.11: Change in river flux between no pumping and pumping

Risk assessment results

Areas of potential high risk are shown in Figure 3-12. This was calculated using the risk assessment framework outlined in Appendix A, and using the likelihood defined in Figure A.1 and Table 3.1, and consequence defined by drawdown predicted in the model.

Figure 3-12 shows the spatial distribution of risk to Barwon River West Branch (together with the East Branch), which has two areas of potential high risk within the model boundary (based on drawdown). The potential high risk areas are located near the headwaters of the Barwon River West Branch and immediately upstream of the Bambra Fault (south east). In other areas, the risk to the Barwon River West Branch is moderate to low due to the predicted drawdown being much less at this risk location.

Along this reach, the Barwon River West Branch flows over outcropping aquifer (LTA) and aquitard (MTD). Where the river flows across outcropping LTA, the likelihood of the river being connected to the regional groundwater system is classified as certain. Where the river flows over the regional aquitard, the likelihood of it being connected is classified as possible.

The risk outcome is classified as moderate when the consequence is based on the change in flux to rivers (shown in Figure 3.11) estimated by the groundwater model.

There are three active streamflow gauge monitoring the Barwon River and the Barwon River West Branch. The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and the very edge of the model domain. The most relevant active streamflow gauge within the model domain is Site 233224 Barwon River @ Ricketts Marsh, which monitors flow in the Barwon River downstream of the confluence with Boundary Creek. The 10th percentile of flow (Q90) from this gauge is 4.9 M/day based on monitoring data collected between 1971 – 2017.

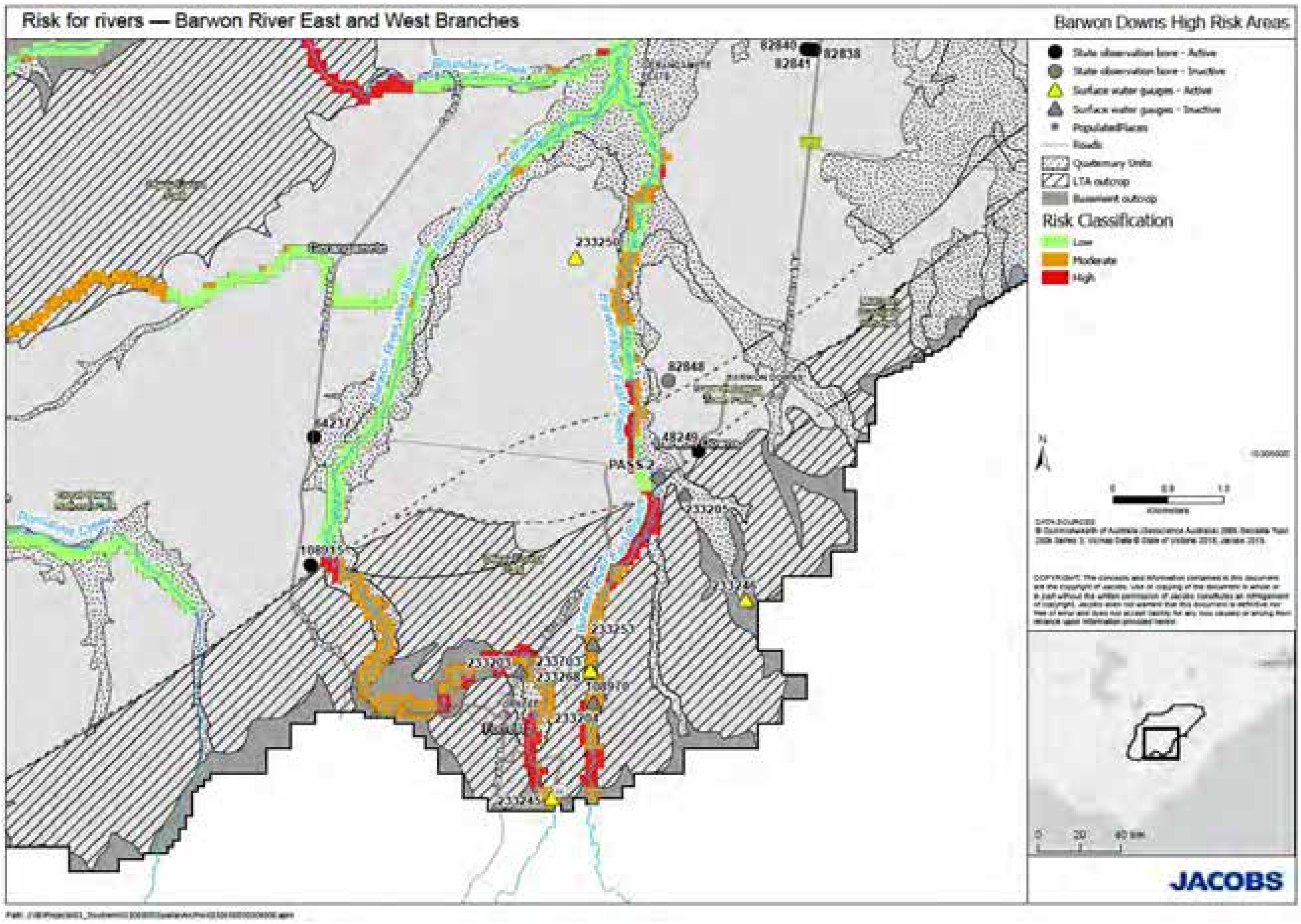
The change in river flux was calculated for reaches that flow over the LTA and the MTD. This shows that the maximum impact predicted by the model is 1.5 L/sec for both reaches (0.1 ML/day). Figure 3.11 shows that the maximum impact predicted by the model is negligible for the West Branch where is flows over the LTA and around 1.5 L/sec where is flows over the MTD. The maximum predicted impact equates to <1% of low flow for the West Branch where it flows over the LTA and 2% of low flow where it flows over the MTD.

Based on the likelihood and consequence classifications (based on change in river flux), both river reaches are classified as moderate risk (see Table 3.2). Small areas of potential high risk are identified when the consequence classification is defined by drawdown, therefore further work is recommended on the Barwon River West Branch to confirm the impacts and risk. It should be noted that there is limited monitoring data to confirm this drawdown impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.2: Risk assessment results for Barwon River West Branch

River Reach	Likelihood	Consequence	Risk
Barwon River West Branch LTA	Certain	Minor	Moderate
Barwon River West Branch MTD	Possible	Moderate	Moderate

Figure 3-12 Location of areas of potential high risk along the Barwon River East (and West) Branches using drawdown to define the consequence



3.2.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River West Branch and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River West Branch gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix C.

The primary data gaps identified for the Barwon River West Branch relate to information that can be used to determine if the rivers are gaining or losing to groundwater, and how drawdown propagates through the LTA (especially across the Bambra Fault) and the potential impact this has on groundwater levels in the shallow LTA, the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above.

<u>Additional Groundwater Monitoring</u>

- Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Bores should be located on the south eastern side of the Bambra Fault.
- Monitoring bores to be installed with a data logger, with a monitoring frequency of at least daily readings. Quarterly manual water level readings are also recommended for a minimum period of 5 years. The datalogger is recommended to be downloaded on a quarterly basis, when the manual readings are collected.
- Ongoing monitoring of existing bores 64237 and 108915.

<u>Additional Surface water monitoring</u>

- Install one stream gauge on the West Branch near Boundary Road to record all flows (with a priority to accurately measure low flows) and level. Collect a survey level of the base of the river at the gauge location.
- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

3.3 Barwon River downstream confluence with Boundary Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River downstream of the confluence with Boundary Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

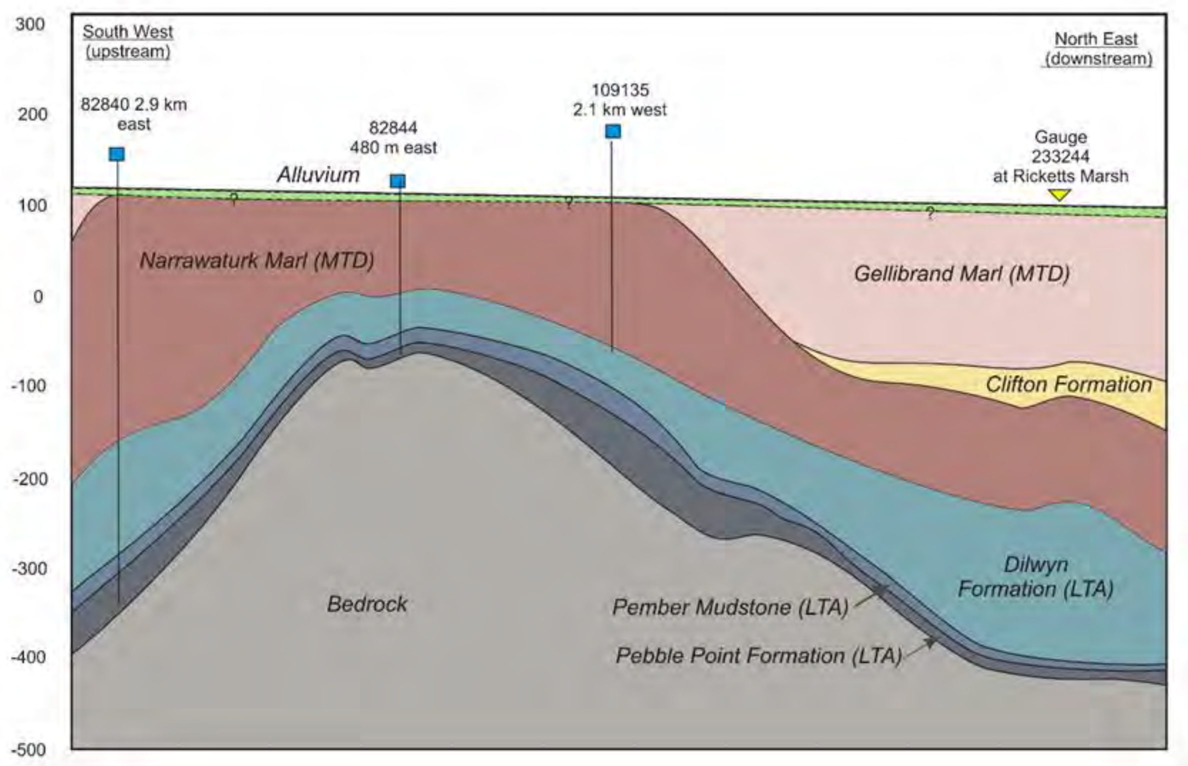
3.3.1 Why it was classified high risk

The Barwon River downstream of the confluence is classified as high risk as there is a small reach considered to have a moderate likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.13 shows a long section along the Barwon River downstream of the confluence with Boundary Creek, which shows the stratigraphy as presented in the regional groundwater model. The Barwon River flows through the centre of the graben over alluvial sediments, which in turn, overlie the regional Mid Tertiary Aquitard (MTD), which confines the LTA. The alluvial sediments are more extensive downstream (to the north) as the floodplain widens, however the thickness of the alluvium is not known. The MTD is reasonably thick in the centre of the graben, up to 300 meters thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.13: Long section along Barwon River downstream of the confluence



Regional groundwater model results

Figure 3.14 shows the estimate of river seepage calculated by the model for the Barwon River downstream of the confluence. The Barwon River downstream of the confluence is represented generally as a gaining river with seasonal variability. During summer months (low flows), the river is predicted to be gaining and during the winter months (high flows), the river is predicted to become losing.

Figure 3.14 also shows there is declining trend in groundwater contributions to baseflow over the years. The decline in more pronounced in the pumping scenario, with longer periods of losing conditions predicted in response to pumping. The regional groundwater model predicts there is a potential peak impact of around 7.5 L/sec in response to pumping.

Figure 3.15 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model change in river flux of around 7.5 L/sec, experienced at the end of the Millennium Drought.

Figure 3.14: River seepage to/from the Barwon River downstream of the confluence

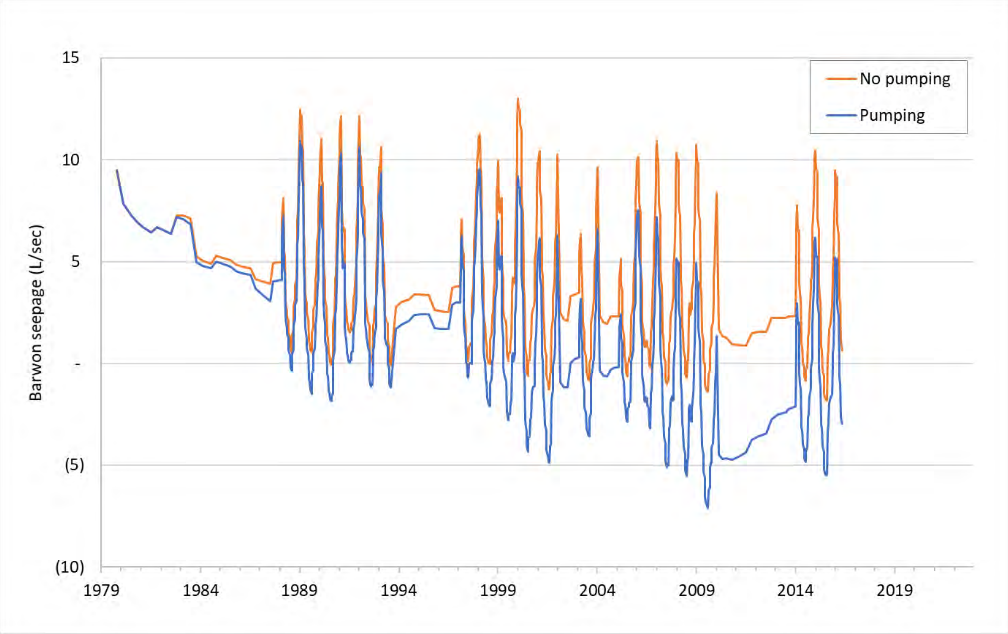
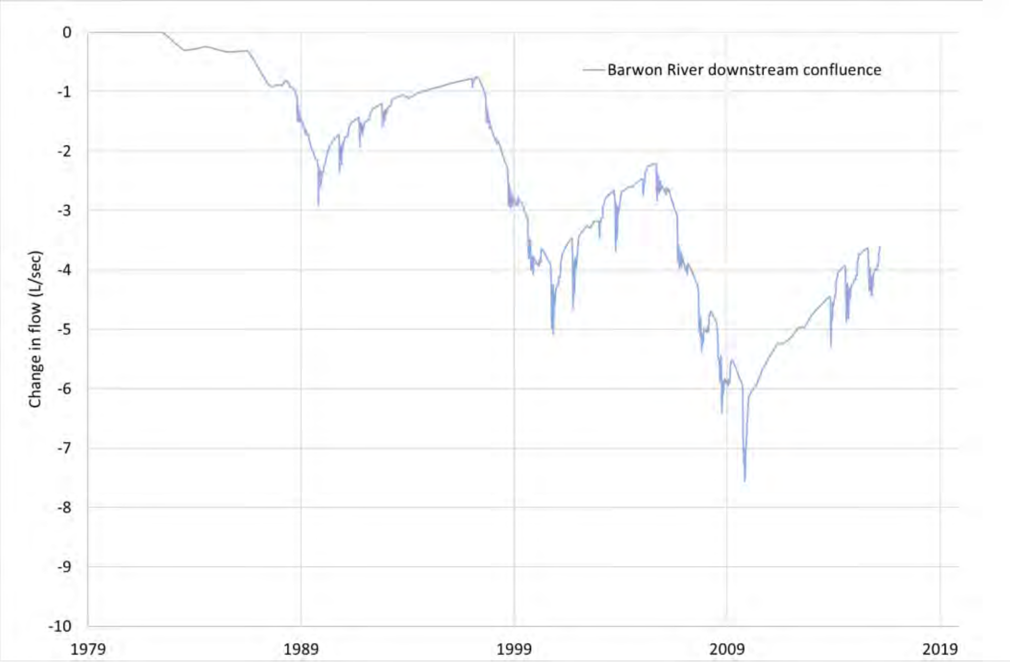


Figure 3.15: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 3-16. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 3.2 and the consequence defined by drawdown predicted in the model.

Figure 3-16 shows the spatial distribution of risk to Barwon River, which has one small area of potential high risk within the model boundary (based on drawdown). The potential high risk area is located downstream of the confluence with Boundary Creek. In other areas, the risk to the Barwon River is moderate to low due to the predicted drawdown being much less at this risk location.

Along this reach, the Barwon River flows over the regional aquitard (MTD). The likelihood of the river being connected to the regional groundwater system is classified as possible.

The risk outcome is high when the consequence is based on the change in flux to rivers (shown in Figure 3.11) estimated by the groundwater model.

There is currently only one surface water gauge located downstream and near the edge of the model domain at Ricketts Marsh (site 23324). The 10th percentile of flow (Q90) from this gauge is 4.9 ML/day based on monitoring data collected between 1971 – 2017.

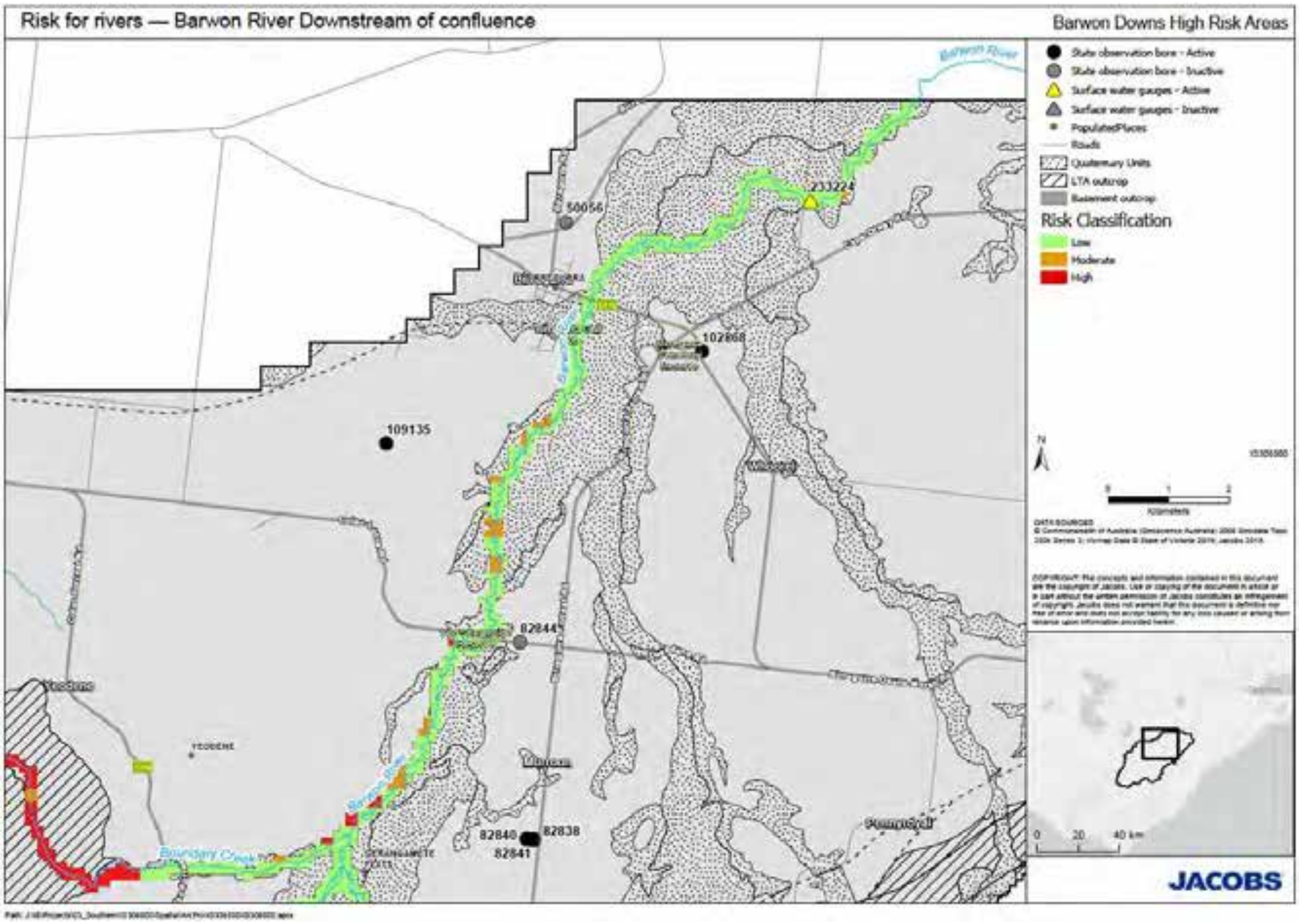
The change in river flux was calculated along the entire reach. This shows that the maximum impact predicted by the model is 7.5 L/sec for both reaches (0.7 ML/day) or 14% of low flow.

Based on the likelihood and consequence classifications (based on change in river flux), the Barwon River downstream of Boundary Creek is classified as high risk (see Table 3.3). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.3: Risk assessment results for Barwon River downstream of Boundary Creek

River Reach	Likelihood	Consequence	Risk
Barwon River downstream confluence	Possible	Significant	High

Figure 3-16 Location of areas of potential high risk along the Barwon River downstream of the confluence with Boundary Creek using drawdown to define the consequence



3.3.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River, the alluvial aquifer and regional groundwater system in LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA;
- and if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix D.

The primary data gaps identified for the Barwon River relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer
- Surface water flows and levels in the river
- Groundwater levels in the alluvial aquifer and overlying MTD
- Vertical gradients between aquifers and rivers

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis. Quarterly manual water level readings are also recommended for a minimum period of 5 years.
- Ongoing monitoring of existing bores 82838.

Additional Surface water monitoring

- Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level.
- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

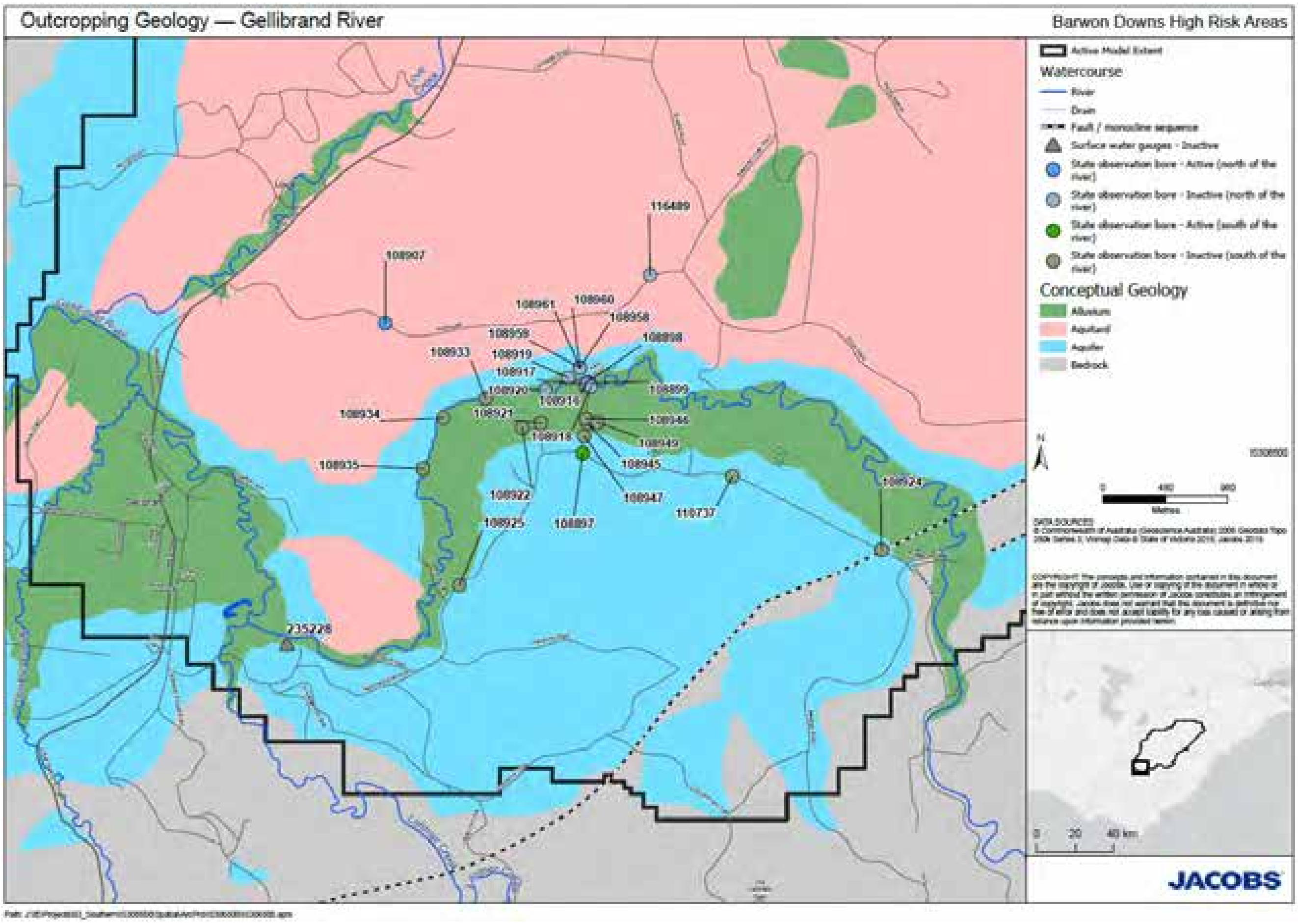
4. Gellibrand River Catchment

The Gellibrand River is located in the south western corner of the LTA extent with tributaries rising in the Otway Ranges and the Barongarook High. Tributaries include Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren. Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

The Gellibrand River is located to the south west of the Barwon Downs bore field and a small section of the river flows through the south western boundary of the groundwater model. The outcropping geology and the regional groundwater model extent are shown in Figure 4-1. The LTA outcrops along the Gellibrand River and because this is a key discharge area for the LTA, the river is gaining in this area (SKM, 2012). The LTA outcrop area is more extensive south of the Gellibrand River, with only a reasonably thin section outcropping north of the river at the southern extent of the regional aquitard.

The alluvial aquifer is also quite extensive in this area, however, its thickness is not known in detail. In most of the focus areas for risk, the river is located near the northern extent of the alluvial sediments where these sediments are likely to be thinner and potentially more hydraulically connected to the underlying LTA. This means that drawdown in the LTA at this location has the potential to influence groundwater levels in the alluvial aquifer.

Figure 4-1 Outcropping geology around Gellibrand River



4.1 Gellibrand River

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Gellibrand River. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.1.1 Why it was classified high risk

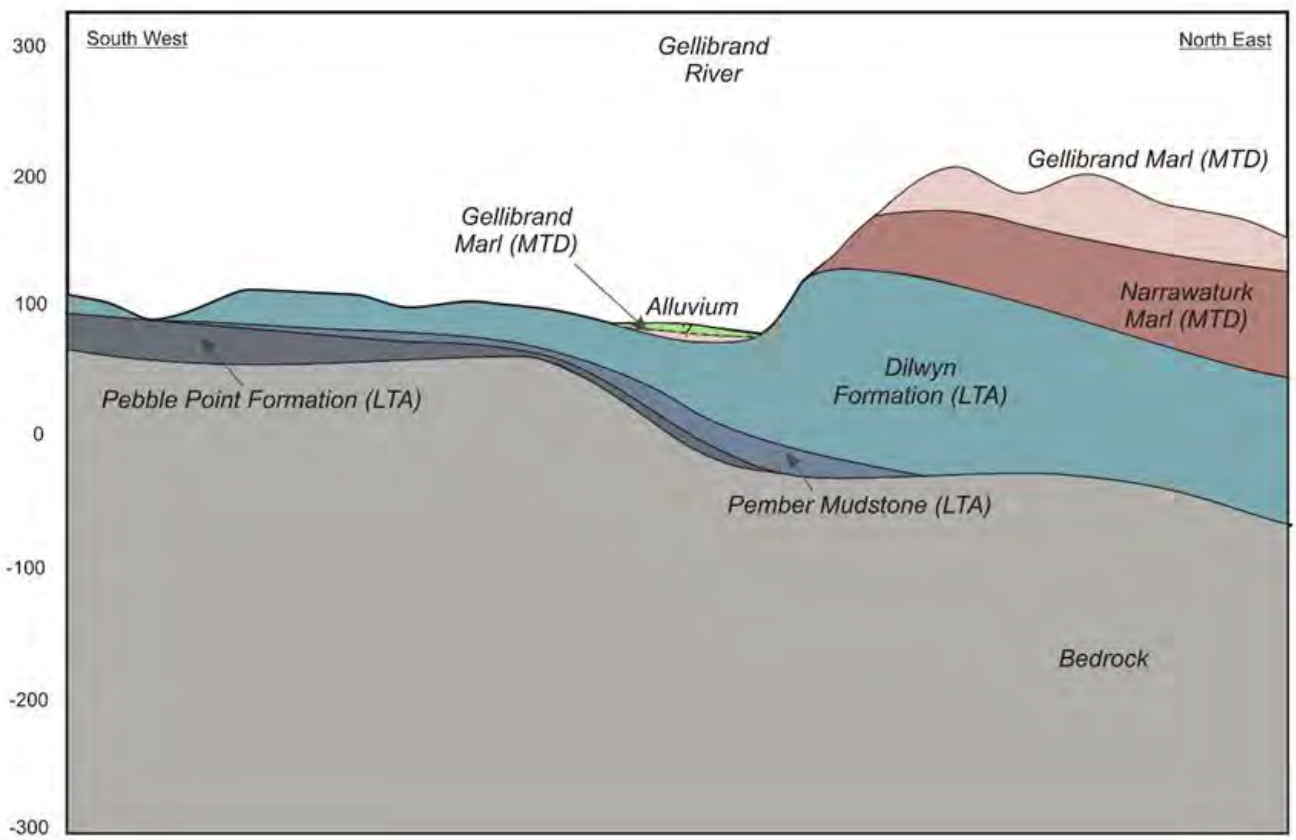
The Gellibrand River is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and to form the basis for further actions.

Figure 4.2 shows a cross section (north east to south west) across the Gellibrand River, which shows the stratigraphy as reflected in the regional groundwater model. This shows that the topography declines significantly in the south of the Barwon Downs graben and drops into the floodplain of the Gellibrand River. The LTA outcrops at the surface through the floodplain and extends south of the river. It is expected that this outcrop area is a key discharge feature of the LTA. The overlying MTD does not extend south into the floodplain of the Gellibrand River.

Alluvial sediments are present beneath the river, and the regional groundwater model also shows a very thin layer of Gellibrand Marl present beneath the alluvial sediments.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4.2: Cross section across the Gellibrand River



Regional groundwater model results

Figure 4.3 shows the estimate of groundwater flux/river seepage calculated by the model for the Gellibrand River. The Gellibrand River is represented as a gaining river and the volumes of groundwater flux to the river are reasonably large ranging between 50 to 80 L/sec. This is consistent with the conceptualisation that the Gellibrand River is a key discharge site. The regional groundwater model predicts that the groundwater contribution to the river declines over the model period (1979 to 2016), however most of this decline is the result of climate. The difference between the pumping and no pumping scenarios is around 5 L/sec.

Figure 4.4 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 4 L/sec in each river reach, at the end of the Millennium Drought.

Figure 4.3: Groundwater flux to Gellibrand River

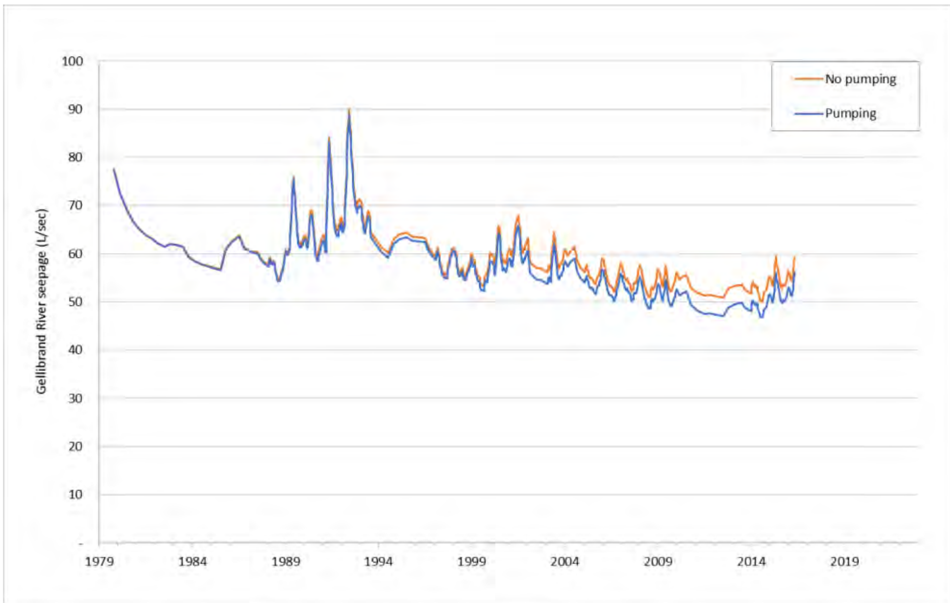
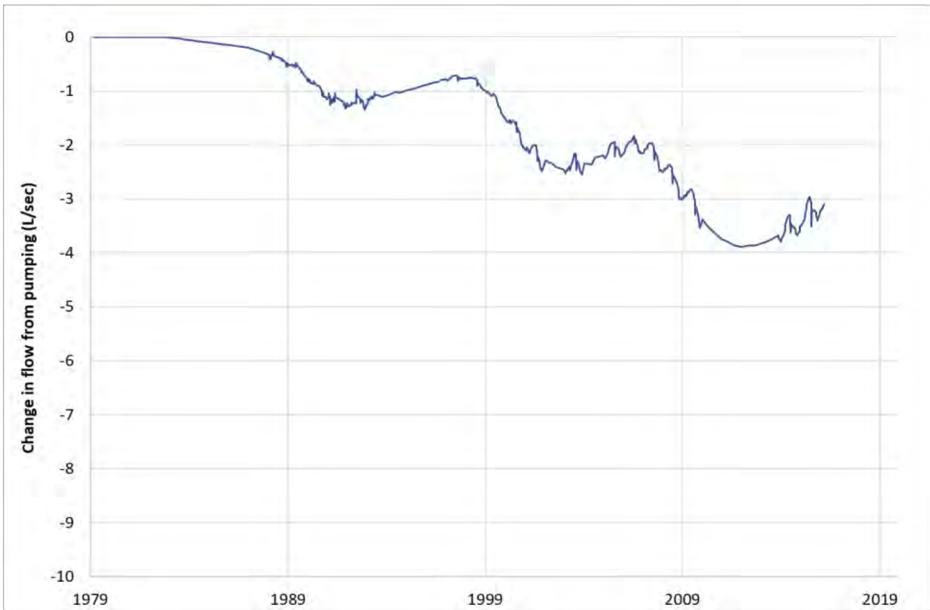


Figure 4.4: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 4-5. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.1 and the drawdown predicted in the model. The Gellibrand River flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-5 shows the spatial distribution of risk to the Gellibrand River, which has three areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the Bambra Fault zone, further downstream in the middle of the model and near the southern boundary of the model. The risk to the river is moderate in other areas.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.4).

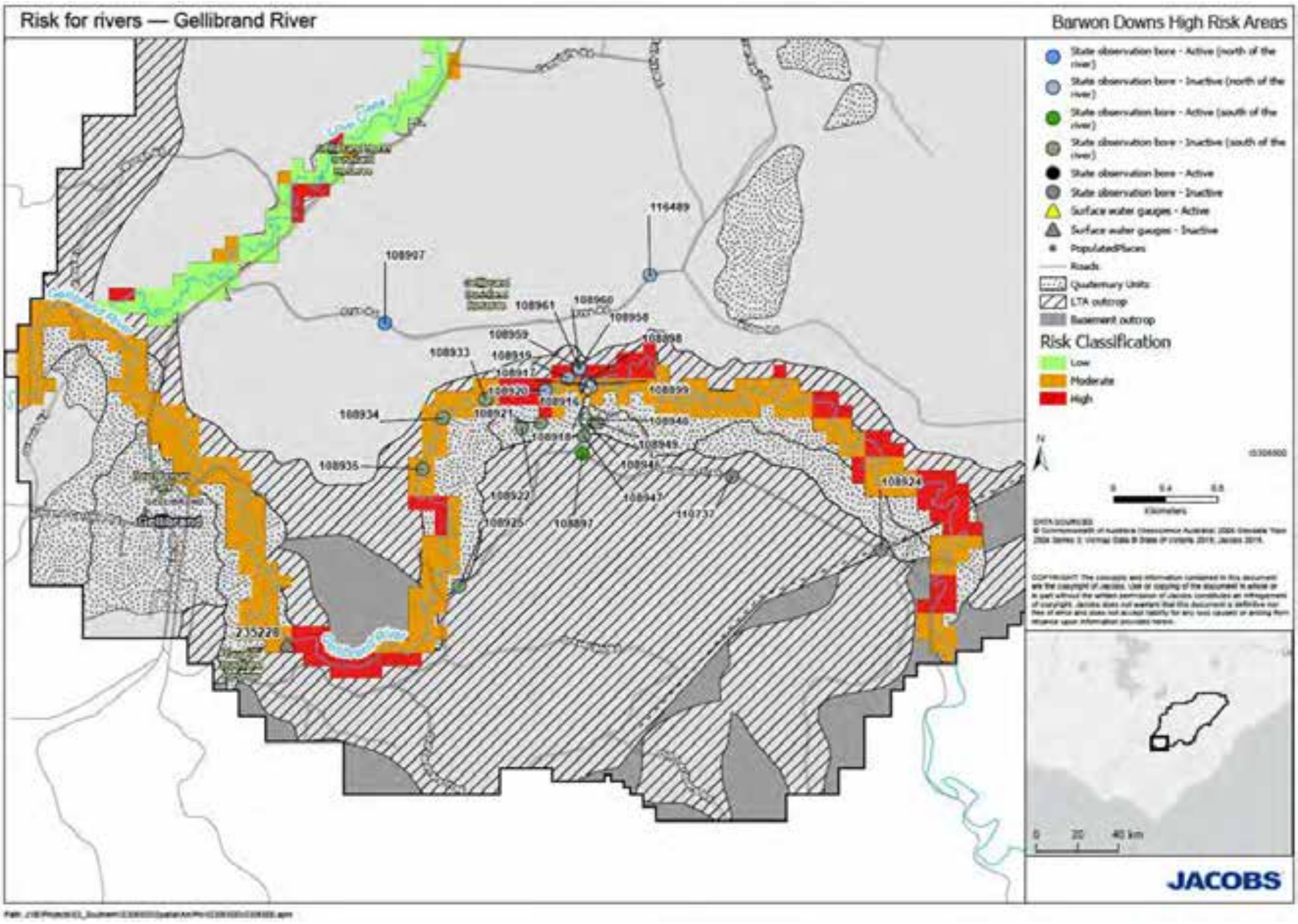
The Gellibrand River is monitored by two active surface water gauges 235227 (Bunkers Hill) and 235202 (Upper Gellibrand) which are located upstream and downstream of the model domain. There is one surface water gauge located in the model domain (235228 at Gellibrand), however monitoring ceased in 1989. The 10th percentile of flow (Q90) from gauge at Bunkers Hill is 12.2 ML/day based on monitoring data collected between 1970 – 2017. The location of these gauges is shown in Figure 4-1.

The change in river flux shows that the maximum impact predicted by the model is almost 4 L/sec (0.3 ML/day). The maximum predicted impact equates to 2% of low flow for the Gellibrand River. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.1). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.1: Risk assessment results for Gellibrand River

River Reach	Likelihood	Consequence	Risk
Gellibrand River	Certain	Moderate	High

Figure 4-5 Location of areas of potential high risk along the Gellibrand River using drawdown to define the consequence



4.1.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Gellibrand River and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Gellibrand River is gaining flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix E.

The primary data gaps identified for the Gellibrand River relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or when manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level.

- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

4.2 Ten Mile Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on Ten Mile Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.2.1 Why it was classified high risk

Ten Mile Creek is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 4-6 shows the outcropping geology along Ten Mile Creek and Figure 4.7 shows a long section along the creek. Both figures show the stratigraphy as presented in the regional groundwater model, which highlights that the LTA outcrops in the upper reaches of the creek and further downstream, the MTD overlies the LTA. Although there is a thin sequence of MTD shown in Figure 4-6 in the upper reaches of the creek, the creek is incised into the LTA, so the MTD doesn’t extend beneath the creek at this location. This area is marked by a question mark (?) in Figure 4.7.

Alluvial sediments are not expected to be present beneath the creek (based on regional mapping).

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4-6 Outcropping geology around Ten Mile Creek

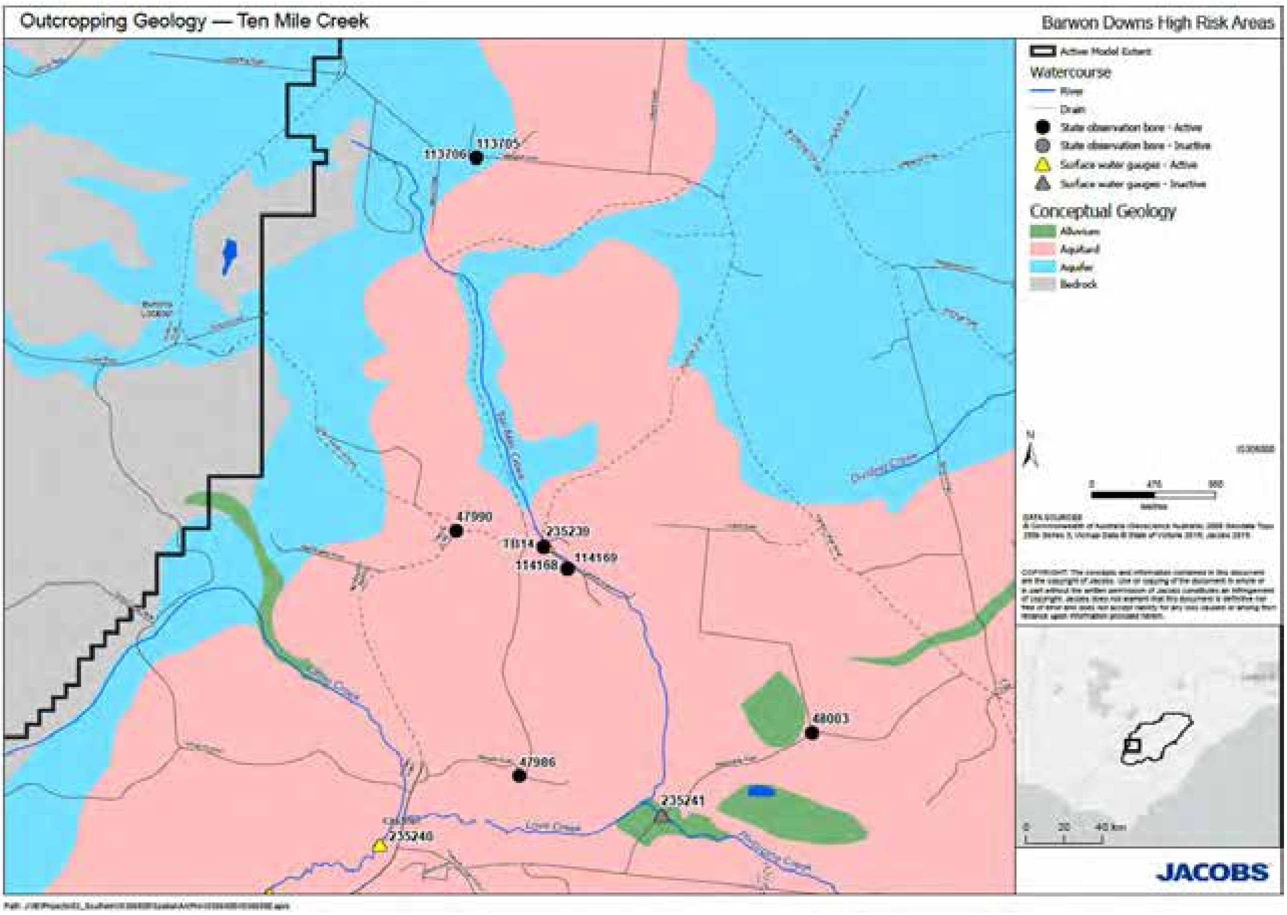
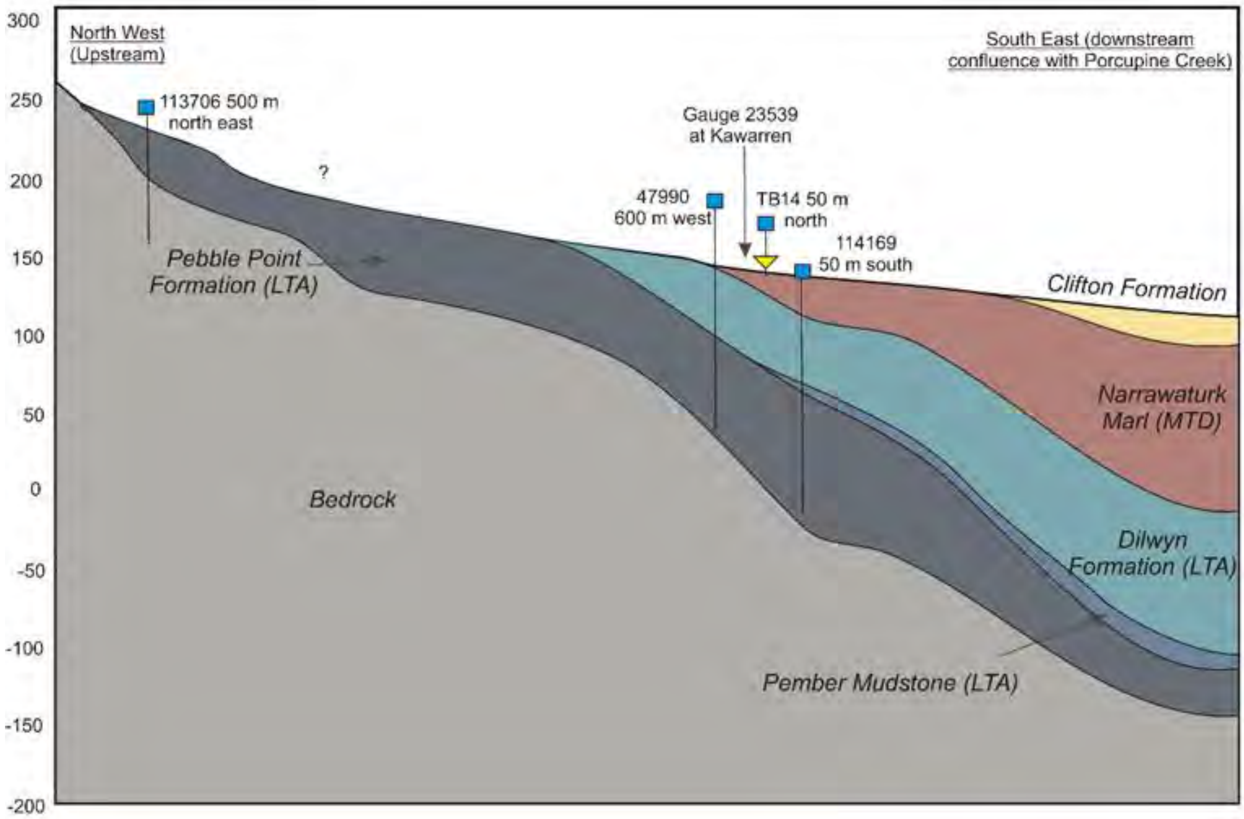


Figure 4.7: Long section along Ten Mile Creek (area marked with a question mark is where the creek is likely incised into LTA through thin MTD).



Regional groundwater model results

Figure 4.8 shows the estimate of groundwater flux/river seepage calculated by the model for Ten Mile Creek. Ten Mile Creek is represented as a gaining river and the volumes of groundwater flux to the river is typically less than 10 L/sec. The regional groundwater model predicts that the groundwater contribution to the river declines marginally over the model period (1979 to 2016) in response to climate. However there is also a noticeable difference in groundwater flux to the river predicted between the pumping and no pumping scenarios.

Figure 4.9 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 2.5 L/sec, at the end of the Millennium Drought.

Figure 4.8: Groundwater flux to Ten Mile Creek

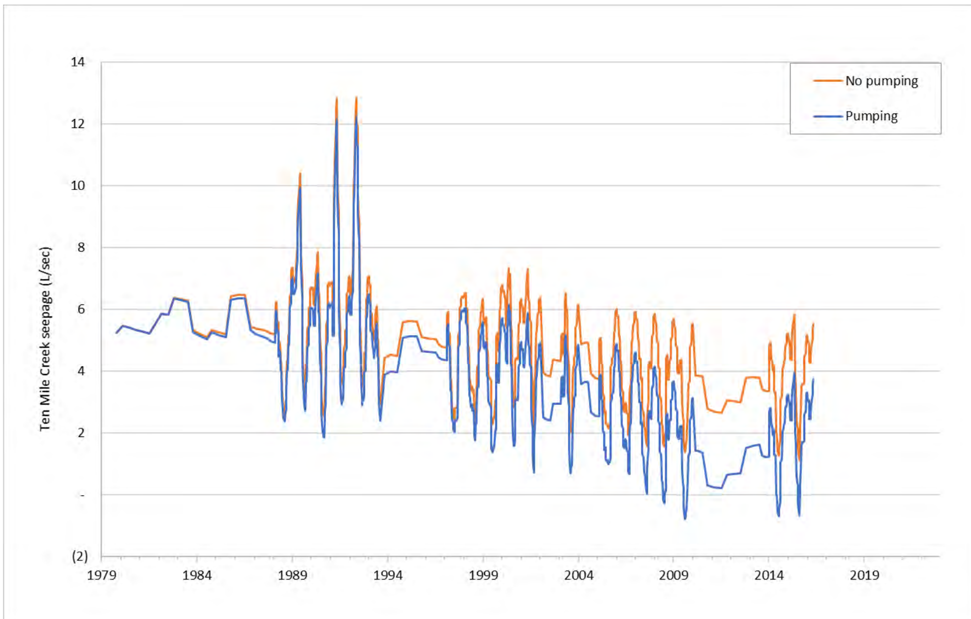
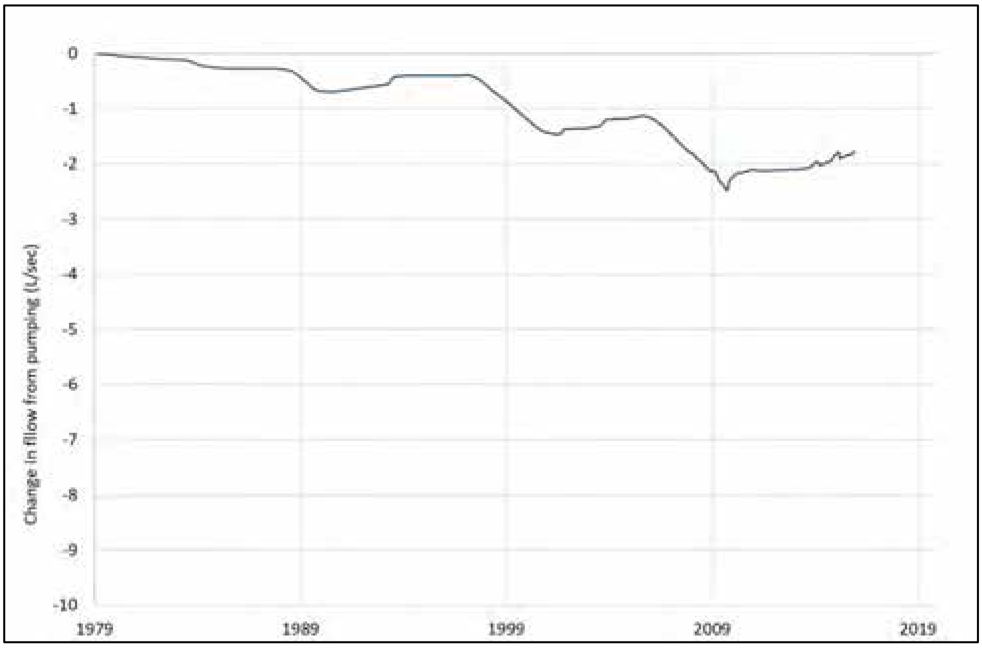


Figure 4.9: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 4-10. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.2 and the drawdown predicted in the model. Ten Mile Creek flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-10 shows the spatial distribution of risk to the creek, which has roughly two areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the headwaters of the creek and further downstream on the LTA outcrop. The risk to the river is low to moderate in other areas.

The risk outcomes remain high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.8).

There is one active surface water gauge (235239) monitoring flow in Ten Mile Creek, however the flow record is intermittent. Monitoring commenced in 1985 and continued until 1995. The gauge was monitored again in 2008-2009 and has recommenced again in 2018. Intermittent monitoring periods since the mid-1990s show a very different flow regime, with flow not recorded above 5 ML/day during the winter months of 2008 or 2019. More detail on the surface water monitoring is provided in Appendix F. The 10th percentile of flow (Q90) from this gauge is 1.3 ML/day based on the available monitoring data.

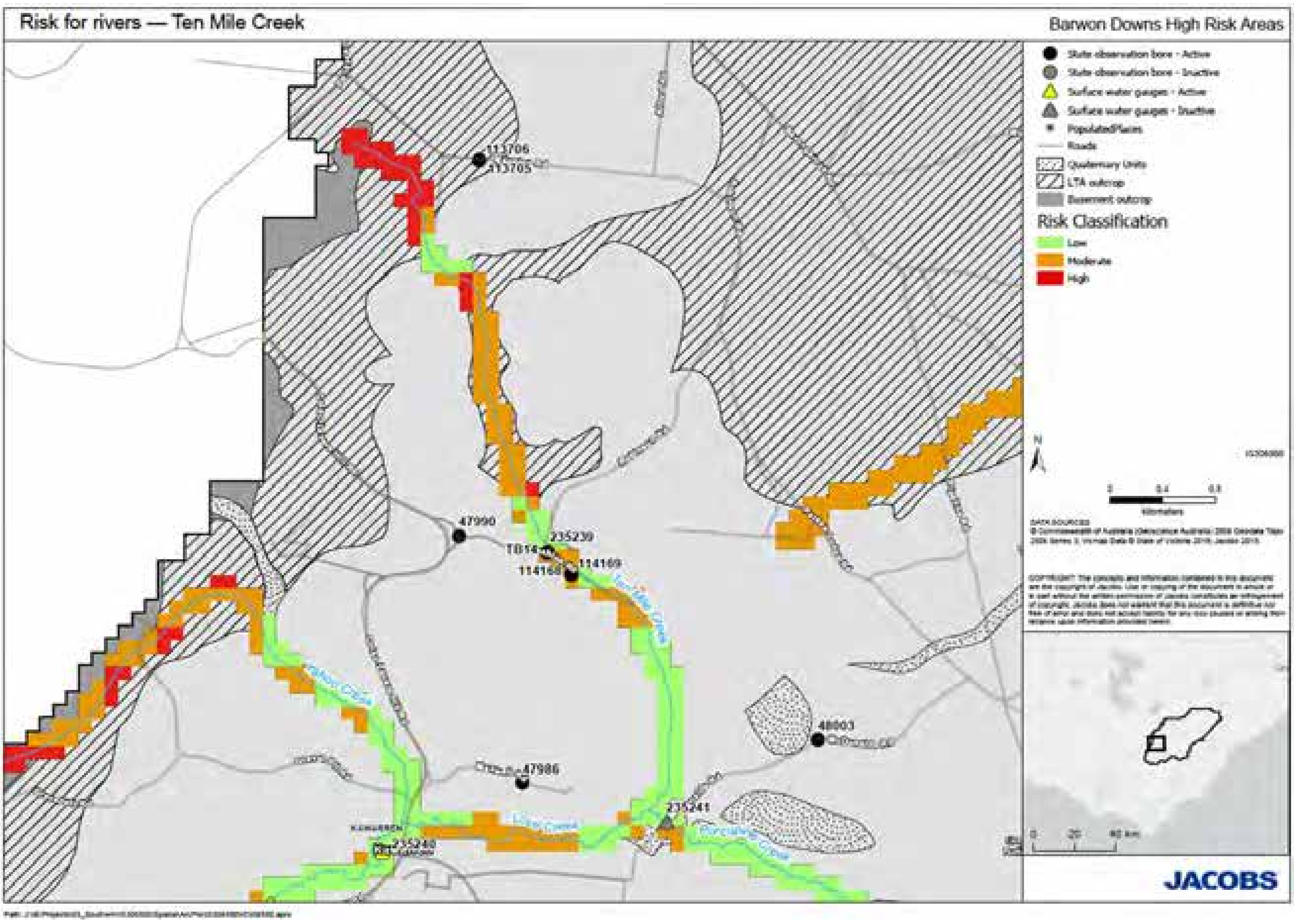
The location of these gauges is shown in Figure 4-6.

The change in river flux shows that the maximum impact predicted by the model is almost 2.5 L/sec (0.2 ML/day). The maximum predicted impact equates to 15% of low flow for Ten Mile Creek. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.2). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.2: Risk assessment results for Ten Mile Creek

River Reach	Likelihood	Consequence	Risk
Ten Mile Creek	Certain	Significant	High

Figure 4-10 Location of areas of potential high risk along Ten Mile Creek using drawdown to define the consequence



4.2.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Ten Mile Creek is gaining flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix F.

The primary data gaps identified for the Ten Mile Creek relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or when manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Continue monitoring at existing stream gauge;
- Survey the stream bed elevation in the vicinity of the gauge and the bores.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

4.3 Yahoo Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on Yahoo Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.3.1 Why it was classified high risk

Yahoo Creek is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 4-11 shows the outcropping geology along Yahoo Creek and Figure 4.12 shows a long section along the creek. Both figures show the stratigraphy as it is represented in the regional groundwater model, which highlights that the LTA outcrops in the upper reaches of the creek and further downstream, the MTD overlies the LTA. Alluvial sediments are present in a small area where the outcropping geology changes from LTA to MTD, however these are not present in the regional groundwater model.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4-11 Outcropping geology around Yahoo Creek

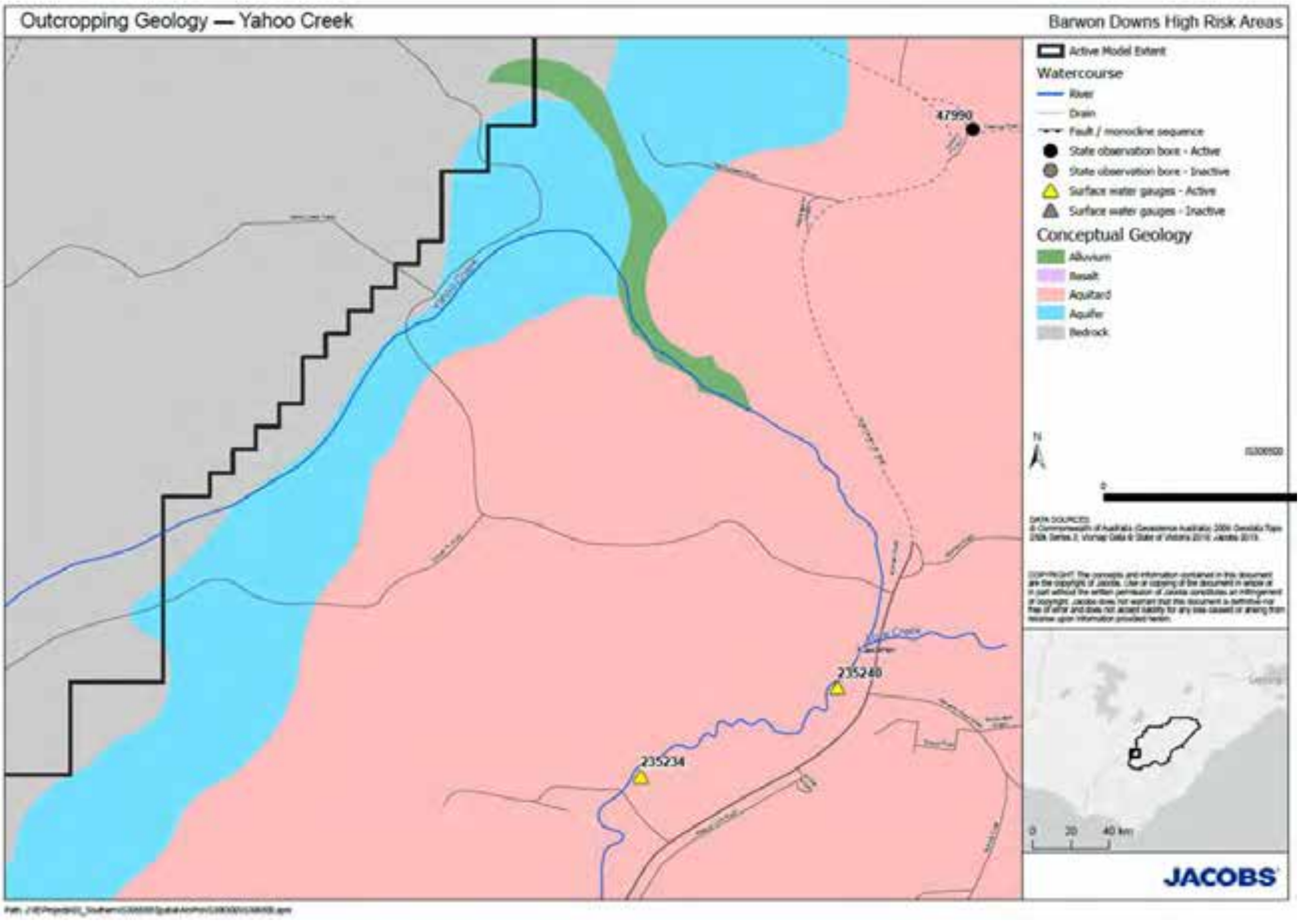
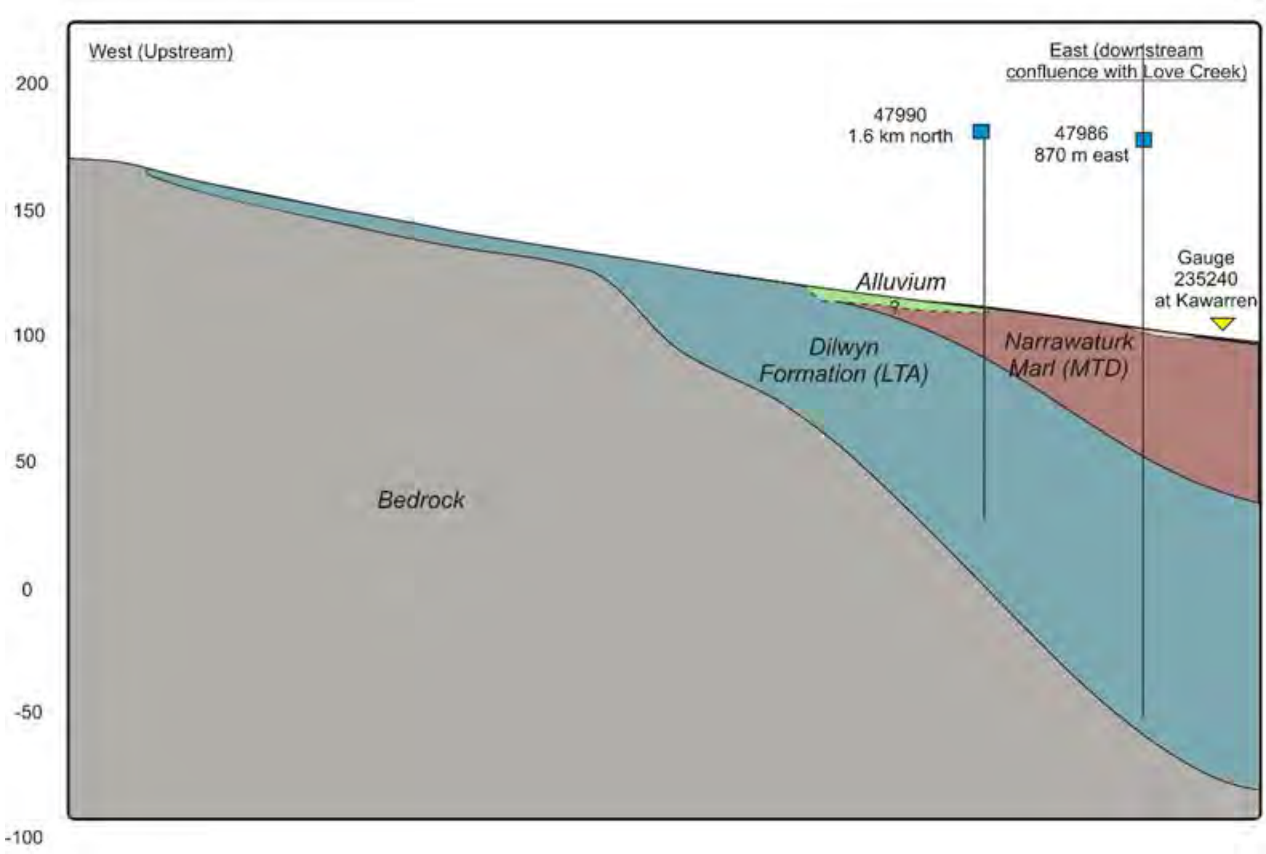


Figure 4.12: Long section along Yahoo Creek



Regional groundwater model results

Figure 4.13 shows the estimate of groundwater flux/river seepage calculated by the model for Yahoo Creek. Yahoo Creek is represented as a losing river (represented by negative seepage rates) and the volumes of river seepage to groundwater is typically less than 8 L/sec. After an initial rise which is likely to be a response to the model initial conditions, the regional groundwater model predicts that seepage from the river to marginally increase over the model period (1979 to 2016) in response to climate. However, there is also a noticeable difference in groundwater flux from the river predicted between the pumping and no pumping scenarios.

Figure 4.14 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model is an increase in seepage from the river of around 1 L/sec, at the end of the Millennium Drought.

Figure 4.13: Groundwater flux to Yahoo Creek (the y-axis of this graph is negative, so this graph indicates seepage from the creek into the model at all times)

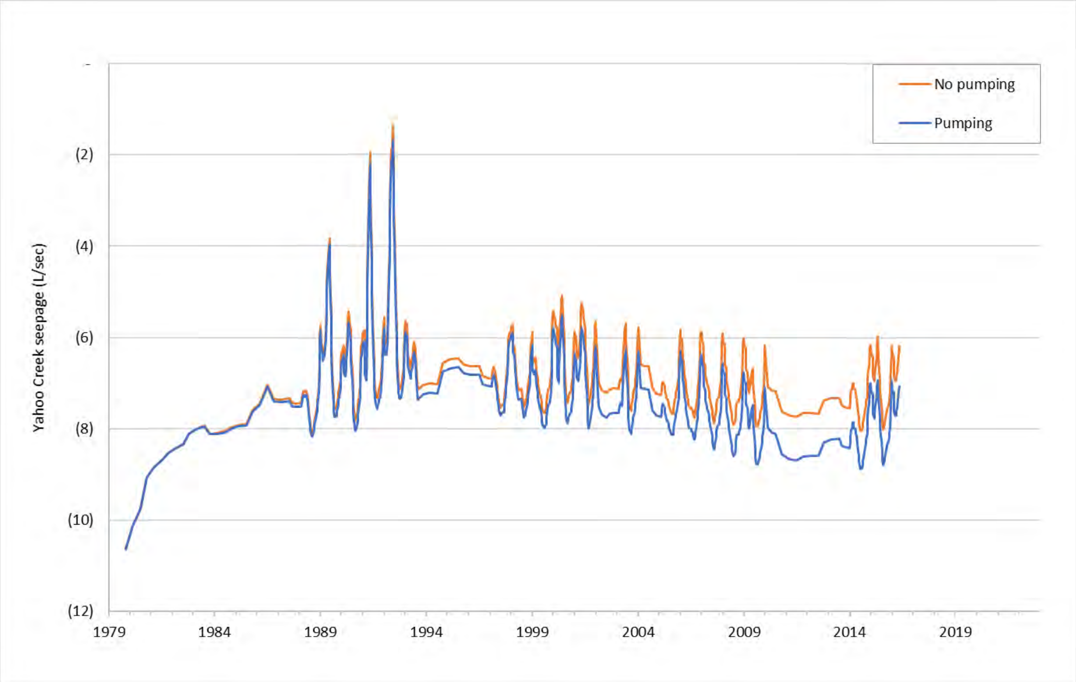
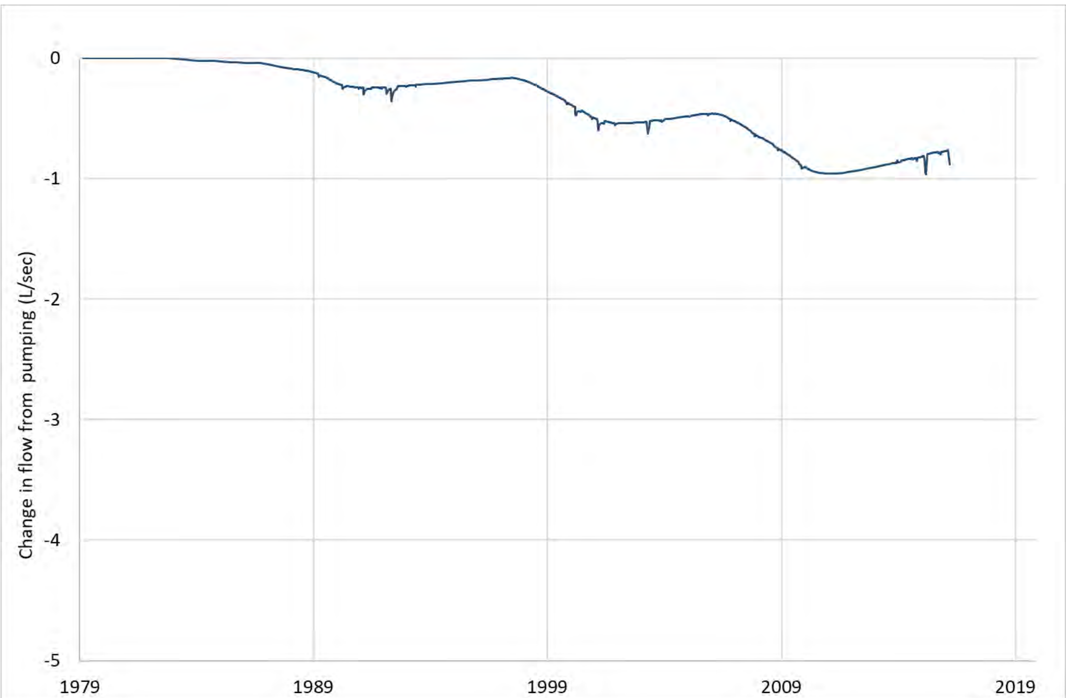


Figure 4.14: Change in river flux between no pumping and pumping (negative numbers indicate seepage from the river to the aquifer).



Risk assessment results

Areas of potential high risk are shown in Figure 4-10. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.2 and the drawdown predicted in the model. Yahoo Creek flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-15 shows the spatial distribution of risk to the creek, which shows isolated areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the headwaters of the creek where the LTA outcrops. The risk to the river is low to moderate in other areas.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.14).

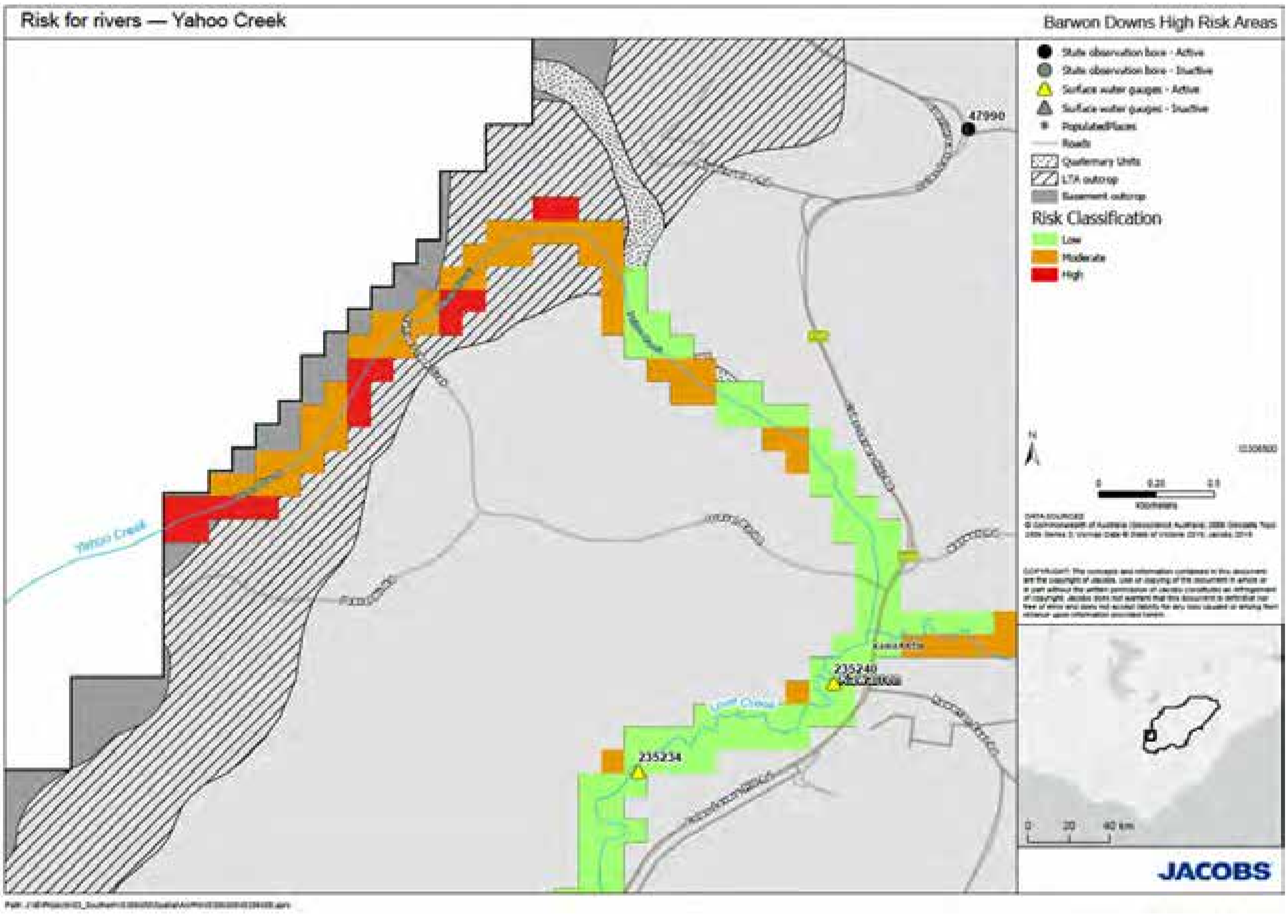
There is currently one surface water gauge located on Yahoo Creek upstream at Kawarren (235240). The location of these gauges is shown in Figure 4-11. The gauge was monitored between 1985 and 1995, and has recently been reactivated. The flow record in the 1980s shows seasonal variations in flow, with flow frequently dropping below 5 ML/day. Flow in 2019 has not been reported above 2 ML/day. More detail on the surface water monitoring is provided in Appendix G. The 10th percentile of flow (Q90) from this gauge is 1.0 ML/day based on the available monitoring data.

The change in river flux shows that the maximum impact predicted by the model is approximately 1 L/sec (<0.1 ML/day). The maximum predicted impact equates to 8% of low flow for Yahoo Creek. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.2). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.3: Risk assessment results for Yahoo Creek

River Reach	Likelihood	Consequence	Risk
Yahoo Creek	Certain	Moderate	High

Figure 4-15 Location of areas of potential high risk along Yahoo Creek using drawdown to define the consequence



4.3.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Yahoo Creek and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Yahoo Creek is losing flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix G.

The primary data gaps identified for Yahoo Creek relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above.

<u>Additional Groundwater Monitoring</u>

- Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

<u>Additional Surface water monitoring</u>

- Continue monitoring at existing stream gauge.

<u>Survey data</u>

- Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5. Vegetation and PASS investigation areas

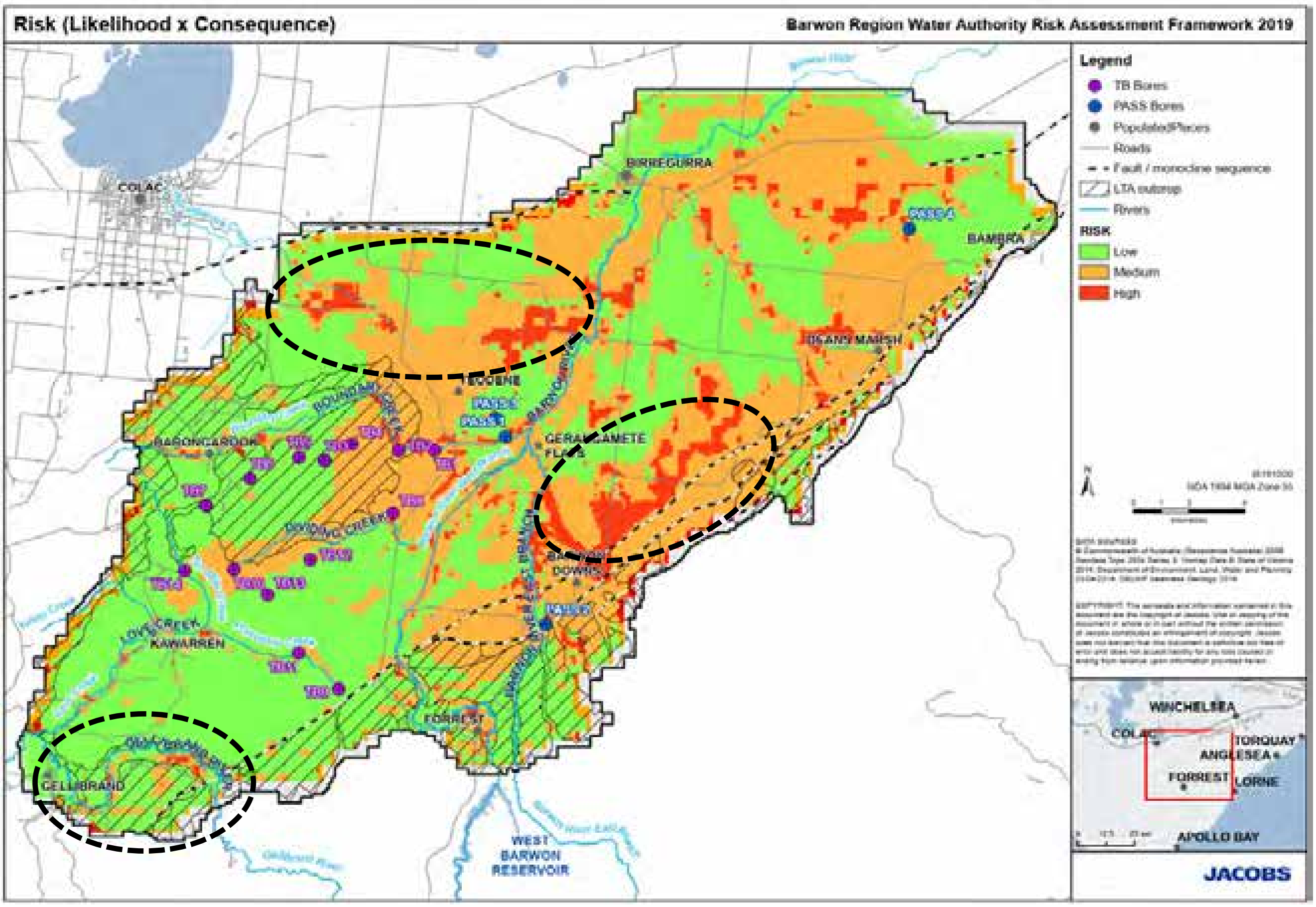
The risk to groundwater dependent vegetation across the catchment was determined using the depth to water table from the regional groundwater model and the drawdown predicted in the water table aquifer as a result of historical groundwater extraction. More detail on the risk assessment framework is provided in Appendix A.

The risk to groundwater dependent vegetation is presented in Figure 5-1. This shows that there are three key (largest) areas the model estimates the risk to be high:

- West of the Barwon River to the north of Yeodene;
- East of the Barwon River between Barwon Downs and Yeodene; and,
- Along the Gellibrand River.

These are the largest areas of potential high risk. Further investigations may be recommended in other isolated areas of potential high based on the outcomes of the investigation plan. These are discussed in the following sections.

Figure 5-1: Historical risk across the study area based on modelled drawdown (consequence) and modelled depth to watertable (likelihood)



5.1 North of Yeodene

The area is bounded by Boundary Creek to the south, Barwon River to the east and Colac Fault to the north west. The Colac Fault represents the edge of the model domain. Barongarook Creek is also located in this area. The headwaters of Barongarook Creek are located in the centre of the area and the creek flows in a north westerly direction towards Lake Colac.

5.1.1 Why it was classified as high risk

Vegetation and PASS in some areas north of Yeodene is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area west of Barwon River is shown with the outcropping geology in Figure 5-2. The regional aquitard (MTD) outcrops across most of the area. The LTA outcrops on the Barongarook High located in the south of this area, and this is the key recharge area for the aquifer. North of the Barongarook High, the LTA is confined by the MTD which is 70-100 m thick.

Alluvial sediments are present along the Barwon River and although there are no bores located in the alluvial sediments, it's likely that the alluvial sediments form the water table aquifer. The alluvial aquifer is expected to be hydraulically isolated from the LTA by a thick sequence of MTD. It should be noted that the alluvial aquifer is not included in the groundwater model as the aquifers are localised and not continuous across the model domain.

Error! Reference source not found. shows the spatial distribution of risk across the area. Areas of potential h igh risk are located around Barongarook Creek and north east of Yeodene. There is limited information to inform the accuracy of the assigned risk in these areas. Information on groundwater monitoring in the area is limited to the deeper formations. More detail is provided in Appendix H.

Figure 5-2 Outcropping geology – vegetation west of Barwon River to the north of Yeodene

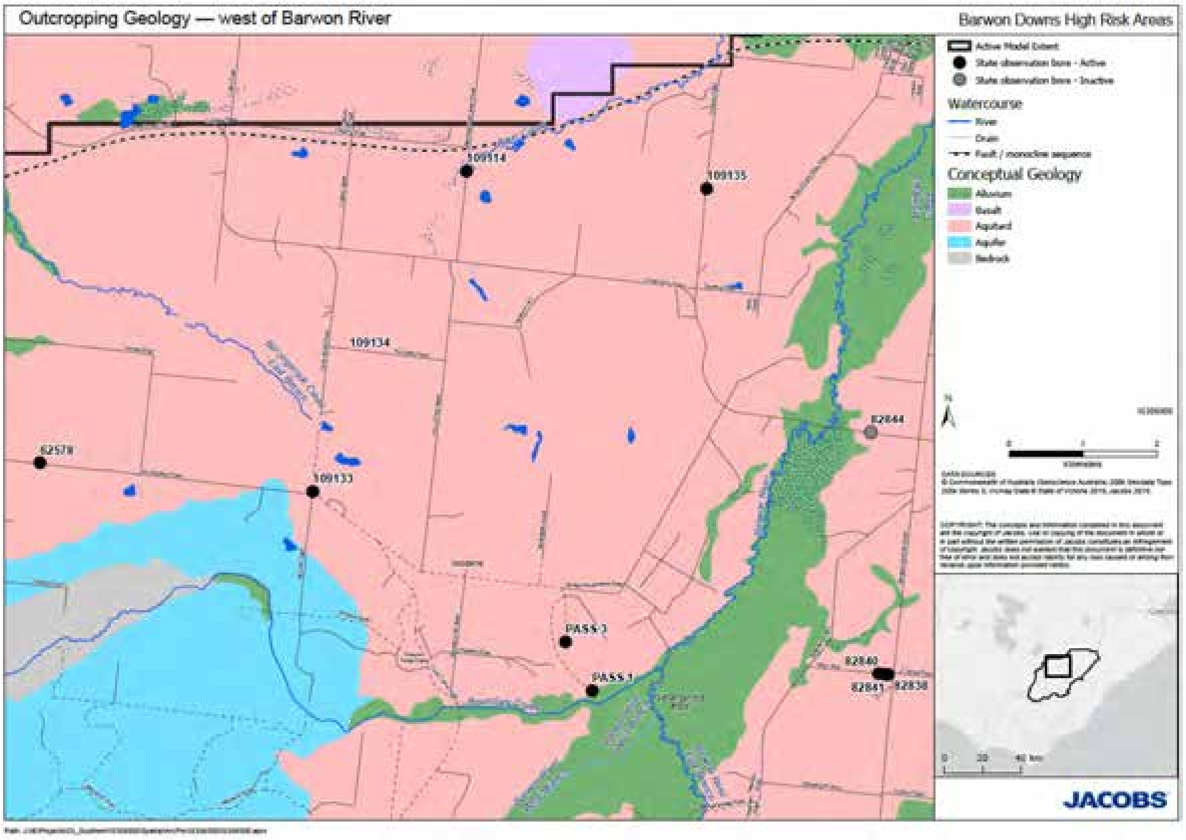
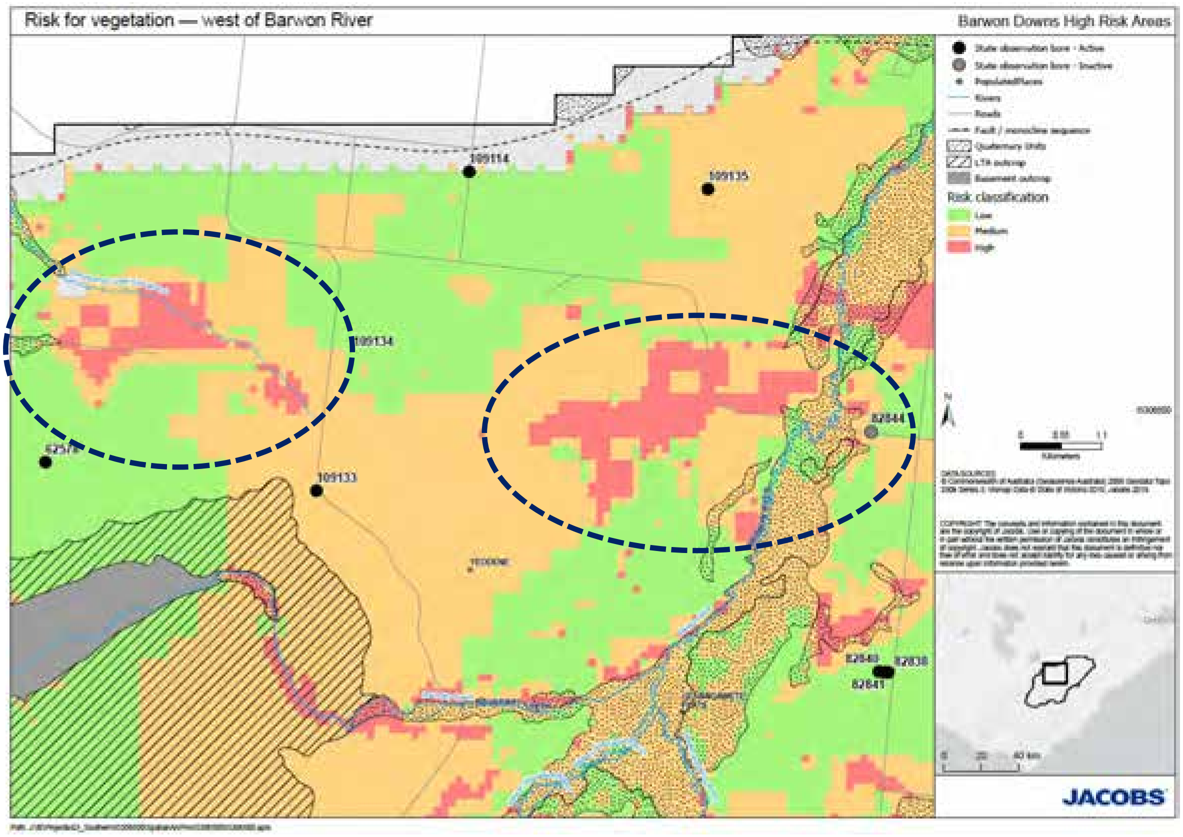


Figure 5-3: Risk to vegetation – vegetation west of Barwon River to the north of Yeodene



5.1.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve understanding of:

- the depth to watertable;
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and,
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers; and,
- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

<u>Additional Groundwater Monitoring</u>

- Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis, or whenever manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

<u>Additional Surface water monitoring</u>

- Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level.
- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
- Survey the elevation of the creek bed close to the bores and at any gauge locations.

<u>Additional Vegetation monitoring</u>

- Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5.2 Deans Marsh

The area around Deans Marsh is bounded by the Bambra Fault to the south east and the Barwon River to the north west. Several tributaries of the Barwon River flow in a north westerly direction from the Otway ranges to the Barwon River, including Mathews Creek, Deans Marsh Creek and Yan Yan Gurt Creek.

5.2.1 Why it was classified as high risk

Vegetation and PASS in some areas around Deans Marsh is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area east of the graben is shown with the outcropping geology in Figure 5-4. The regional aquitard (MTD) outcrops across most of the area. The LTA outcrops on the south eastern side of the Bambra Fault, and this is the minor recharge area for the aquifer. North west of the Bambra Fault, the LTA is confined by the MTD which is up to 100 m thick.

Alluvial sediments are present along the tributaries and the Barwon River and although there are no bores located in the alluvial sediments, these are likely to contain the water table aquifer. The alluvial aquifer is expected to be hydraulically isolated from the LTA by a thick sequence of MTD. It should be noted that the alluvial aquifer is not included in the groundwater model as the aquifers are localised and not continuous across the model domain.

Figure 5-4 Outcropping geology – vegetation east of Barwon River around Deans Marsh

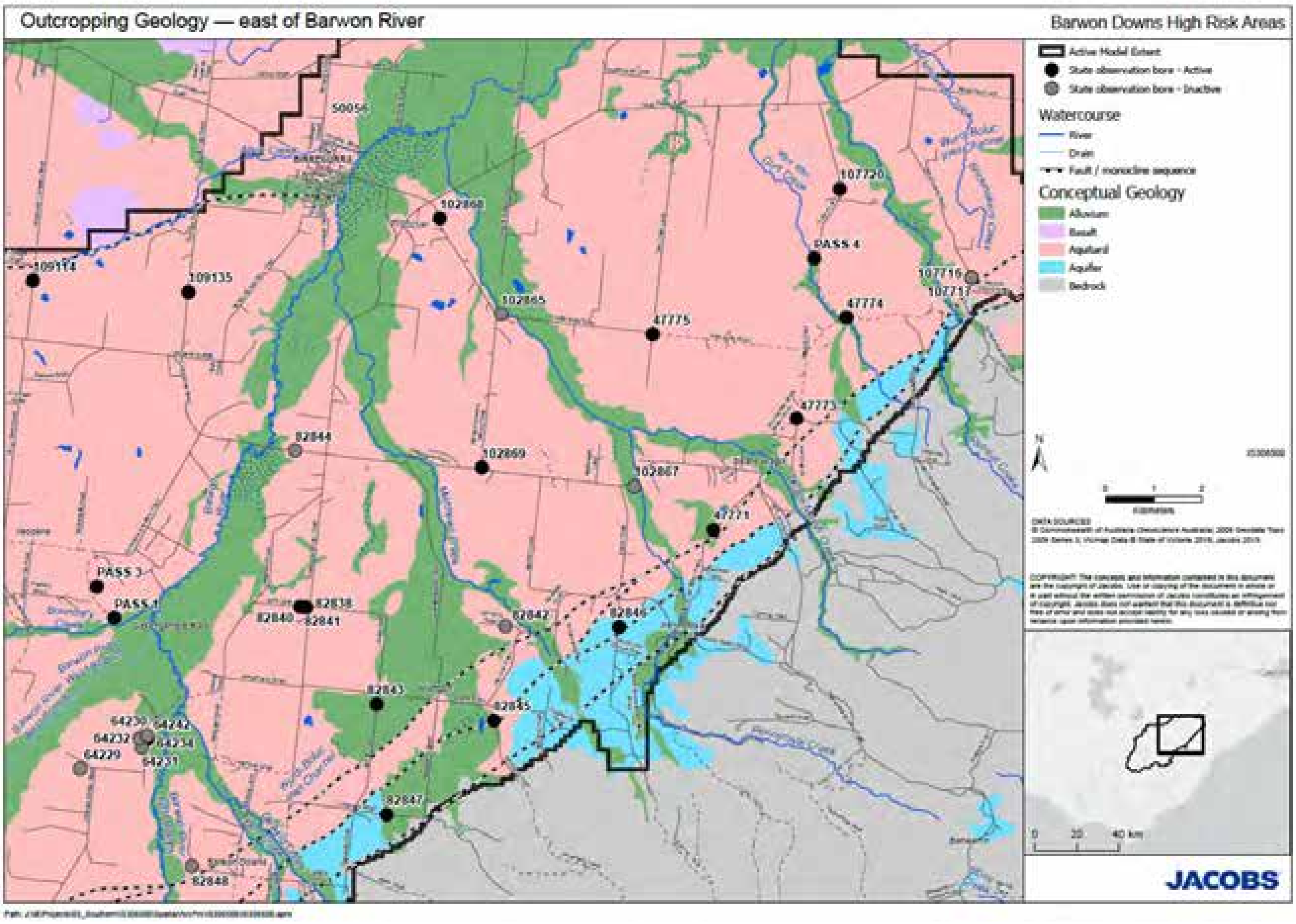
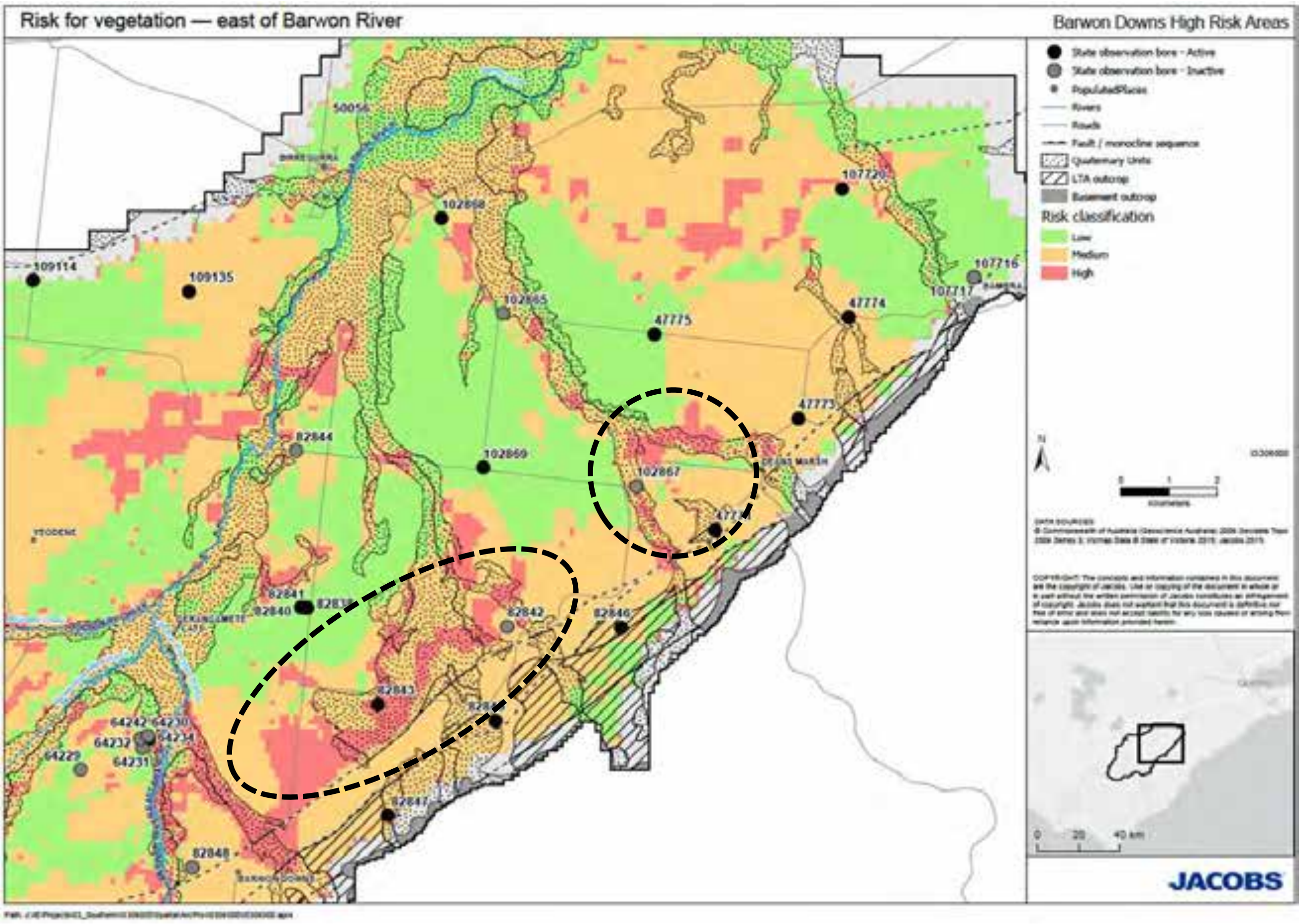


Figure 5-5 shows the risk to the groundwater dependent vegetation in this area of the catchment is focussed in areas where there are alluvial sediments, for example, around Mathews Creek and Deans Marsh Creek. Other areas of high risk are located in the north east of the area.

Figure 5-5: Risk to vegetation – vegetation east of Barwon River around Deans Marsh



5.2.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve the understanding of:

- the depth to watertable
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers; and,

- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).

- Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).

- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Vegetation monitoring

- Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition.

- Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5.3 Gellibrand River

The area along the Gellibrand River is the same area covered in Section 4.1, however the focus is on vegetation in the area, rather the groundwater contributions to the river.

5.3.1 Why it was classified as high risk

Vegetation and PASS in some areas around the Gellibrand River is classified as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to water table as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area along the Gellibrand River is shown with the outcropping geology in Figure 5-6. As described in Section 4.1, the LTA outcrops near the Gellibrand River and alluvial sediments are also present. The alluvial sediments are expected to form water table aquifer where present.

Figure 5-7 shows the risk to the groundwater dependent vegetation around the Gellibrand River using depth to watertable (likelihood) and drawdown (consequence). This shows the highest risks are expected to be in the areas to the east and close to the Bambra Fault. The risk across the remainder of the area is considered to be moderate and low.

Figure 5-6 Outcropping geology – vegetation around Gellibrand River

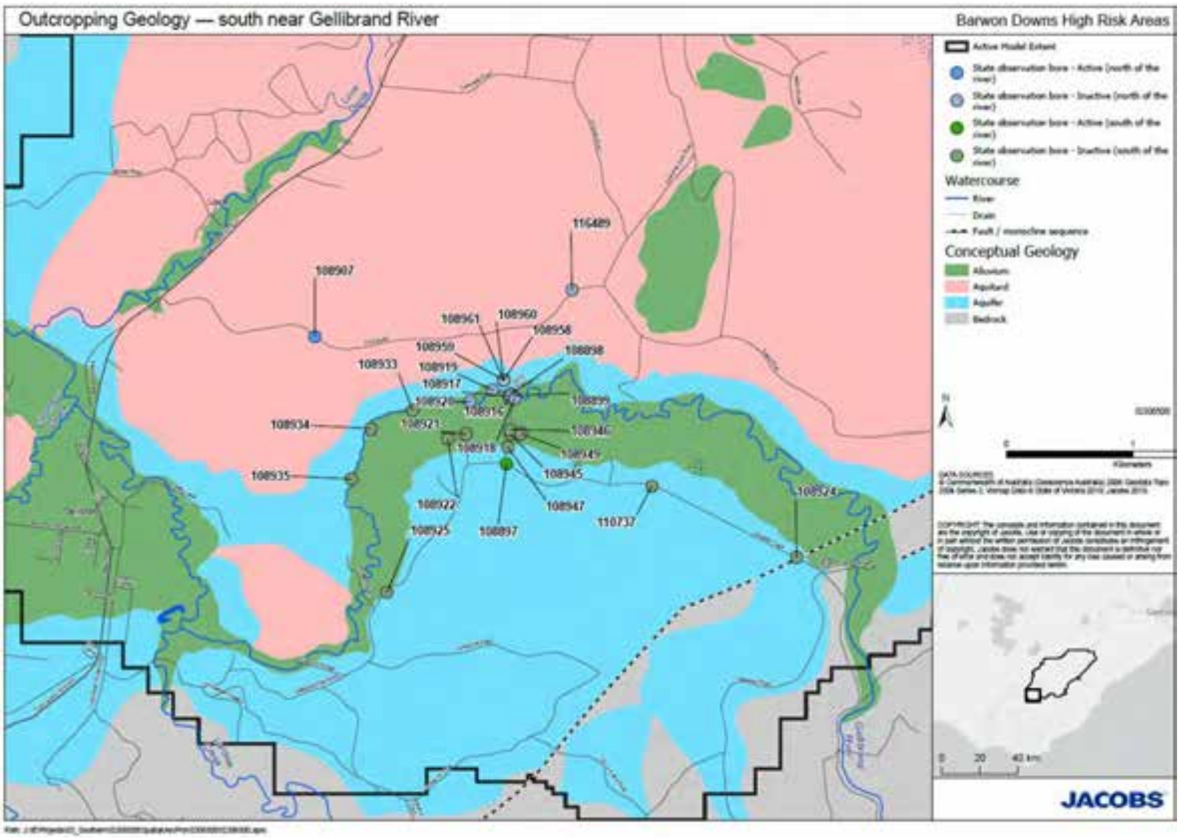
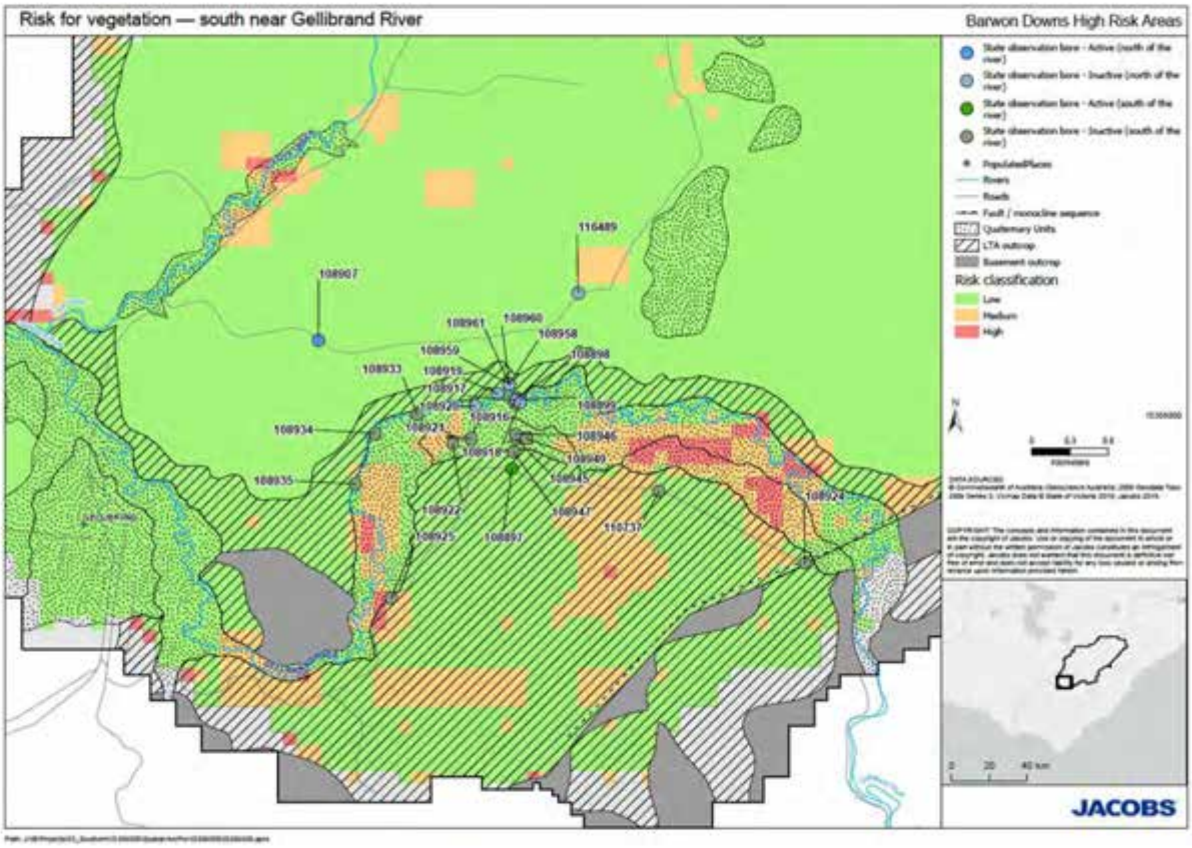


Figure 5-7: Risk to vegetation – vegetation around Gellibrand River



5.3.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve the understanding of:

- the depth to watertable
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer
- Groundwater levels in the alluvial aquifer and MTD
- Vertical gradients between aquifers
- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- See recommendations for Gellibrand River in Section 4.1.3

Additional Vegetation monitoring

- Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

6. Recommendations for the Surrounding Environment investigation plan

This report outlines the rationale and recommendations for additional monitoring assets and an associated monitoring program where areas of potential high risk have been identified by the regional groundwater model. Adverse impacts in these areas of potential high risk have not been confirmed due to insufficient monitoring to validate groundwater model predictions. Further work involving the installation of new monitoring assets, together with review of the data and possible development of local groundwater models, is recommended for Surrounding Environment investigation plan.

An overview of the recommendations for additional monitoring assets to install as part of the investigation plan, together with the rationale, is outlined in Table 6.1.

After 12 months of data has been collected, it is recommended that the data is reviewed and the risk re-evaluated. The review would confirm the following:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer, LTA or MTD;
- Vertical gradients between aquifers and rivers;
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers); and,
- Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS).

The review of the additional data and hydrological conceptual model could result in one of the following three scenarios:

1. Site specific monitoring data confirms a lower risk than that predicted by the regional groundwater model, presumably based on the following criteria:
    - Regional groundwater model over-predicts impact;
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed upward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or water table decline predicted by model with the observed flow data confirms low risk.
2. Site specific monitoring data confirms the high risk predicted by the regional groundwater model, based on the following criteria:
    - Confirmed absence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer consistent with regional groundwater model predictions; and,
    - Groundwater flux predicted by model confirmed with observed data.

3. Site specific monitoring data confirms a high risk, based on the following criteria:
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed downward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or watertable flux predicted by regional model with the observed flow data confirms high risk.

If scenario 1 occurs – no further action is required, results presented to Southern Rural Water for consideration

If scenario 2 occurs – it is recommended that the regional groundwater model is used to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for any further action.

If scenario 3 occurs – recommended that a local groundwater model(s) is/are developed for each location to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for further action.

Table 6.1: Rationale and recommendations for additional monitoring

Area	Why	What is the information gap	Recommended additional monitoring assets
BARWON RIVER CATCHMENT			
Barwon River east branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River east branch and regional groundwater system / outcropping LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing), if there is baseflow contribution from the LTA and if borefield impacts on baseflow are buffered by the presence of alluvial aquifers.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores PASS 2 and 48249 **Additional Surface water monitoring** Install one stream gauge on the East Branch near Seven Bridges Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. **Survey data** Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction. Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.
Barwon River west branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact	Currently there is limited data to confirm surface water groundwater connection between Barwon River west branch and regional groundwater system / outcropping LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 64237 and 108915. **Additional Surface water monitoring** Install one stream gauge on the West Branch near Boundary Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Barwon River downstream of confluence	Rated as high risk as there are particular sections considered to have a possible likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River downstream of the confluence and the regional groundwater system / MTD. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the MTD.	**Additional Groundwater Monitoring** Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 82838. **Additional Surface water monitoring** Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
GELLIBRAND CATCHMENT			

Gellibrand River	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between the Gellibrand River and the regional groundwater system / LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Ten Mile Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. Survey the stream bed elevation in the vicinity of the gauge and the bores.
Yahoo	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact	Currently there is limited data to confirm surface water groundwater connection between Yahoo Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e.	**Additional Groundwater Monitoring** Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. **Survey data** Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.
Vegetation and PASS investigations			
Yeodene	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA).	**Additional Groundwater Monitoring** Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. Survey the elevation of the creek bed close to the bores and at any gauge locations.

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			Additional Vegetation monitoring Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.
Deans Marsh	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA). Vegetation assessments are required to confirm vegetation types and their reliance groundwater.	**Additional Groundwater Monitoring** Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Vegetation monitoring** Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition. Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.
Gellibrand	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS.	Currently there is limited data to confirm the depth to watertable and connection with the LTA. This data is required to understand the nature of groundwater dependence from the LTA.	**Additional Groundwater Monitoring** See recommendations for Gellibrand River **Additional Vegetation monitoring** Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

	Additional on-ground data is required to validate the predicted impact and inform further actions		

7. References

DELWP (2015) Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems.

Jacobs (2015) Barwon Downs Monitoring Program – Review of conceptual model and numerical model boundaries. Final. 28 August 2015

Jacobs (2016) Field Investigations Report – Installation of new monitoring assets. Final. 5 August 2016

Jacobs (2017a) Barwon Downs Vegetation Survey 2016. Final 31 January 2017.

Jacobs (2017b) Barwon Downs Borefield – PASS Baseline Assessment. 19 December 2019

Jacobs (2018) Numerical model calibration and historical impacts. Report for Barwon Water. Final 22 August 2018

SKM, (2001) Barwon Downs Groundwater Flow and Subsidence Modelling Project. Report on the Groundwater Flow Model, Draft D, May 2001. Prepared by Sinclair Knight Merz for Barwon Region Water Authority.

SKM, (2011) Climate Change Modelling for the Barwon Downs Aquifers. Draft 1, May 2011. Prepared by Sinclair Knight Merz for Barwon Region Water Authority.

SKM (2012) Newlingrook Groundwater Investigation - Gellibrand springs assessment. File note to Barwon Water 25 October 2007.

Appendix A. Risk Assessment Framework

The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) have been used to identify areas of potential high risk that may require further investigations to validate the model results and confirm the presence of high value GDEs. The guidelines have been used to assess the potential risk to vegetation and rivers and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The guidelines outline a risk assessment process involving seven steps:

1. Determine the licence application area and identify high value ecosystems. Determine that the aquifer is unconfined and identify any features within that area, such as river, springs, soaks or terrestrial vegetation containing high value ecosystems. If the aquifer if unconfined and high value ecosystems are identified, go to step 2, otherwise assess the risk as low.

2. Determine the likelihood that the proposed groundwater extraction will interact with the feature.

3. Determine the consequence of the proposed groundwater extraction on the features.

4. Determine the risk to the high value ecosystems dependent on groundwater.

5. Determine how risk will be managed for groundwater licence application with a risk assessment of medium or high.

6. Consult with relevant Catchment Management Authority

7. Make a final decision.

This report is limited to steps 1 through to 5. It is envisaged that Steps 6 and 7 will be undertaken by Southern Rural Water in consultation with DELWP.

During Step 1, all features within the study area were assessed, regardless of whether they were situated where the regional aquifer is unconfined or identified as a high value GDE. The reason for this is that the location of all high value GDEs across the whole study area is not known. Consequently, the guidelines were adapted to understand the potential areas at high risk and allow for a more targeted assessed to identify potential high value GDEs. In addition to this, drawdown from the regional aquifer has the potential to propagate through the overlying hydrogeological units, especially where the overlying aquitard is thin, therefore areas where the aquitard is present were also considered in the first instance.

The Guidelines state that:

- If the risk is low, the groundwater extraction licence application can be approved.

- If the risk is moderate, risk treatment options would be developed to manage risk and the groundwater licence can be approved with conditions.

- If the risk is high, risk treatment options to reduce the risk to medium or decide to accept the risk and fully document the reason, or the groundwater licence application many be refused.

For sites classified as medium and high risk, risk treatment options would be developed.

Areas classified as medium or high risk will require further work to improve the understanding of the local hydrogeological conceptual model and validate the model predictions. The presence of high value GDEs would also need to be confirmed as well as the potential impact of groundwater extraction on the identified GDEs. It is envisaged that any potential further work would be completed before consultation and final decision is made on the groundwater licence. If necessary, triggers levels would be identified for those areas where high value GDEs were identified and a potential impact was predicted. In the context of the Guidelines, this study presents the additional work that would be expected to support a licence determination.

A.1 Risk assessment framework for rivers

The risk posed to rivers as a result of groundwater extraction from the Barwon Downs borefield was assessed using the risk assessment framework outlined in the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).

The risk assessment framework as outlined in the Ministerial Guidelines is:

- **Likelihood** of groundwater-surface water interaction defined by either (see Table A.1):
    - The depth to watertable in the regional aquifer OR
    - The time lag until 60% of extraction comes from the river.
- **Consequence** of the proposed groundwater extraction on the river defined by either (see Table A.2):
    - The drawdown in the regional aquifer OR
    - The percentage reduction in low flow.
- **Risk** is considered in terms of low, medium, high risk using the following equation:
    - Likelihood x Consequence = Risk

A.1.1 Likelihood

The likelihood was defined based on a qualitative assessment of the time lag for a potential impact to reach the river or creek. The likelihood of connection to the regional aquifer and aquitard was defined as (see Figure A.1):

- Unlikely – rivers and creeks known to be disconnected (e.g. Dividing Creek)
- Possible – rivers and creeks where they flow over the regional aquitard, on the basis that the aquitard is a low permeability which increases the time lag for impact of groundwater extraction.
- Certain – rivers and creeks where they flow over the regional aquifer, on the basis that the permeability of the aquifer is high so the time lag for potential impact of groundwater extraction will be less.

Figure A.1 shows the spatial representation of the likelihood of river being connected to the regional groundwater system.

Table A.1: Likelihood of rivers being dependent of groundwater (surface flow)

Likelihood	Description	Ministerial Guidelines		Application for this project
		Measure depth to watertable	Measure surface flow	
Unlikely (low)	A disconnected ecosystem	Depth to watertable > 6 m from surface	>12 months' time lag until 60% of extraction comes from river	River known to be disconnected
Possible (moderate)	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface	Between 3 – 12 months' time lag until 60% of extraction comes from river.	River flows over regional aquitard
Certain (high)	A well-connected ecosystem	Depth to watertable < 2 m from surface	<3 months' time lag until 60% of extraction comes from river	River flows over regional aquifer

A.1.2 Consequence

The **consequence** of pumping has been considered using both measures outlines in Table A.2:

1. Percentage reduction in low flows (10th percentile low flow, or low) defined by the change in river flux. The change in river flux represents the difference in river flux between no pumping (Scenario 0) and the pumping scenarios (Scenarios 2 and 3).

2. Drawdown in the aquifer where the aquifer outcrops near the river.

Two consequence measures have been used because there is limited flow data available for many of the creeks, which introduces uncertainty when comparing the reduction in baseflow predicted by the model. Therefore, drawdown in the regional aquifer was used as another measure. The drawdown in the aquifer, where the aquifer outcrops is provided in Figure A.2.

Table A.2: Consequence classifications for streams (drawdown and reduction in baseflow to river)

Consequence	Description	Measure Drawdown (m)	Measure % Low (low) flow
Minor	Proposed extraction impacts on natural or current streamflow are small	Watertable decline of <0.1 m	Less than 1% reduction in the low flow rate
Moderate	Proposed extraction impacts measurably on natural or current streamflow	Watertable decline of 0.1 - 2 m	Between 1% and 10% reduction in the low flow rate
Significant	Proposed extraction impacts significantly on natural or current streamflow	Watertable decline of > 2 m	More than 10% reduction in the low flow rate.

Figure A.1: Likelihood of surface water connection to groundwater

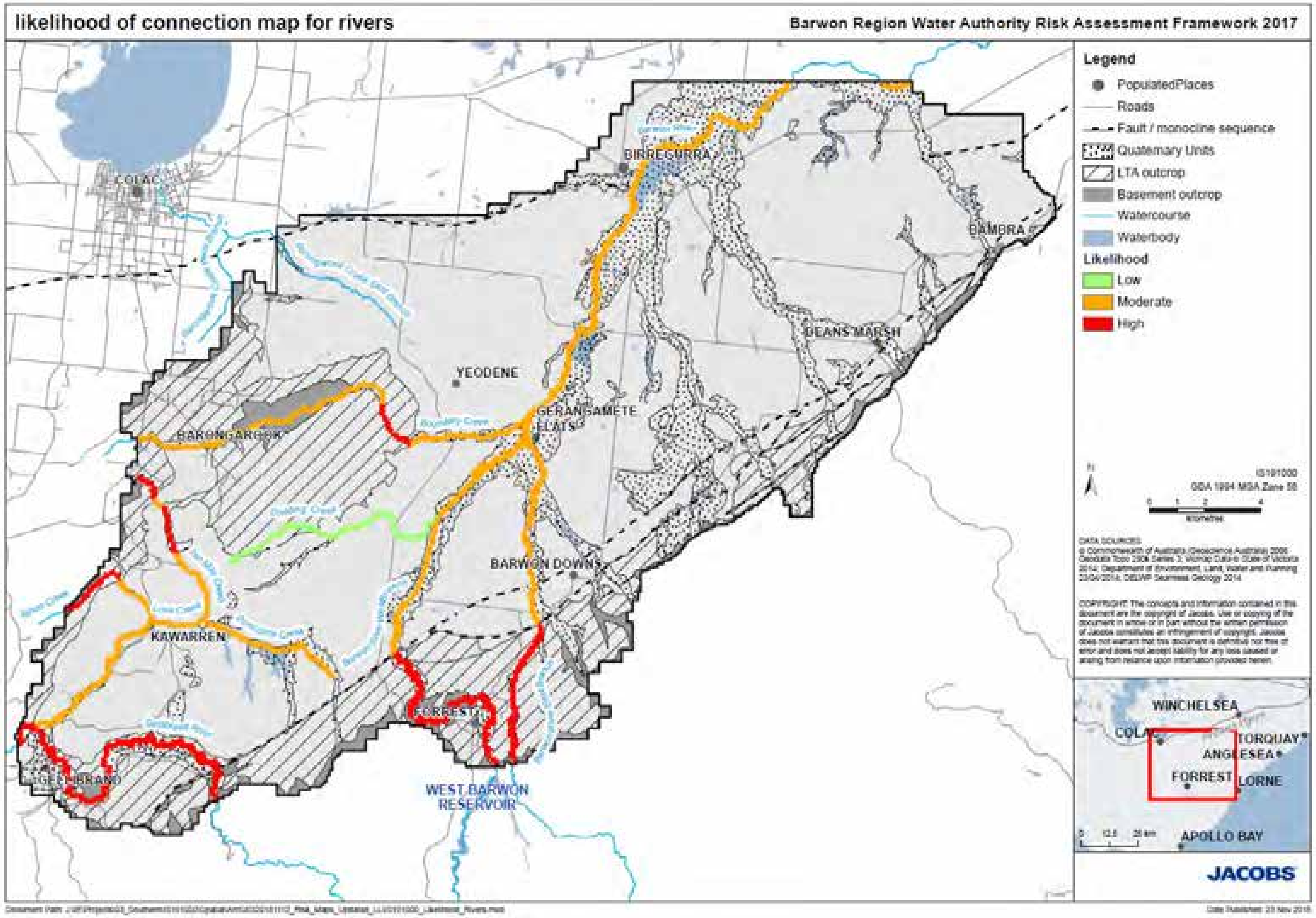
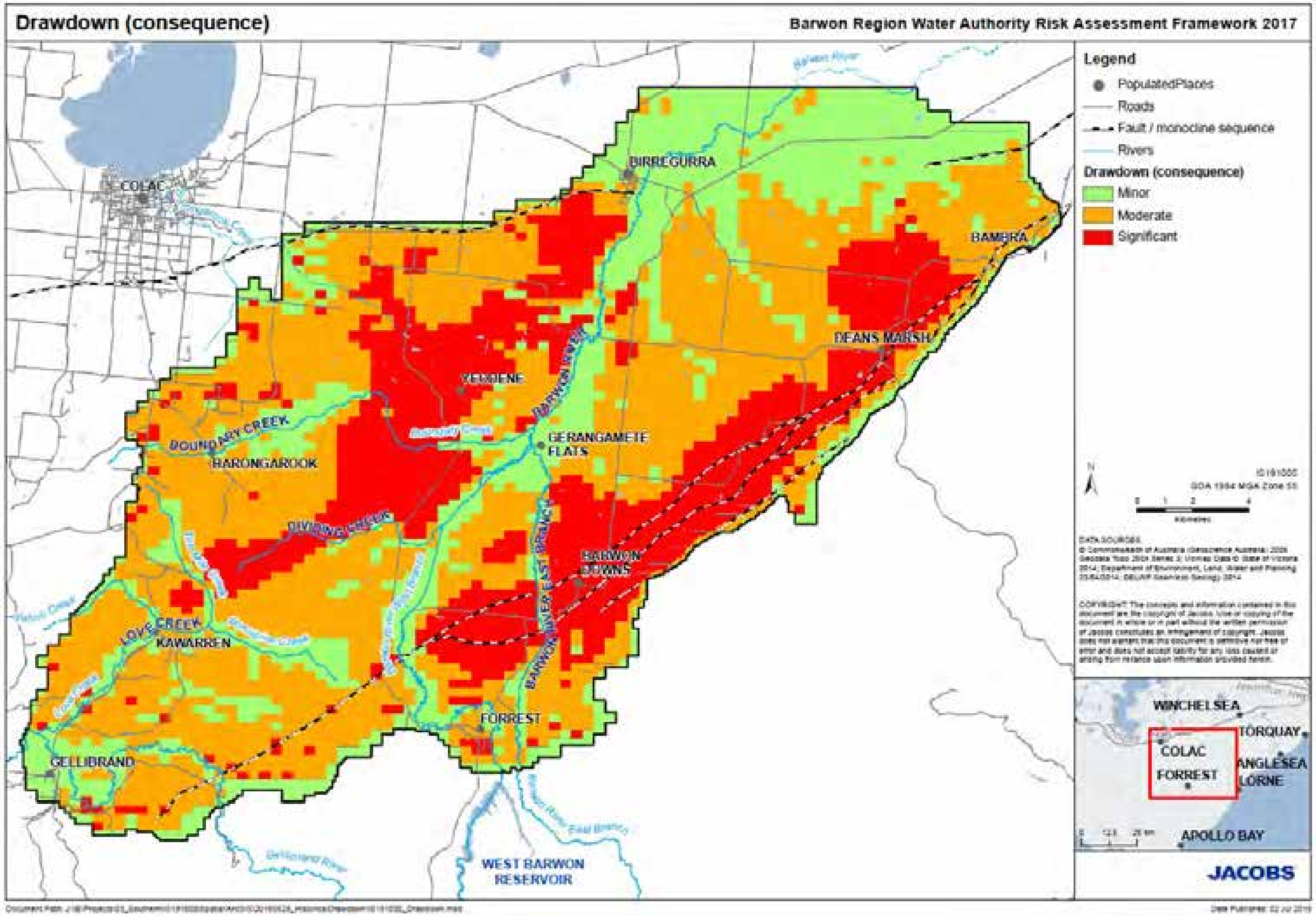


Figure A.2: Drawdown in the model watertable aquifers as a measure of consequence of impact of the borefield



A.1.3 Risk

The risk assessment framework is shown in Figure A.3.

There is limited site specific information along many of creeks and rivers in terms of both streamflow monitoring and groundwater monitoring of both alluvial and regional aquifers. However other site specific studies completed as part of the Technical Works Monitoring Program have highlighted there are physical attributes, such as the presence of a local alluvial quifer and the regional aquitard, that essentially mitigate the risk the drawdown. Consequently, risk of groundwater extraction to creeks and rivers maybe over-estimated.

Figure A.3: Risk assessment framework

Connection between receptor class and groundwater		Minor	Moderate	Significant
	Unlikely	Low	Low	Medium
	Possible	Low	Medium	High
	Certain	Medium	High	High

Reduction in streamflow / Drawdown

A.2 Risk assessment framework for vegetation and PASS

The Ministerial Guidelines have been adopted to assess the potential risk to groundwater dependent vegetation and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The risk assessment framework is based on the following:

- **Likelihood** that groundwater will interact with the high value GDE defined by the depth to watertable in the regional aquifer (see Table A.3)
- **Consequence** of the proposed groundwater extraction on the feature defined by the drawdown in the regional aquifer (see Table A.4)
- **Risk** is considered in terms of low, medium, high risk using the following equation:
    - Likelihood x Consequence = Risk

Table A.3: Likelihood of terrestrial vegetation being dependent of groundwater (depth to watertable)

Likelihood	Description	Measure
Unlikely	A disconnected ecosystem	Depth to watertable > 6 m from surface
Possible	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface
Certain	A well-connected ecosystem	Depth to watertable < 2 m from surface

Table A.4: Consequence (drawdown in watertable level)

Consequence	Description	Measure
Minor	Proposed extraction is small with respect to the aquifer's ability to supply	Watertable decline of <0.1 m
Moderate	Proposed extraction impacts measurably with respect to the aquifer's ability to supply	Watertable decline of 0.1 - 2 m
Significant	Proposed extraction impacts is large with respect to the aquifer's ability to supply	Watertable decline of > 2 m

Figure A.4: Risk assessment framework

Connection between receptor class and groundwater		Minor	Moderate	Significant
	Unlikely	Low	Low	Medium
	Possible	Low	Medium	High
	Certain	Medium	High	High

Groundwater Drawdown

Appendix B. Barwon River East Branch Monitoring Data

B.1 Available surface water monitoring data

Flow in the Barwon River East Branch is currently monitored by three surface water gauges – one at Forrest which is located upstream and outside of the model domain (233214); one at Flume located further downstream (233268) and another at the inlet channel which flows to the Wurdee Buloc Reservoir which monitor Barwon Water's diversion channel, not the river itself. The elevation of the surface water gauge is not known, so it is not possible to determine the hydraulic gradient between the surface water and groundwater to inform the nature of the groundwater surface water interactions.

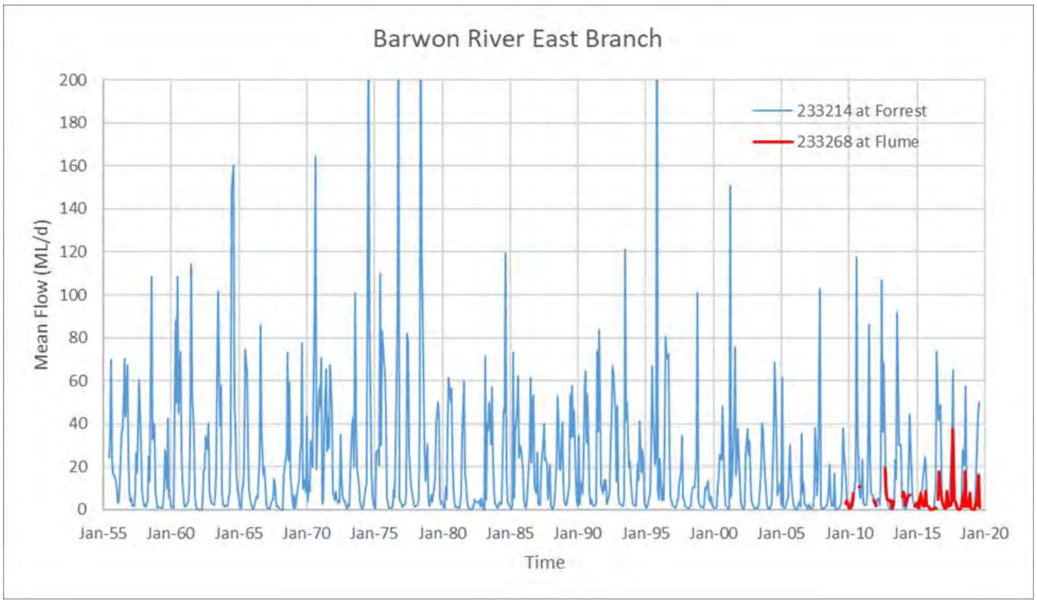
The flow monitoring record at the Forrest and Flume gauges is shown in Figure B.1. This shows that flow is generally higher upstream at Forrest compared to downstream at Flume due to diversions into the Wurdee Boluc Inlet Channel in accordance with the Upper Barwon Bulk Entitlement. The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and at the very edge of the model domain. This gauge measures passing flow, environmental releases and spills from the West Barwon Reservoir.

A summary of the gauges is provided in Table B.1 and the locations are shown in Figure 3-1.

Table B.1: Barwon River East Branch surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233214	(Upstream) Barwon River East Branch at Forrest	June 1955 - Present	Active
233268	(Upstream) East Barwon River at Flume	Jul-2009 to present	Active
233253	(Upstream) East Barwon River at Offtake	May-2002 to Oct-2015	Inactive
233204	(Upstream) Barwon River East Branch at Forrest (Below Tunnel)	Oct-1926 to Oct-1959	Inactive
233703	(Upstream) Wurdiboluc Inlet Channel at East Barwon Offtake	Jul-2000 to present	Active

Figure B.1: Average monthly flow in the Barwon River East Branch



B.2 Available Groundwater monitoring data

There are two active monitoring bores in the vicinity of the Barwon River East Branch – bore 48249 and PASS 2. Another two bores are also present in the area, however these bores are no longer monitored (bores 82848 and 108970). A summary details of these bores are provided in Table B.2 and the locations of the active monitoring bores are shown in Figure 3-1.

The active monitoring bores intersect the confined LTA below the MTD north west of the Bambra Fault. Bore 48249 is located in the confined LTA in the middle of the Bambra Fault zone (between two fault lines) where the MTD confines the LTA. The observed depth to groundwater is around 35 m below ground surface (elevation around 145 mAHD) and groundwater levels have declined approximately 5 m since monitoring commenced in the early 1990s.

Bore PASS 2 is the only bore monitoring the water table aquifer near the Bambra Fault. The observed groundwater level is around 138 mAHD and is marginally artesian at this location. Given the groundwater level in bore 48249 is higher in elevation (145 mAHD), this suggests that the groundwater levels in the watertable aquifer could be supported by an upward gradient from the LTA.

Table B.2: Barwon River East Branch groundwater monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
48249	LTA	136	Oct-1982 - Aug-2019	Active
82848	LTA	353	Jul-1985 - May-1997	Inactive
108970	Not known	30	Aug-1986 - Nov-1988	Inactive
PASS 2	Quaternary Alluvium	9.8	Mar-2015 – Jun-2016	Active

B.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores with long and consistent monitoring trends. The observed and modelled groundwater levels for bores located close to the Barwon River East Branch are outlined below.

East Branch of the Barwon River:

- Bore 48249 monitors the LTA at 136 m depth. The model estimates that the groundwater level in the LTA at this location is influenced by groundwater pumping more than observed and that levels are up to 10 meters lower than observed. In this area the model is over-estimating the drawdown.

- Bore PASS 2 was installed recently and is less than 10 m deep. The observed groundwater level is slightly artesian in this bore (Jacobs, 2017b). Based on the limited observed water levels, the model appears to be representing the groundwater level in the water table aquifer reasonably well at this location.

The groundwater model estimates the groundwater level is around 140 mAHD in both PASS2 and 48249. However, the observed groundwater level is around 137 mAHD in the shallow PASS 2 bore and 145 mAHD in the deeper bore (48249). This indicates there is an upward gradient in the LTA at this location, generating groundwater flow from the LTA to the overlying hydraulic units (MTD and alluvial aquifer) and potentially the Barwon River East Branch of the Barwon River. The model may be over-predicting drawdown and hence risk in this area.

Figure B.2: Groundwater hydrograph – bore 48249

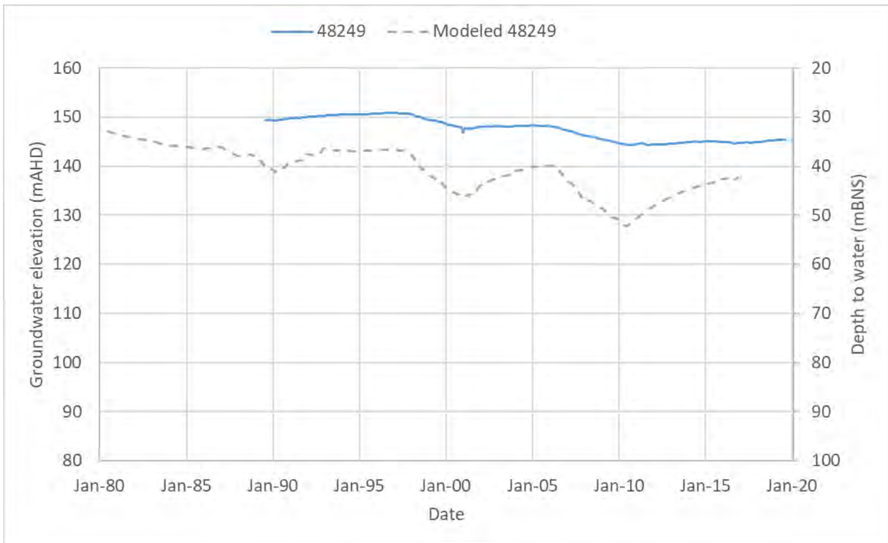
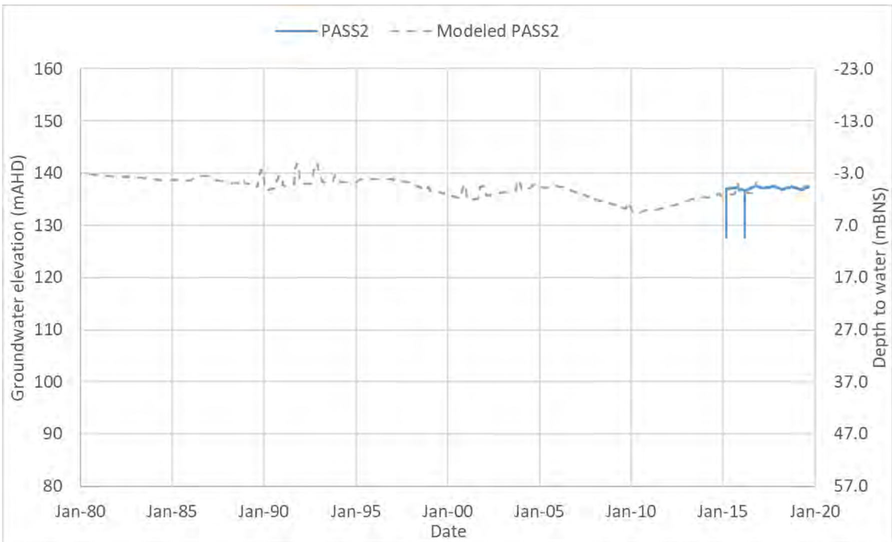


Figure B.3: Groundwater hydrograph – bore PASS 2



Appendix C. Barwon River West Branch Monitoring Data

C.1 Available surface water monitoring data

The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and the very edge of the model domain.

A summary of the gauges is provided in Table C.1 and the locations are shown in Figure 3-1.

Table C.1: Barwon River West Branch surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233203	(Upstream) Barwon River West Branch at Forrest	Oct-1926 to May-1965	Inactive (no data)
233245	(Upstream) West Barwon River at Compensation Weir Spillway	October 2000 - Present	Active
233244	(Reservoir) West Barwon River at West Barwon Reservoir H.G.	Nov-2001 to present	Active (no data)

C.2 Available groundwater monitoring data

There are two active monitoring bores in the vicinity of the Barwon River West Branch – bores 108915 and 64237. These bores both intersect the confined LTA below the MTD north west of the Bambra Fault.

A summary of the bores is provided in Table C.2 and their locations are shown in Figure 3-1.

Bore 108915 is 209 m deep and is located close to the Bambra Fault. The depth to watertable is this bore is approximately 35 m depth and has declined around 5 m over the monitoring period. The waterlevel in the overlying MTD and alluvial aquifer is not known, so the potential interactions between the regional and local groundwater systems and the West Branch is not clear.

Bore 64237 is located in the centre of the graben and is over 400 m deep. Groundwater levels in the LTA were artesian (10 m above ground surface) prior to pumping from Barwon Downs. The current groundwater level is slightly artesian (around 1 m above ground surface) which suggests there is approximately 10 m residual drawdown in the LTA at this location. The waterlevel in the LTA is heavily influenced by pumping.

There are no bores on the south east side of the Bambra Fault where the LTA outcrops.

Table C.2: Barwon River East groundwater monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
64237	LTA	422	Sep-1985 - Aug-2019	Active
108915	LTA	209	May-1987 - Aug-2019	Active

C.3 Interpretation of groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores with long and consistent monitoring trends. The observed and modelled groundwater levels for bores located close to the Barwon River West Branch are outlined below.

Barwon River West Branch:

- Figure C.1 shows the model estimates the groundwater levels in bore 64237 reasonably well, however in this case the observed groundwater levels are influenced groundwater pumping and the model underestimates the drawdown in the LTA in response to pumping in this location.
- Groundwater level in the model for bore 108915 is slightly higher than the observed groundwater level (see Figure C.2), although the trend appears to be accurate.
- There is an upward gradient in the LTA at this location from the deeper bore (64237) to the shallower bore (108915) and the groundwater model provides a reasonable representation of this.

In summary, a high risk is predicted in this area, where the model indicates a decline in groundwater levels from 148 to 138 mAHD, while the observed groundwater levels is currently around 145 mAHD. To confirm the vertical hydraulic gradients in the vicinity of the high risk areas, it is recommended that river bed elevation be surveyed and ongoing monitoring of existing bores to confirm groundwater levels in relation to the river in this location.

Figure C.1: Groundwater hydrograph – bore 64237

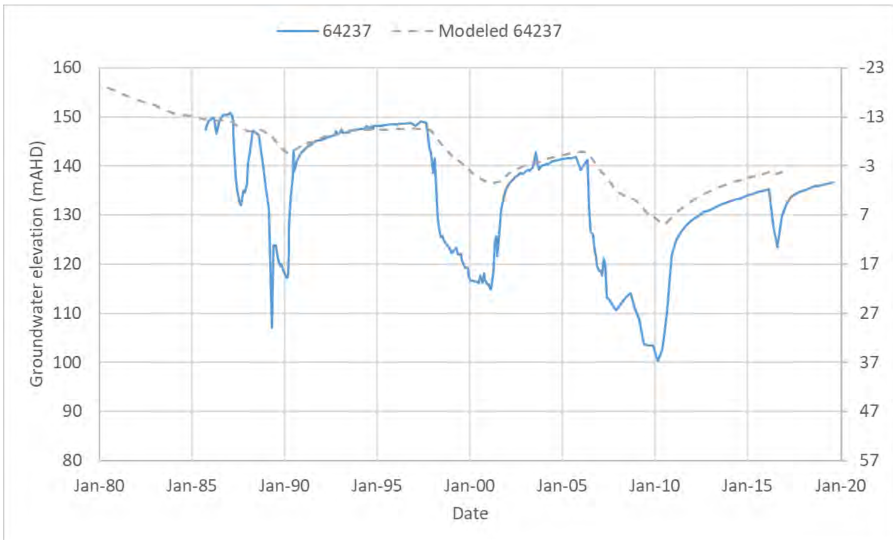
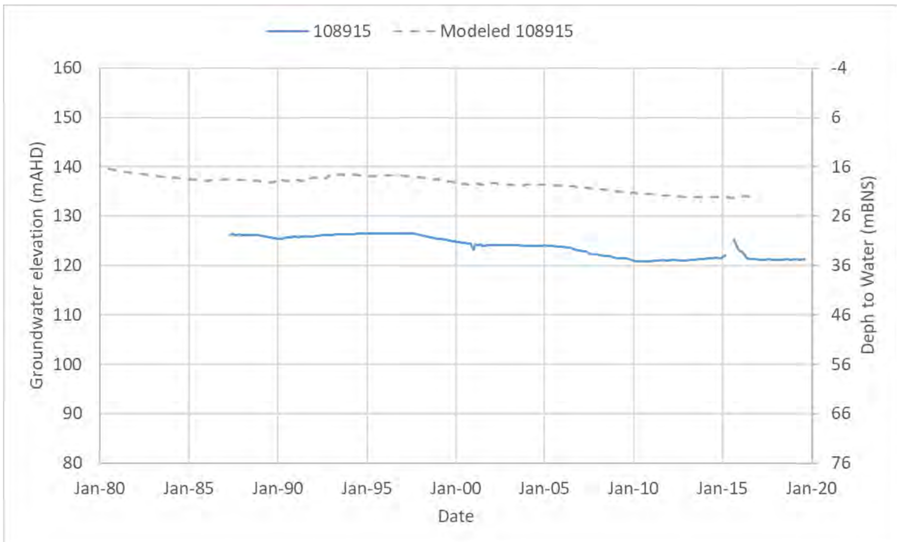


Figure C.2: Groundwater hydrograph – bore 108915



Appendix D. Barwon River downstream of Boundary Creek

D.1 Available surface water data

There is currently only one surface water gauge located downstream and near the edge of the model domain (23324).

The flow monitoring record at the Ricketts Marsh gauge is shown in Figure D.1, which highlights that there has been a decline in flow over the monitoring record (since 1971). Flow in the 1970s was often recorded above 1000 ML/day during the winter months, however since the mid 1990s, flow has only exceeded 1000 ML/day on one occasion (during the winter 2013). Very low flows (10 ML/day) were often recorded during summer months, although again since mid 1990s, these low flow periods appear to be pronounced and longer. It should be noted that this is consistent with rainfall in the region. Rainfall was typically above average between 1970 and 1995 before the Millennium Drought commenced in mid to late 1990s.

The surface water elevation at this location is shown in Figure D.2. This indicates the surface water level typically ranges between 97 and 98 mAHD at this location. The shift in surface water levels in the late 1970s is likely due to the gauge being replaced and re-surveyed.

A summary of the gauges is provided in Table D.1 and the locations are shown in Figure 3-2.

Table D.1: Barwon River Downstream of Confluence surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233224	Barwon river at Ricketts Marsh	1971 to 2019	Active

Figure D.1: Monthly mean flow - 233224 at Rickets Marsh

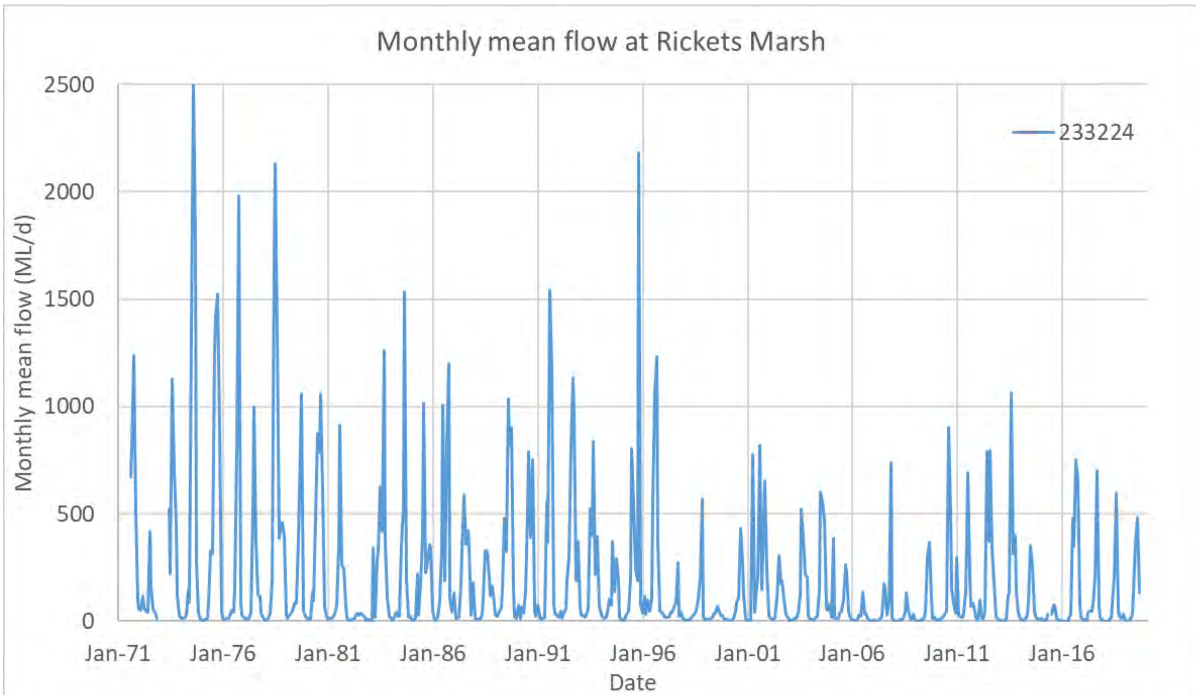
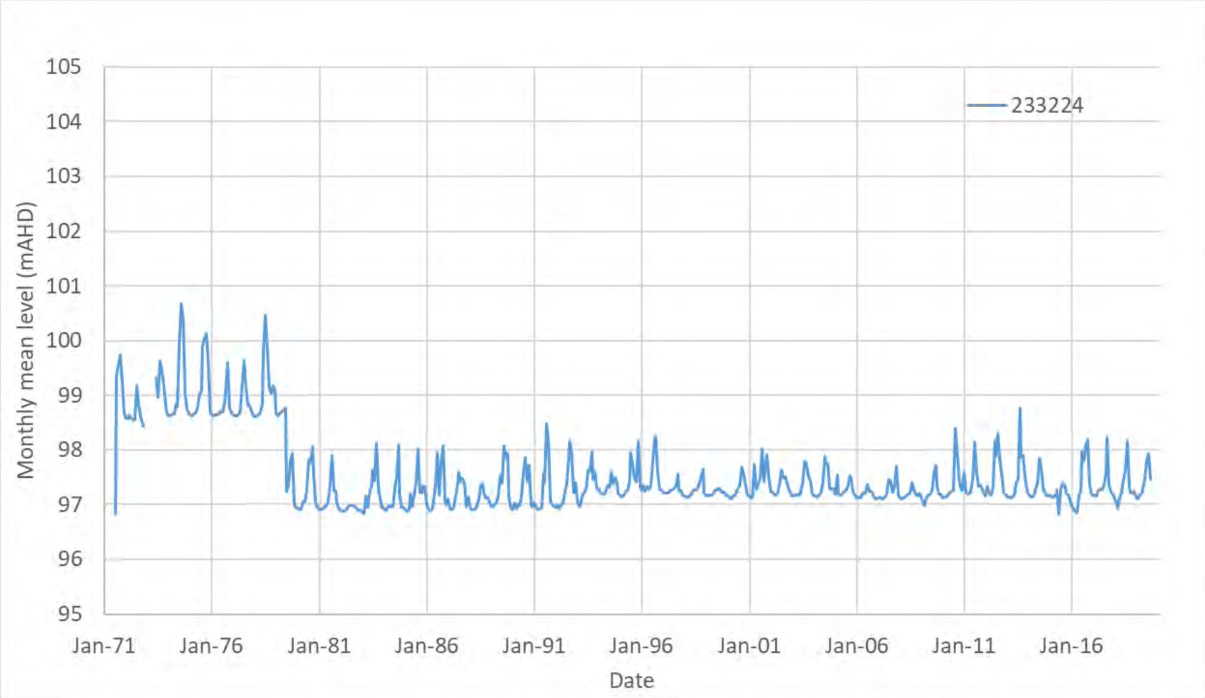


Figure D.2: Monthly mean level - 233224 at Rickets Marsh



D.2 Available groundwater monitoring data

There are five active monitoring bores in the vicinity of Barwon River Downstream of confluence – three bores are located to the east of Gerangmete Flats (82838, 82840 and 82841) and two located downstream (109135 and 102868). Another bore is located further downstream; however it is no longer active (82814).

A summary of the bores is provided in Table D.2 and hydrographs are shown in **Error! Reference source not found.** to Figure D.7. The bores monitor the regional aquifer (LTA) at depths ranging between 233 and 422 m depth. Bores 82838, 82840 and 82841 are located in the centre of graben at different depths, so can be used to inform the groundwater trends in different levels in the LTA. Groundwater levels in the deeper bores (82840 and 82841) are strongly influenced by pumping, while the shallower bore (82838) shows a stronger seasonal response and much less drawdown. The most recent readings from the shallow bore (82838) indicate that the condition of the bore could be compromised and should be assessed.

Groundwater levels in many of the deeper LTA bores were artesian prior to pumping, and now currently 10-20 m below ground level. With the exception of bore 109135 and 82838, water levels are 10-20 meters lower than the pre-pumping groundwater level. Both these bores are shallower bores and 109315 is also located further from the bore field.

Additional shallow bores are recommended along the Barwon River downstream of the confluence to confirm the groundwater levels in the alluvial aquifer and thickness.

Table D.2: Barwon River Downstream of confluence monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
82838	MTD	285.1	1974 - 2019	Active
82840	LTA	610.8	1973 - 2019	Active
82841	LTA	484.6	1974 - 2019	Active
82844	LTA	233.0	1985 - 2007	Inactive

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
109135	LTA	237.0	1986 - 2019	Active
102868	LTA	577.0	1984 - 2019	Active
50056	NKN	336.2	1986 - 1992	Inactive

D.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores and the observed and modelled groundwater levels is shown in Figure D.3 to Figure D.7. The groundwater level in the LTA in the centre of the model is typically underestimated in the groundwater model. For example:

- Model estimates the groundwater levels in bore 82838 are lower than the observed water level. Model also estimates impacts from pumping, however observed data is more influenced by seasonal variations.
- Groundwater level in the model for bore 82840 is generally lower than the observed groundwater level. However the model predicts less drawdown than observed at this location. The trend is reasonably accurate.
- Groundwater level in the model for bore 82841 is lower than the observed groundwater level. The predicted drawdown and the trends appear accurate.
- Model estimates the groundwater levels in bore 109135 are lower than observed groundwater level. The trend appears to be accurate until most recent predictions, where a significant recovery in water level has been observed at the bore, although there has been a sharp decline in waterlevels in 2019 and the reason for this is not known. Given observed groundwater levels are much higher than modelled, this is likely to influence the drawdown predictions and risk assessment.
- Groundwater level in the model for bore 102868 is lower than the observed groundwater level. The modelled trends appear accurate.
- There is a downward gradient in the LTA in the centre of the graben. Its likely that groundwater levels would have been similar at different levels in the aquifer prior to groundwater pumping and pumping and drought have induced a downward gradient in the aquifer.

In summary, although the model under predicts groundwater levels, the calibration appears to be fairly accurate in the LTA. Given observed groundwater levels are higher than modelled, this is likely to impact on the drawdown estimates in the model and subsequent risk assessment.

Figure D.3: Groundwater hydrograph – bore 82838

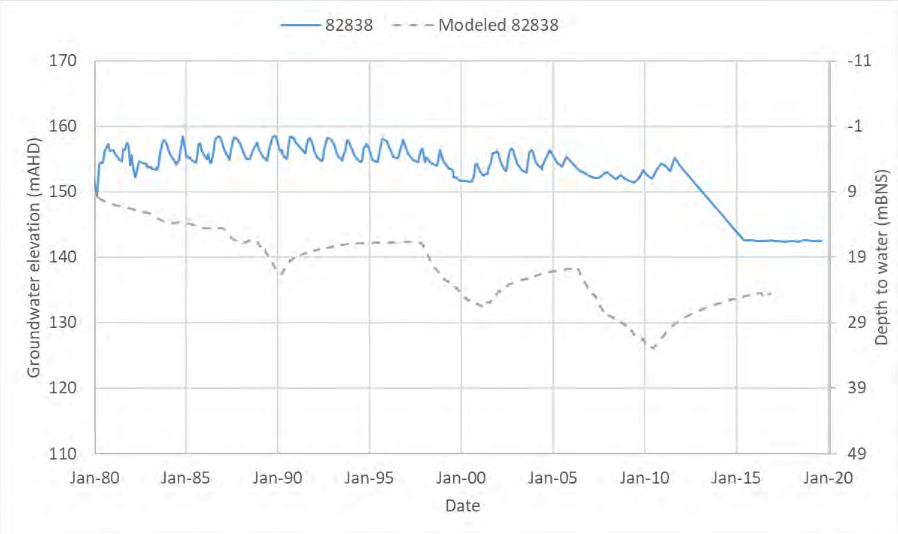


Figure D.4: Groundwater hydrograph – bore 82840

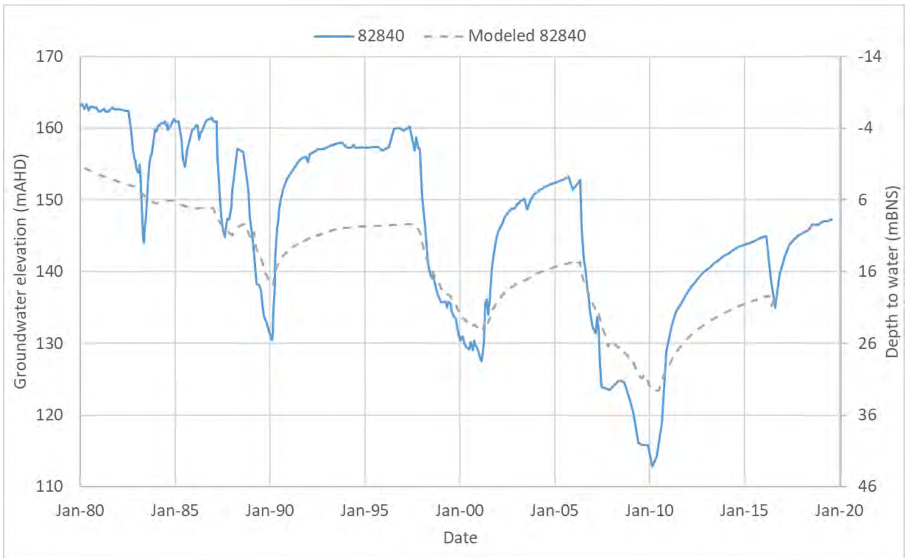


Figure D.5: Groundwater hydrograph – bore 82841

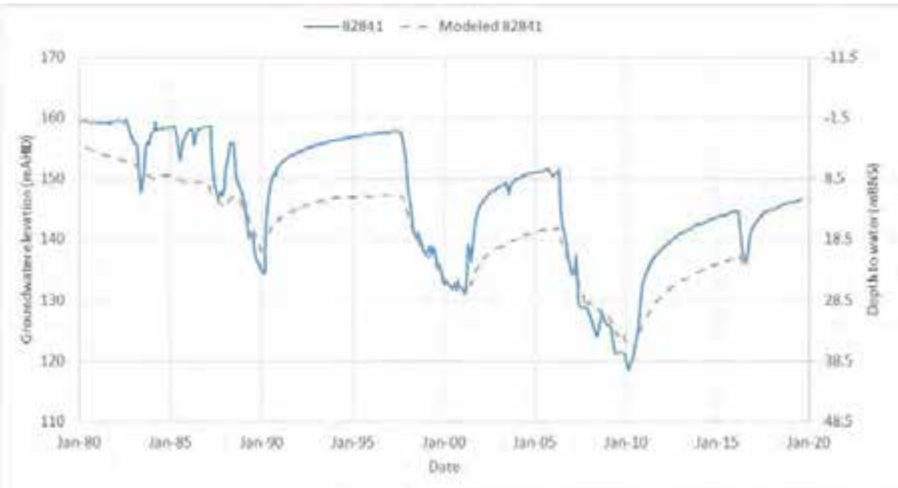


Figure D.6: Groundwater hydrograph – bore 82844

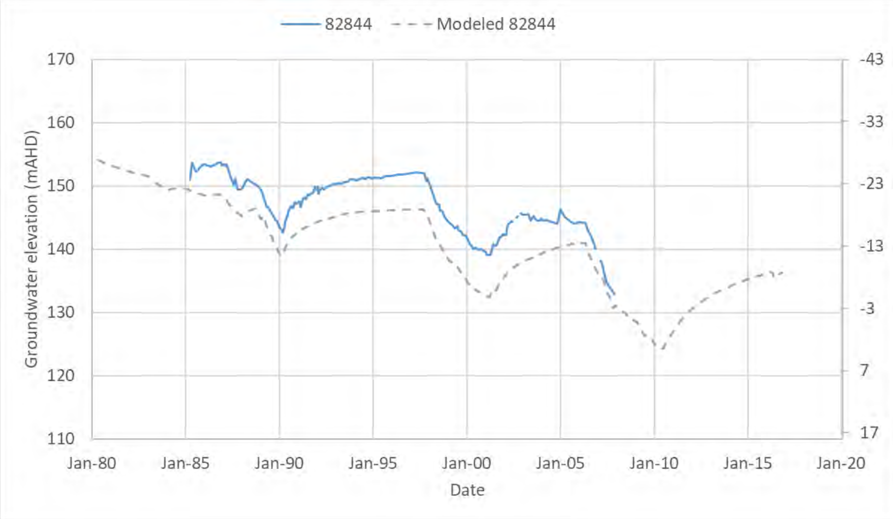
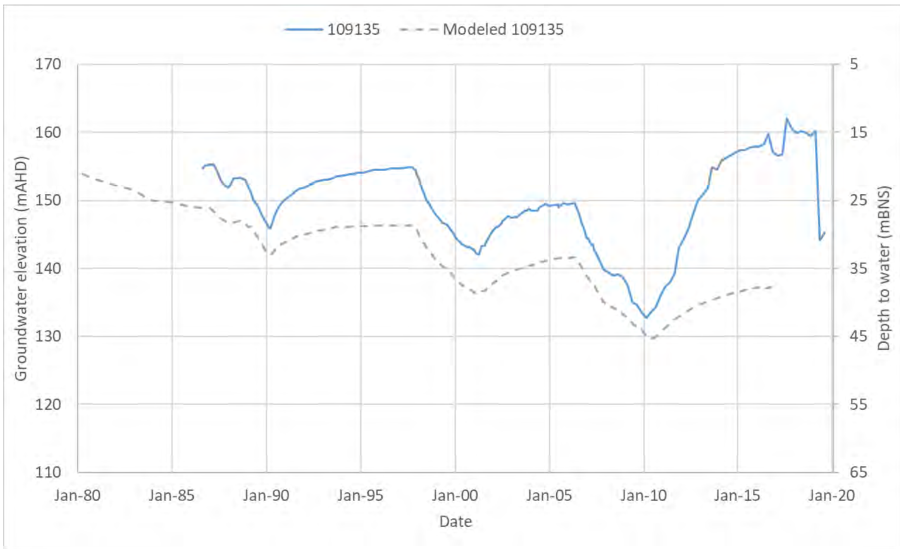


Figure D.7: Groundwater hydrograph – bore 109135



Appendix E. Gellibrand River

E.1 Surface water monitoring data

The Gellibrand River is monitored by two active surface water gauges 235227 (Bunkers Hill) and 235202 (Upper Gellibrand) which are located upstream and downstream of the model domain. There is one surface water gauge located in the model domain (235228 at Gellibrand), however monitoring ceased in 1989. The location of these gauges is shown in Figure 4-1.

The flow in the Upper Gellibrand is typically up to 250 ML/day during high flow periods, with short periods of very low flow (<1 ML/day) during the summer months (see Figure E.1). In contrast, the flow downstream at Bunkers Hill often exceeds 750 ML/day and appears to have a reasonable baseflow maintaining flow during the summer months. The river is considered to be a key discharge area for the LTA, and Loves Creek and its associated tributaries also join the Gellibrand between the two gauges.

There is no information on the elevation of the surface water at Upper Gellibrand (235202), however there is elevation data at the downstream gauge at Bunkers Hill shown in Figure E.2. The elevation of the surface water ranges between 50 and 51 mAHD at this location, which is downstream of the model domain.

Table E.1: Gellibrand River surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235202	Gellibrand River at Upper Gellibrand	1949 to 2019	Active
235228	Gellibrand River at Gellibrand	1970 to 1989	Inactive
235227	Gellibrand River at Bunkers Hill	1970 to 2019	Active

Figure E.1: Monthly mean flow Gellibrand River

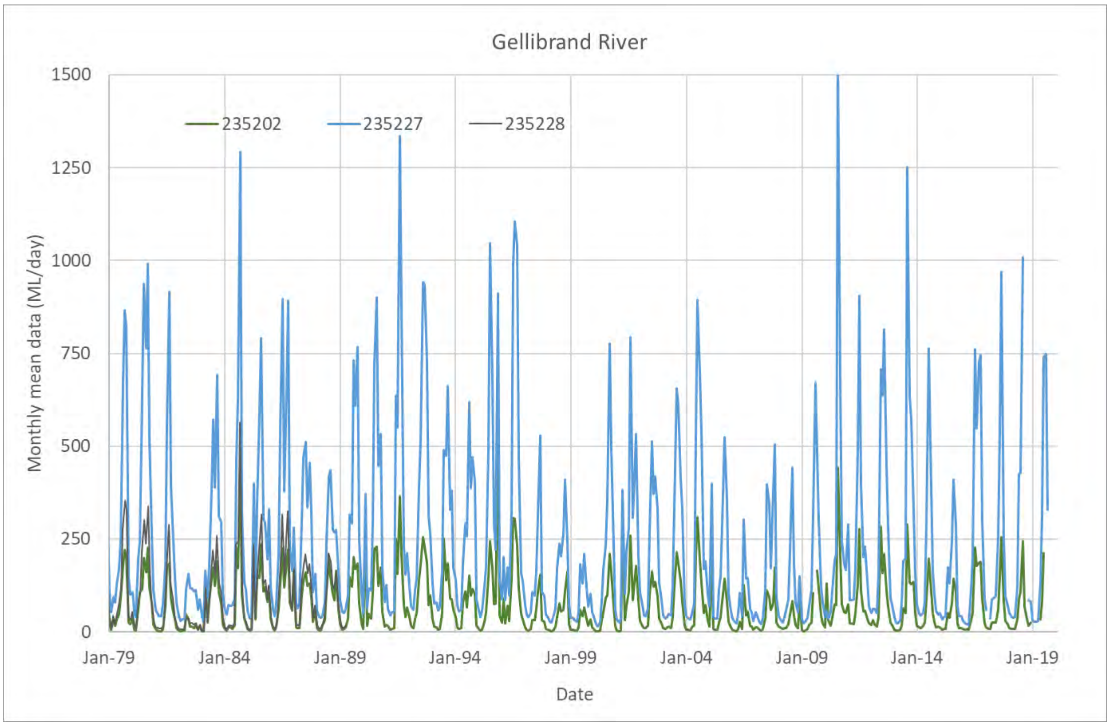
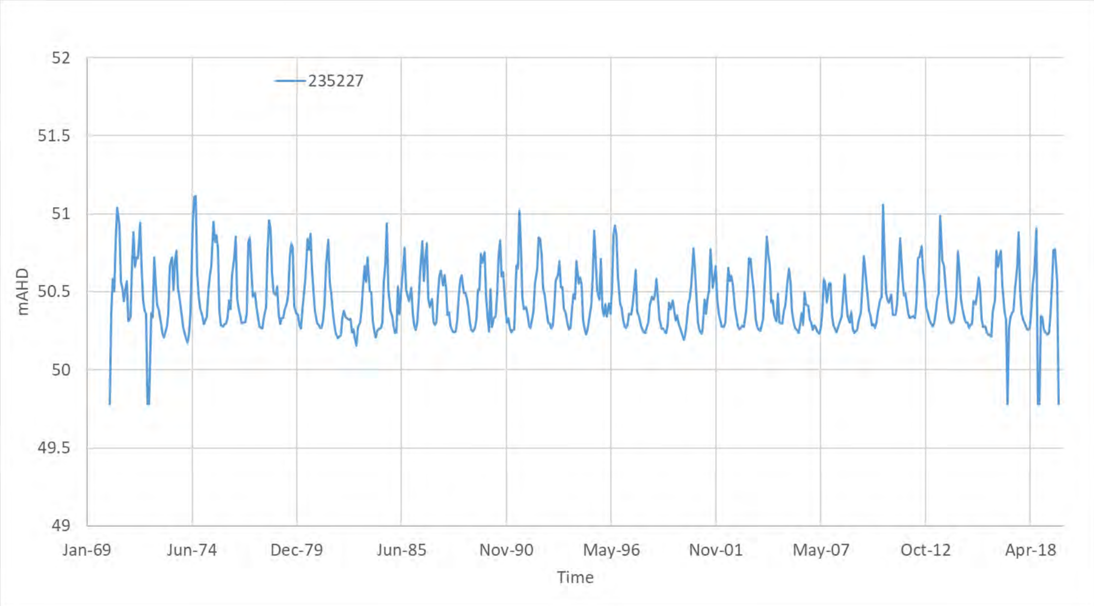


Figure E.2: Monthly mean level – 235227 Gellibrand River at Bunkers Hill



E.2 Groundwater monitoring data

Figure 4-1 shows all the groundwater monitoring bores in the areas. The majority of the existing groundwater monitoring bores are located south of the Gellibrand River where the effects of the bore field are reduced. Bores located on the northern side of the river were reviewed to determine if impacts from groundwater pumping have been observed.

Only one groundwater bore is currently monitored on the northern side of the river (108907) and this is located at some distance from the Gellibrand River. Monitoring has ceased in the other groundwater bores.

There are no existing bores located on the north side of the river in the area of high risk identified. The closest existing bores located along the northern side near this section of the Gellibrand River are listed in Table C.2 and are described below.

- Bores 108958, 108959, 108960 and 108961 have no information on depth, formation monitored or groundwater levels.
- Bores 108916, 108917, 108918, 108919 and 108920 are all shallow bores between 15 and 20 meters deep and are likely to be screened in the shallow regional aquifer (LTA).
- Bores 108898 and 108899 are deeper bores also screened the regional aquifer (LTA).

Bores 108917 and 108919 show steady seasonal fluctuations in the shallow LTA, with groundwater levels around 78 mAHD.

Bore 108899 is slightly deeper in the LTA (34 m deep) and shows a similar steady seasonal trend with waterlevels around 82 mAHD, indicating an upward gradient. Bore 108919 intersects the LTA at a depth of 272 mAHD. The groundwater level trend shows a similar steady seasonal trend over the monitoring record, with groundwater levels at around 82 mAHD, further supporting that there is an upward hydraulic gradient from the LTA to the shallow aquifer.

Groundwater levels in these bores do not appear to be influenced by pumping from Barwon Downs.

Table E.2: Groundwater bores on the northern side of the Gellibrand River

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
108916	Shallow LTA*	14.9	1981 to 2011	Inactive
108917	Shallow LTA*	15.0	1981 to 2013	Inactive
108918	Shallow LTA*	15.3	1981 to 1994	Inactive
108919	Shallow LTA*	16.6	1981 to 2011	Inactive
108920	Shallow LTA*	18.0	1981 to 1998	Inactive
108898	LTA	272.0	1981 to 2013	Inactive
108899	LTA	34.0	1981 to 2013	Inactive
108958	Unknown	N/A	1979 to 1985	Inactive
108959	Unknown	N/A	1979 to 1983	Inactive
108960	Unknown	N/A	1979 to 1985	Inactive
108961	Unknown	N/A	1979 to 1985	Inactive

E.3 Interpretation of the groundwater model results

The hydrographs with observed monitoring data and the water level predicted by the calibration model are shown in Figure E.3 to Figure E.6.

Monitoring ceased in 2014 for bores 108917, 108919 and 108899, so while they are not currently monitored, a reasonable groundwater trend is available. Bores 1089717 and 108919 both intersect the shallow LTA and show a steady seasonal trend over the monitoring record (1991 – 2014). Groundwater levels are 78 mAHD at this location and the model represents this reasonably well.

Bore 108899 is slightly deeper at 34 m depth and was monitored between 1981 and 2014. The groundwater level is around 82 mAHD, which suggests there is an upward gradient in the vicinity when compared to bores 108917 and 108918. The water level in the groundwater model is less than observed and more consistent with bores 108917 and 108918 (around 78 mAHD). The observed upward gradient is not represented in the groundwater model and this is likely to influence the representation of the groundwater baseflow to the Gellibrand River in the model.

Figure E.3: Groundwater hydrograph – bore 108917

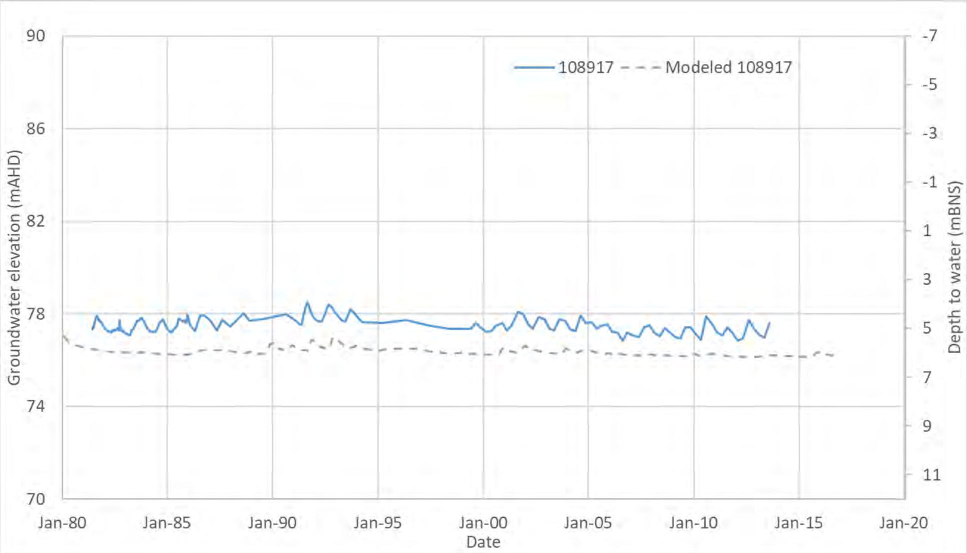


Figure E.4: Groundwater hydrograph – bore 108919

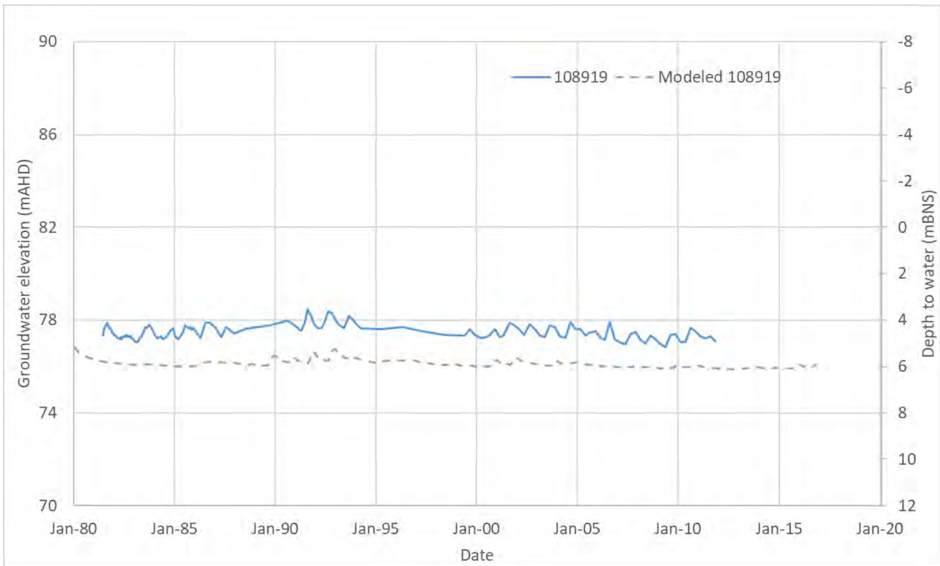


Figure E.5: Groundwater hydrograph – bore 108899

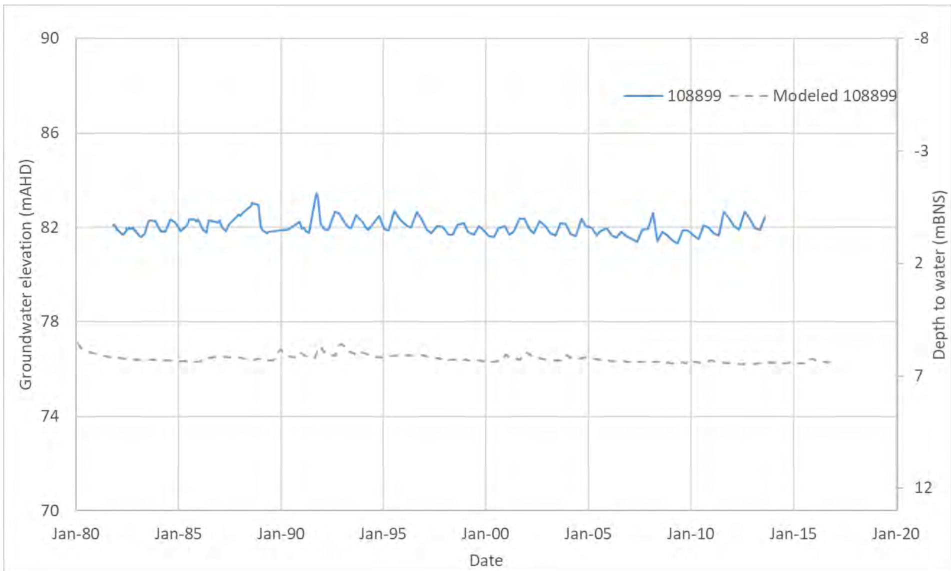
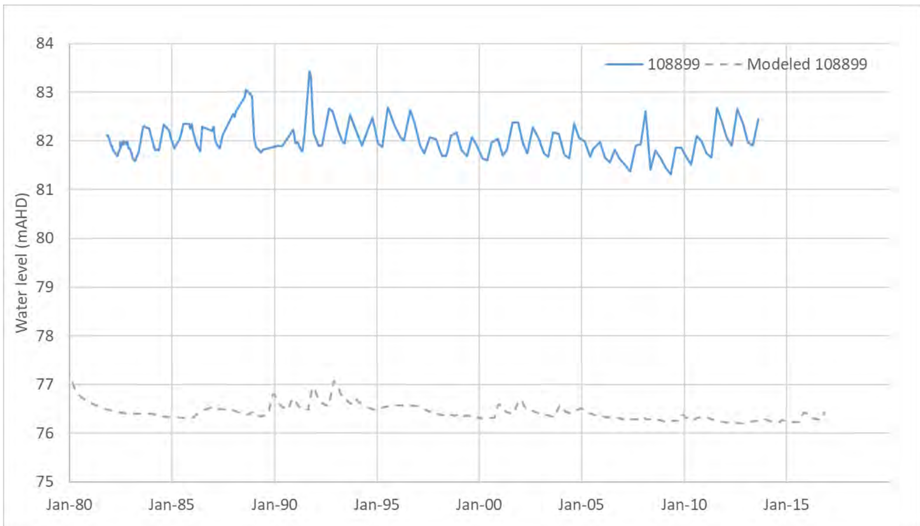


Figure E.6: Groundwater hydrograph – bore 108899



Appendix F. Ten Mile Creek

F.1 Surface water monitoring data

There is one active surface water gauge (235239) monitoring flow in Ten Mile Creek, however the flow record is intermittent. Monitoring commenced in 1985 and continued until 1995. The gauge was monitored again in 2008-2009, and has recommenced again in 2018.

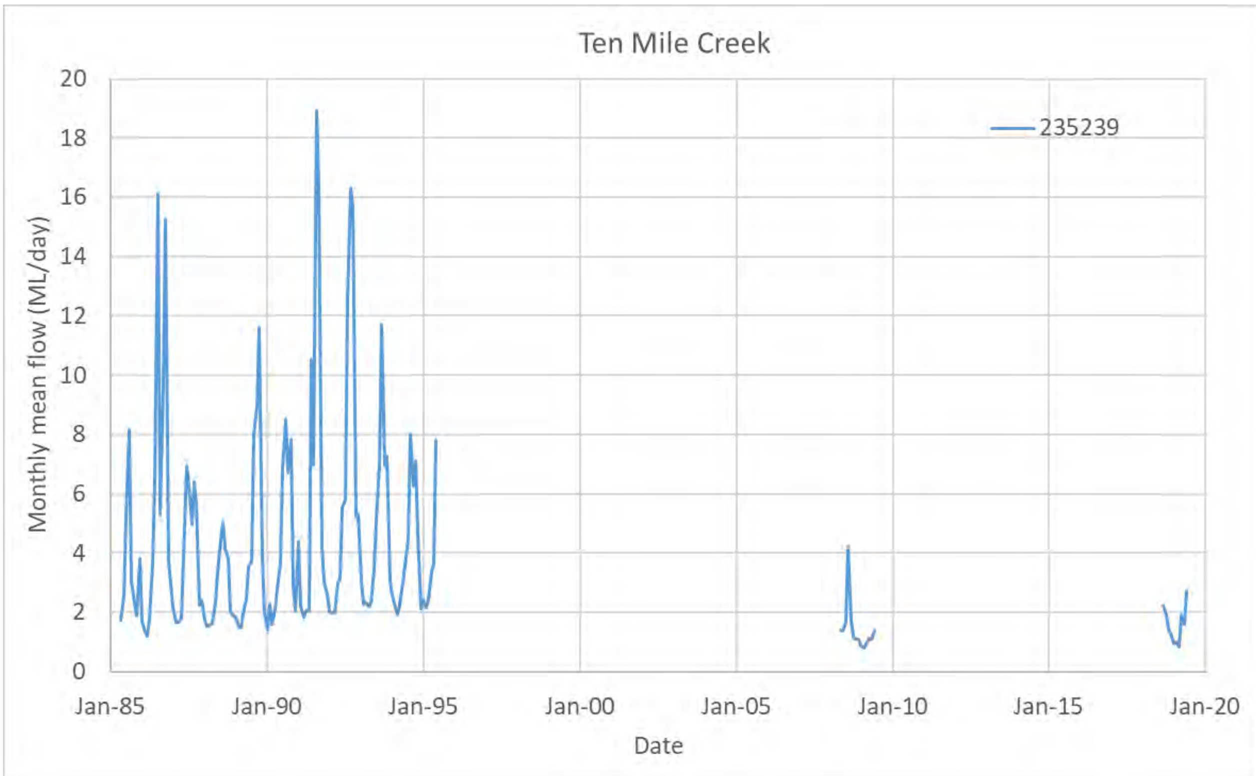
The flow monitoring record at the Kawarren gauge is shown in Figure F.1. This shows that flow during the 1980s and 1990s was typically up to 15-20 ML/day during high flows and during low flow periods flow was around 1-2 ML/day during the summer months. Intermittent monitoring periods since the mid-1990s show a very different flow regime, with flow not recorded above 5 ML/day during the winter months of 2008 or 2019.

A summary of the gauges is provided in Table F.1 and the locations are shown in Figure 4-6. The gauge is not surveyed so the surface water elevation is not known.

Table F.1: Ten Mile Creek surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235239	Ten Mile Creek at Kawarren	1985 – 1995, 2008 – 2009, 2018 to present	Active
235241	Porcupine Creek at Kawarren	1986 to 2009	Inactive

Figure F.1: Monthly mean flow – 235239 at Ten Mile Creek



F.2 Groundwater monitoring data

There are eight active monitoring bores in the vicinity of Ten Mile Creek (see Table F.2). Bores 113705 and 113706 monitor the LTA at different depths (174 m and 90 m respectively). There is a 10 meter difference between the groundwater levels in the bores, highlighting there is an upward gradient in the LTA at this location. Groundwater levels in both bores show a slight downward trend over the monitoring record (1985 – 2019).

Bores 114168 and 114169 also monitor the LTA at different depths (182 m and 82 m respectively), in the middle reaches of Ten Mile Creek. The groundwater levels in these bores are similar, although there is generally a slight upward gradient, but less pronounced compared to bores 113705/113706. Groundwater levels in these bores show a rising trend since monitoring commenced in mid 1990s. These groundwater trends suggest that groundwater levels at this location have not been significantly influenced by climate or pumping.

Bore 48003 monitors the LTA east of Ten Mile Creek, while bores 47990 and 47986 monitor the LTA west of Ten Mile Creek. The groundwater levels are similar and all show a declining trend over the monitoring period with some seasonal fluctuations in bores 48003 and 47990.

Table F.2: Ten Mile Creek groundwater monitoring bores

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
TB14	QA	11.6	2014 to 2015	Inactive
47986	LTA	296.0	1982 to 2019	Active
47990	LTA	153.0	1983 to 2019	Active
48003	LTA	381.4	1987 to 2019	Active
113705	LTA	174.0	1993 to 2019	Active
113706	LTA	90.0	1993 to 2019	Active
114168	LTA	180	1993 to 2016	Inactive
114169	LTA	82.0	1993 to 2019	Active

F.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores and the observed and modelled groundwater levels are shown in Figure F.2 to Figure F.9. The groundwater level in the LTA in this area is typically underestimated in the groundwater model. The model predicts one groundwater level for the whole LTA aquifer, which is estimate at the centre of the layer. Bores nested in the LTA at different depths highlight that there is upward gradient present in the LTA that is not replicated in the model. This means the groundwater model could be over estimating the impact from pumping on groundwater levels in these areas.

For example, for bores 113705 and 113706, the groundwater levels are 232 and 218 mAHD respectively, and the groundwater model estimates it to be 218 mAHD. The groundwater level is under-estimated and the upward gradient cannot be represented in the model as the LTA is a single layer. For bores 114168 and 114169, the groundwater level is reasonably well represented, however the model indicates the water level trend should be declining instead of the while rising groundwater trend that has been recorded.

Figure F.2: Groundwater hydrograph – bore 113705

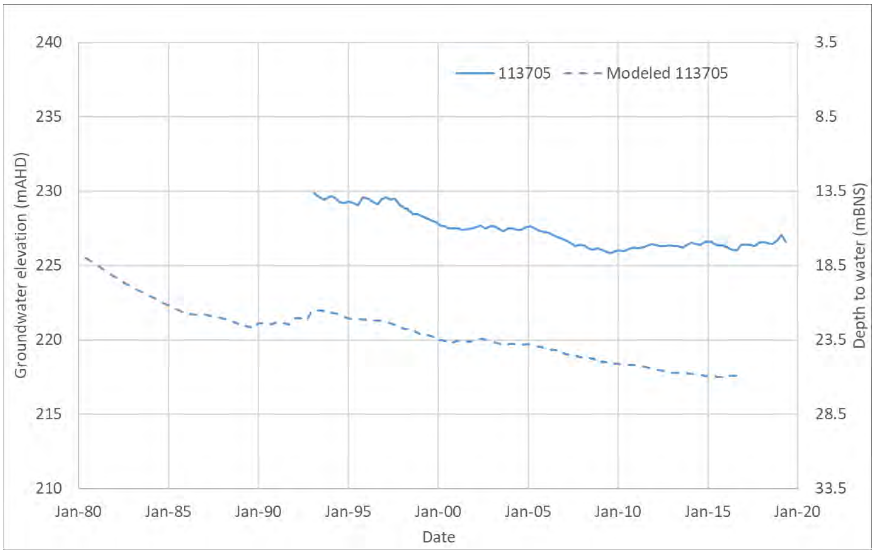


Figure F.3: Groundwater hydrograph – bore 113706

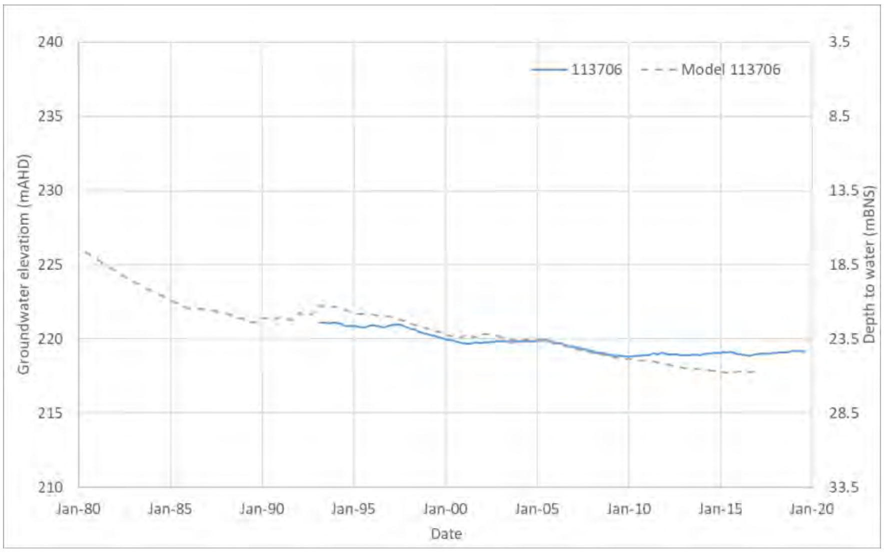


Figure F.4: Groundwater hydrograph – bore 114168

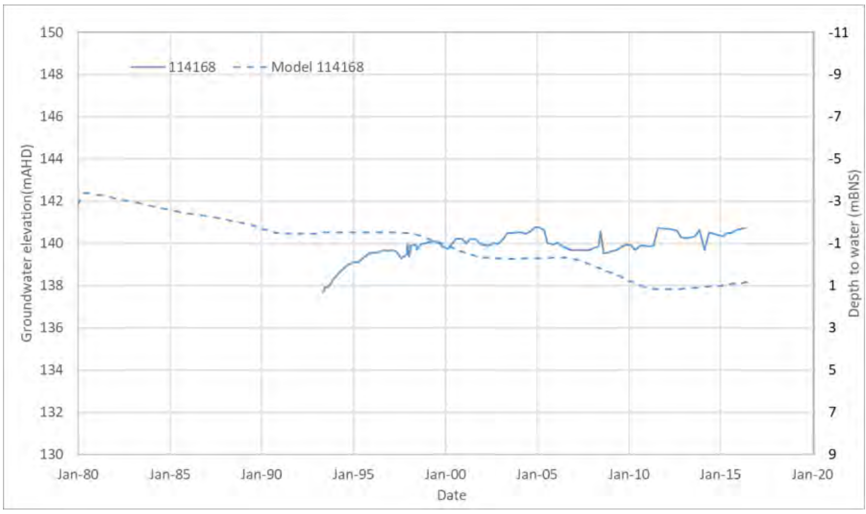


Figure F.5: Groundwater hydrograph – bore 114169

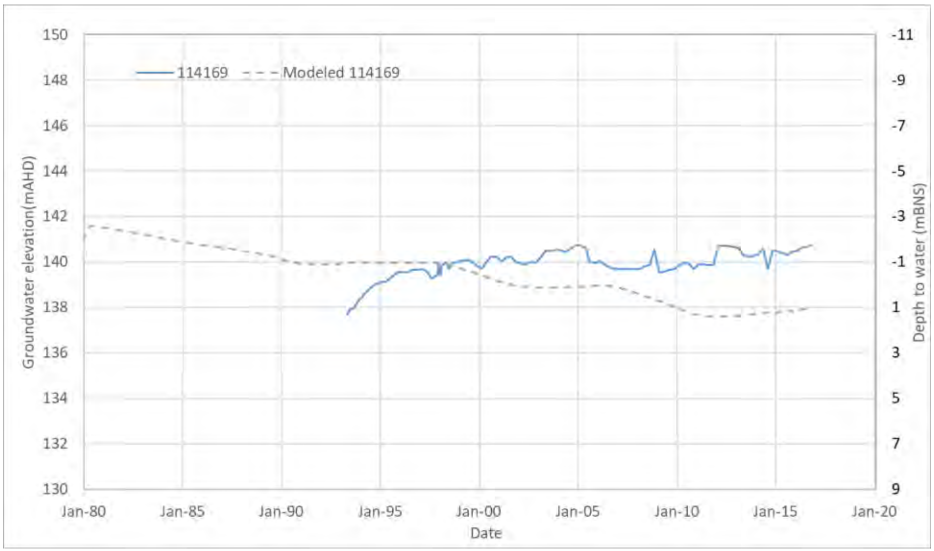


Figure F.6: Groundwater hydrograph – bore 47986

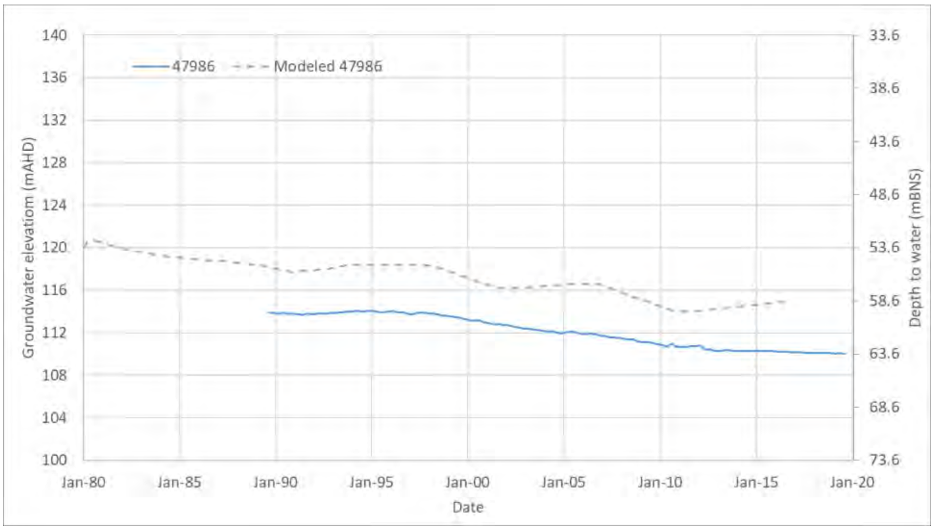


Figure F.7: Groundwater hydrograph – bore 47990

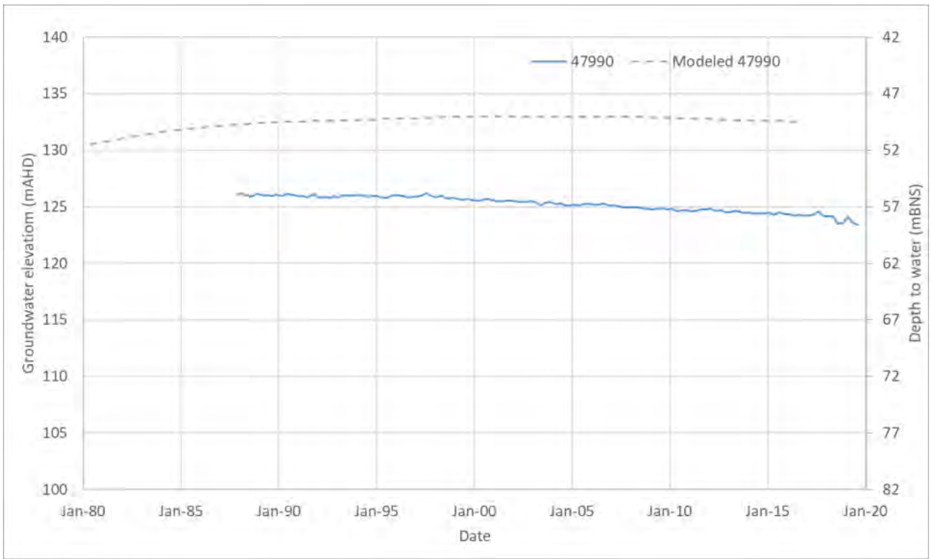


Figure F.8: Groundwater hydrograph – bore 48003

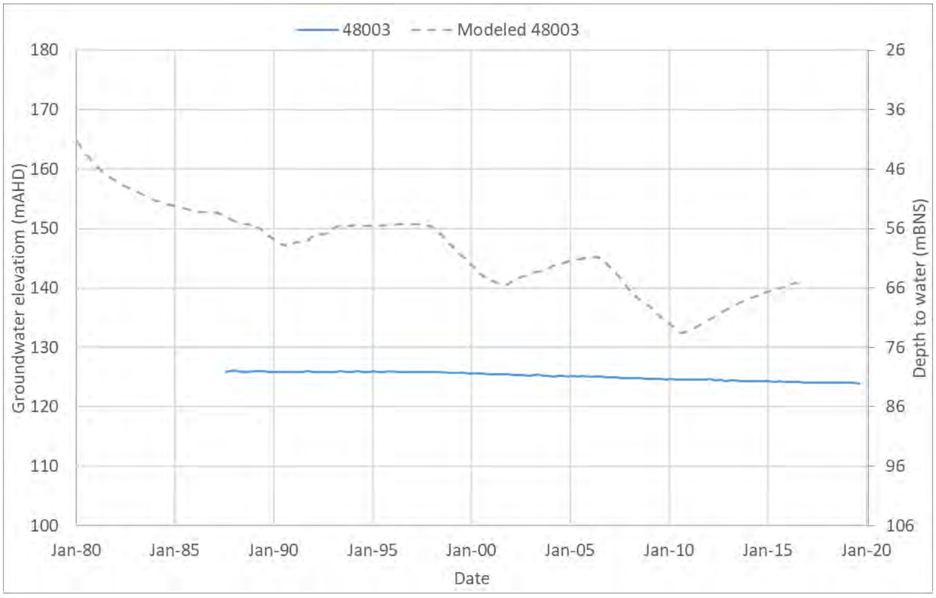
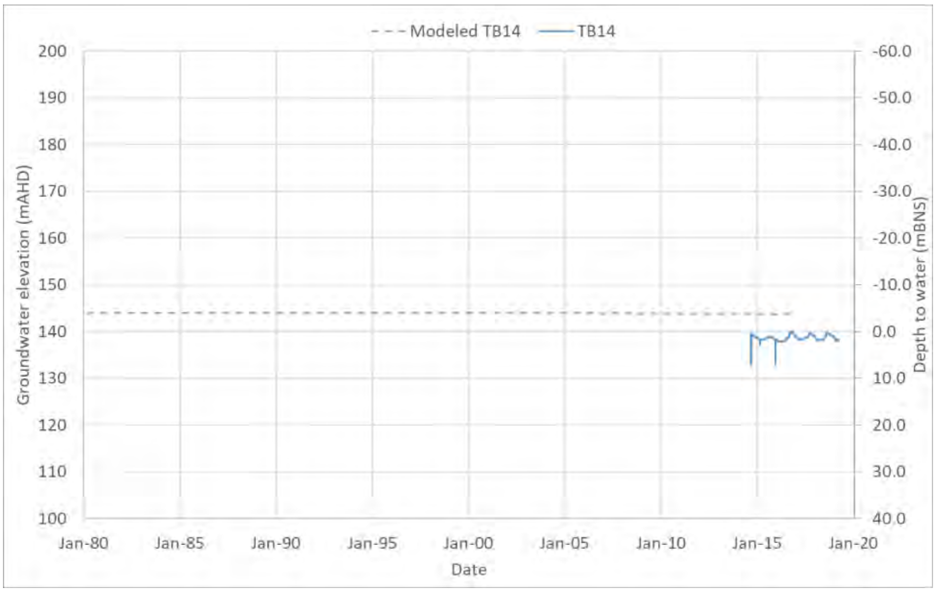


Figure F.9: Groundwater hydrograph – bore TB14



Appendix G. Yahoo Creek

G.1 Surface monitoring data

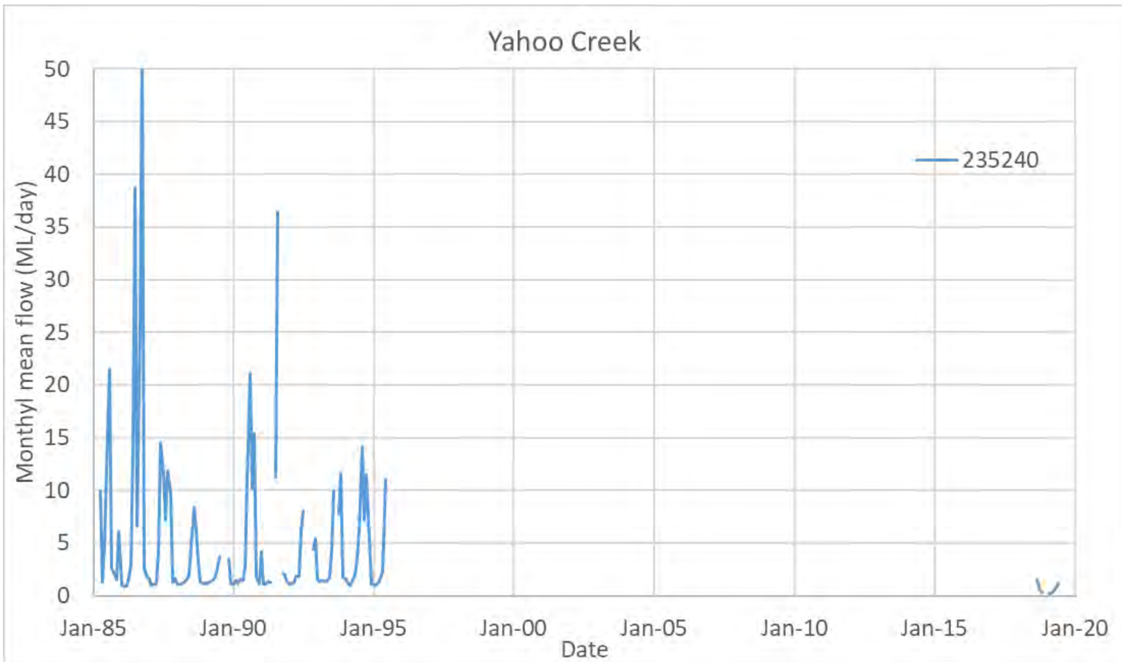
There is currently one surface water gauge located on Yahoo Creek upstream at Kawarren (235240). The flow monitoring record is intermittent (see Figure G.1). The gauge was monitored between 1985 and 1995, and has recently been reactivated. The flow record in the 1980s shows seasonal variations in flow, with flow frequently dropping below 5 ML/day. Flow in 2019 has not been reported above 2 ML/day.

A summary of the gauges is provided in Table G.1 and the locations are shown in Figure 4-11.

Table G.1: Yahoo Creek surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235240	Yahoo Creek at Kawarren	1985 to 1995, 2018 to present	Active
235234	Loves Creek at Gellibrand	1979 to present	Active

Figure G.1: Monthly mean flow - 235240 at Yahoo Creek



G.2 Groundwater monitoring data

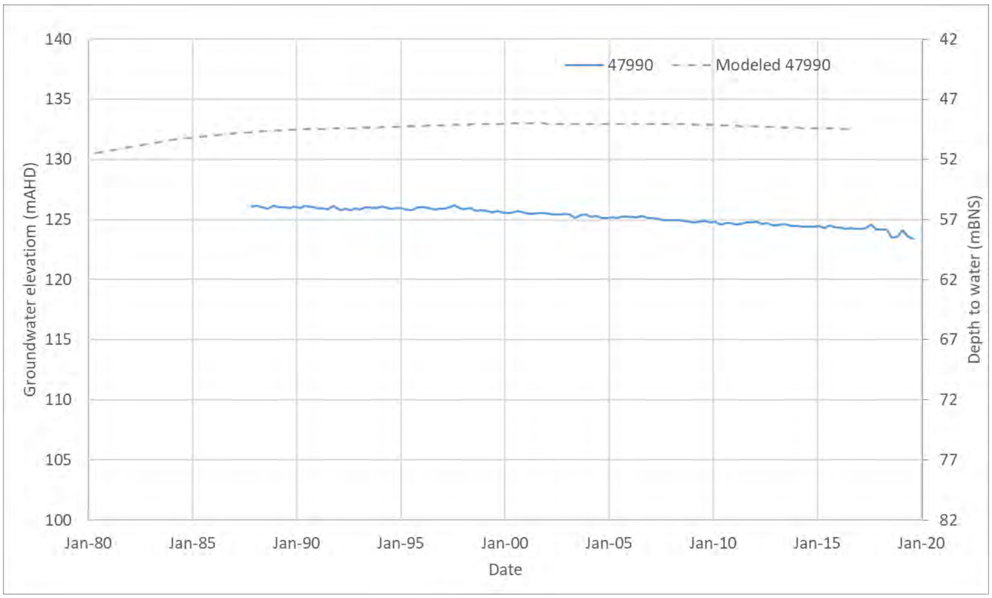
There is one bore located in this part of the study area. Bore 47990 is located north west of the creek and has a monitoring record from 1983 to present. The groundwater level is around 125 mAHD and the depth to water table is around 57 m. The water level trend shows a marginal declining trend.

A summary of bore 47990 is provided in Table G.2 and a hydrograph is provided in Figure G.2. The hydrograph shows that the regional groundwater model predicts the groundwater levels to be 7 m higher at this location and waterlevels are predicted to have risen.

Table G.2: Yahoo Creek groundwater monitoring data

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
47990	LTA	153.0	1983 to 2019	Active

Figure G.2: Groundwater hydrograph – bore 47990



Appendix H. Vegetation

H.1 West of the graben

There are no groundwater monitoring bores located in the areas of high risk, however there are five bores monitoring the LTA at depths ranging between 85 and 306 m around the area. The are no bores monitoring the watertable aquifer. The locations of all groundwater monitoring bores are shown in Figure 5-2.

Bore 62578 is located in the south west and is the shallowest bore at 85 m deep. The bore shows a subdued response to pumping from Barwon Downs and groundwater levels are currently 2 m lower than groundwater levels in the mid-1990s. The depth to water table is around 25 m.

Bore 109133 is also located in the south and monitors the LTA at around 221 m depth. Groundwater levels in the LTA at this location have declined in response to pumping and are currently 10 m lower than groundwater levels in the late 1980s. The depth to water table is around 60 m.

Bores 109134 and 109135 are located in the middle of the area of interest. Bore 109134 is 156 m deep and no longer monitored. Bore 10195 is 237 m deep and shows an interesting groundwater trend that warrants further investigation. The groundwater levels declined in response to pumping but showed a strong recovery and in 2018 groundwater levels were above their pre-pumping levels. However groundwater levels recorded in 2019 have shown a sharp decline and the accuracy of these measurements will need further investigation.

Bore 109114 is located close to the north western boundary of the model and monitors the LTA at a depth of around 300 m. Groundwater levels in the LTA show a strong response to pumping and are currently 10 m lower than their pre-pumping levels.

Bores PASS1 and PASS3 are located in the Boundary Creek catchment. PASS1 is a shallow bore monitoring the alluvial aquifer, located on the northern floodplain of Boundary Creek approximately 1 km upstream of its confluence with the Barwon River (Jacobs, 2017b). The depth to water is shallow (within 2 m of the surface) and groundwater levels show seasonal fluctuations. The regional groundwater model predicts groundwater level are almost 10 m higher than observed with no seasonal fluctuations.

PASS3 monitors the alluvial aquifer along a tributary to Boundary Creek (Jacobs, 2017b). The depth to water is shallow (within 2 m of the surface) and groundwater levels show seasonal fluctuations. While the regional groundwater model predicts groundwater level are with 2 m of the observed levels, the observed seasonal fluctuations are not represented in the model.

This monitoring highlights that groundwater levels in the LTA across this area are influenced by pumping from Barwon Downs. However there is no information to understand the impacts on groundwater levels in the MTD and limited information on the alluvial aquifers. PASS monitoring bores indicate that the groundwater level in the alluvial aquifer is shallow which suggest this alluvial aquifer has not been influence by pumping.

Table H.1: Groundwater bores – West of the graben

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
PASS 1	Quaternary alluvium	10.0	2015 – 2017	Active
PASS 3	Quaternary alluvium	10.0	2015 - 2016	Active
62578	LTA	85.0	1986 - 2019	Active
109114	LTA	308.5	1984 - 2019	Active
109133	LTA	211.5	1986 - 2019	Active
109134	LTA	156.0	1986 - 2008	Inactive
109135	LTA	237.0	1986 - 2019	Active

Figure H.1: Groundwater hydrograph – bore 62578

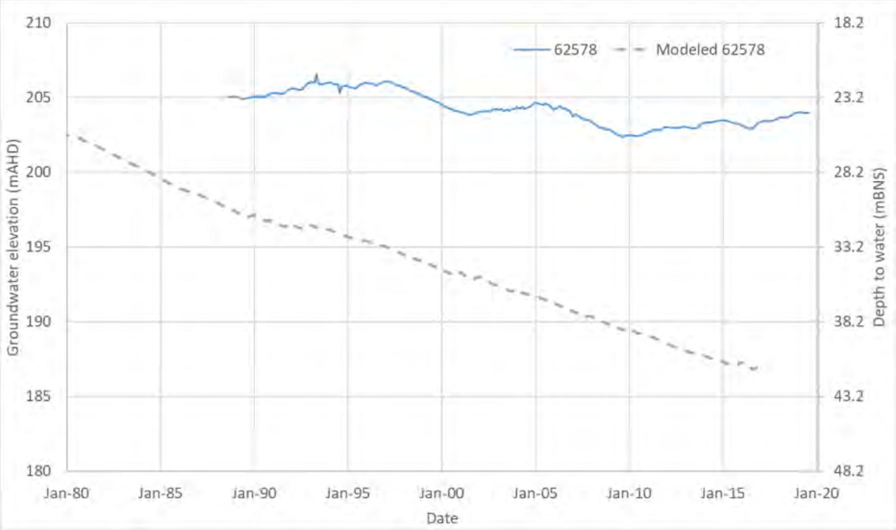


Figure H.2: Groundwater hydrograph – bore 109114

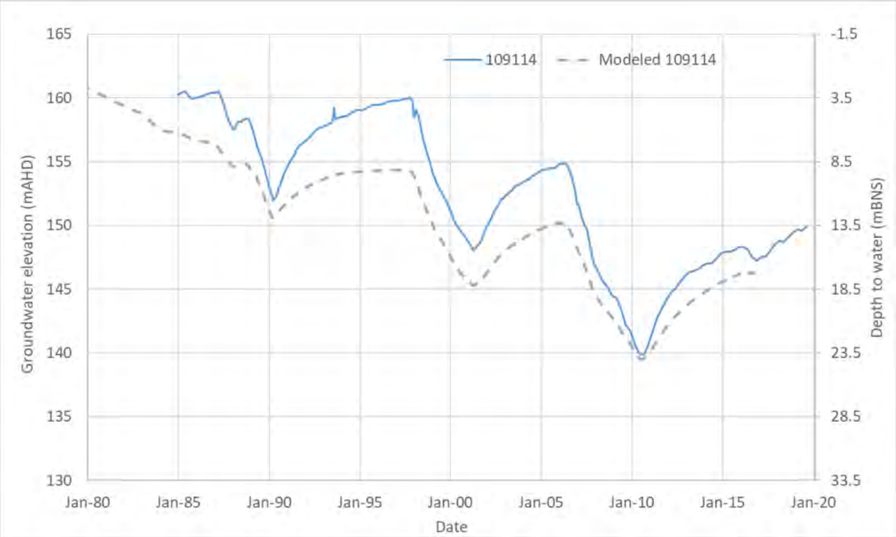


Figure H.3: Groundwater hydrograph – bore 109133

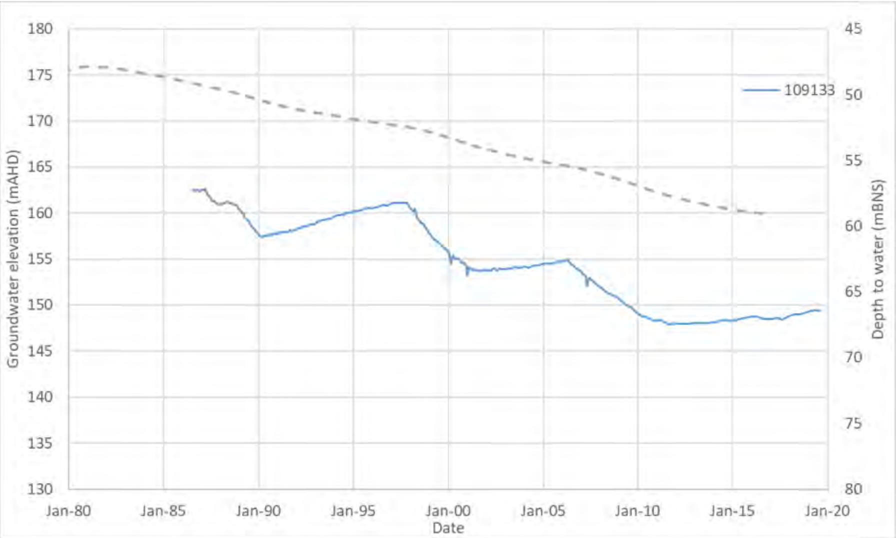


Figure H.4: Groundwater hydrograph – bore 109135

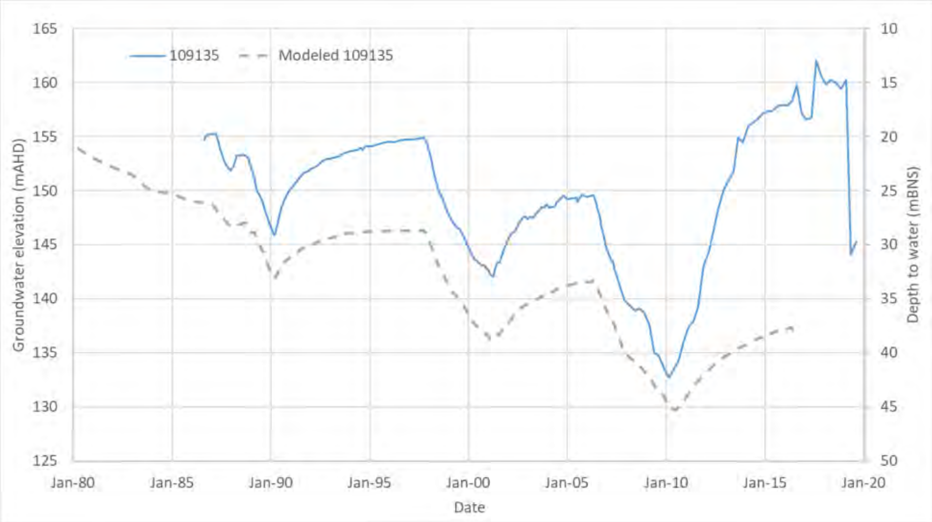


Figure H.5: Groundwater hydrograph – bore PASS 1

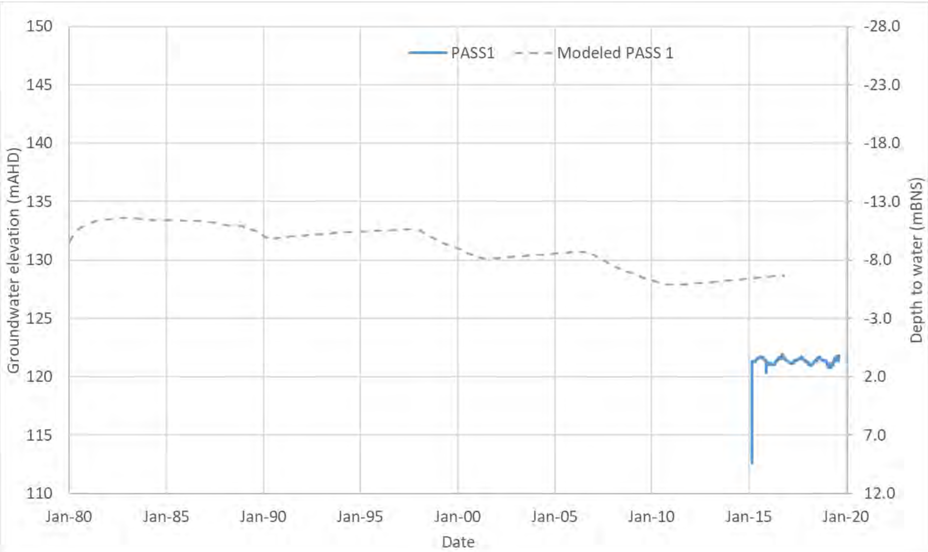
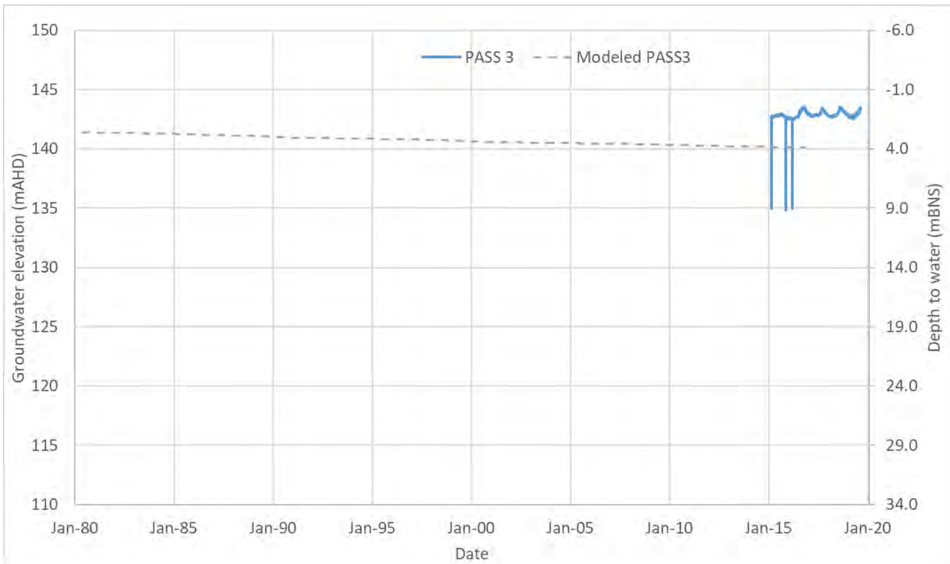


Figure H.6: Groundwater hydrograph – bore PASS 3



H.2 East of the graben

There are 22 groundwater monitoring bores scattered across this area and 17 of these are currently monitored. The bores are all deep bores monitoring the LTA at depths ranging between 117 and 610 m.

Bores 82845, 82846 and 82847 are all monitoring the LTA in the Bambra Fault zone at depths ranging between 114 and 226 m. Bore 82847 is located closest to the Barwon Downs borefield, followed by bore 82845 and 82846 respectively. Groundwater levels in bores 82845 and 82847 are influenced by pumping, and groundwater levels are around 10 m lower than the levels recorded in the 1980s. Bore 82846 shows only a very marginal decline in groundwater levels over the monitoring period (1-2 m).

Bore 82843 monitors the confined LTA on the north western side of the Bambra Fault zone. The groundwater levels are strongly influenced by pumping from Barwon Downs in this location. Although groundwater levels are around 10-15 m lower than the 1980s levels, the aquifer is artesian at this location with groundwater levels recently recorded about 5 m above ground surface.

Bores 82838, 82840 and 82841 are nested bores monitoring the confined LTA at different depths. These bores were discussed in detail in Section 5.4, as they are located close to the Barwon River. The groundwater levels in the deeper bores (82840 and 82841) are strongly influenced by pumping, while the shallower bore (82838) shows a stronger seasonal response and much less drawdown. A condition assessment is required on bore 82838 as the recent water levels are questionable and also make it difficult to assess the vertical gradient in the LTA at this location.

Bores 82844 and 102869 also monitors the confined LTA in the centre of the graben. Bore 82844 is no longer monitored, but did show a strong response to pumping until 2010 when monitoring ceased. Bore 102869 also shows a strong response to pumping and levels are around 5 m below water levels recorded in the 1980s. The aquifer is marginally artesian with current water levels about 1 m above ground surface.

PASS4 is located on the eastern floodplain of Yan Yan Gurt Creek (Jacobs, 2017b). The bore monitors the shallow MTD and groundwater levels in this bore are artesian. This suggests there is an upward gradient at this location supported by groundwater pressures in the MTD.

Table H.2: Groundwater bores – East of graben

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Comments?
PASS 4	Alluvial	8.0	2015 – 2017	Active (datalogger)
47771	LTA	345.0	Nov-1985 to Aug-2019	Active
47773	LTA	297.5	Sep-1986 to Aug-2019	Active
47774	LTA	222.5	Dec-1987 to Aug-2019	Active
47775	LTA	381.2	Dec-1988 to Aug-2019	Active
48249	LTA	135.3	Oct-1982 to Aug-2019	Active
82838	LTA	285.1	Jan-1974 to Aug-2019	Active
82840	LTA	610.8	Dec-1973 to Aug-2019	Active
82841	LTA	484.6	Jun-1974 to Aug-2019	Active
82842	LTA	385.5	Nov-1985 to Aug-2008	Inactive
82843	LTA	462.0	Apr-1986 to Aug-2019	Active
82844	LTA	233.0	Mar-1985 to Nov-2007	Inactive
82845	LTA	226.0	Jan-1986 to Aug-2019	Active

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Comments?
82846	LTA	131.0	Apr-1986 to Aug-2019	Active
82847	LTA	117.0	May-1986 to Aug-2019	Active
82848	LTA	352.6	Jul-1985 to May-1997	Inactive
102865	LTA	435.9	Dec-1973 to Nov-2011	Inactive
102867	LTA	281.6	Dec-1973 to Sep-2008	Inactive
102868	LTA	577.0	May-1984 to Aug-2019	Active
102869	LTA	431.0	Jan-1986 to Aug-2019	Active
107716	LTA	254.0	Dec-1987 to May-2016	Inactive
107717	LTA	193.5	Dec-1987 to Aug-2019	Active
107720	LTA	259.0	Dec-1988 to Aug-2019	Active

Figure H.7: Groundwater hydrograph – bore 47771

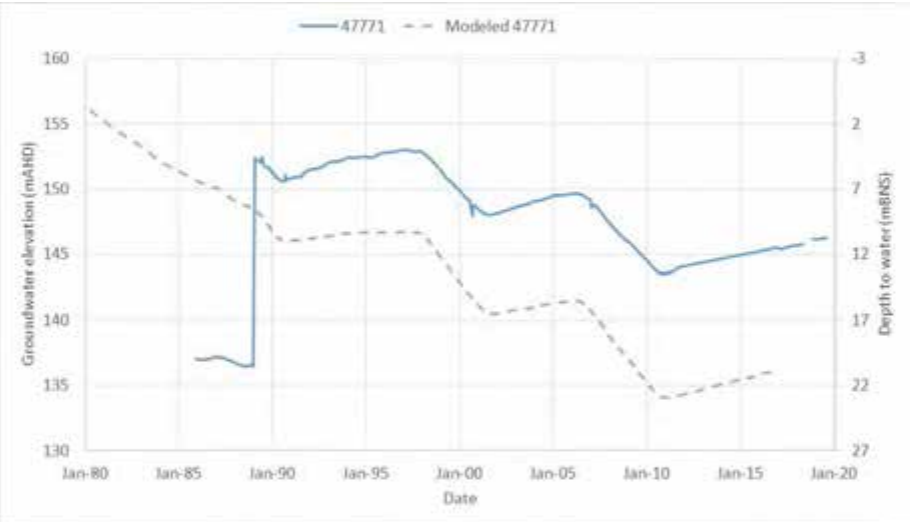


Figure H.8: Groundwater hydrograph – bore 47773

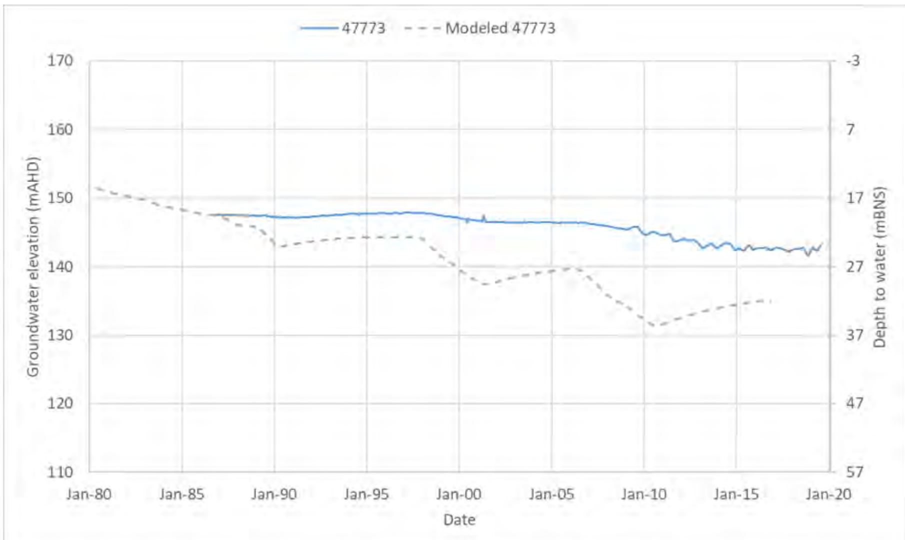


Figure H.9: Groundwater hydrograph – bore 47774

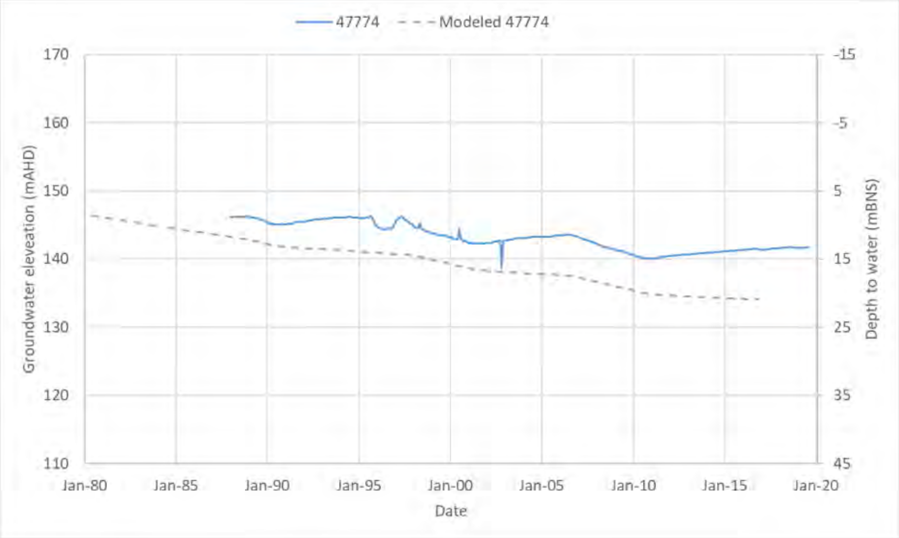


Figure H.10: Groundwater hydrograph – bore 47775

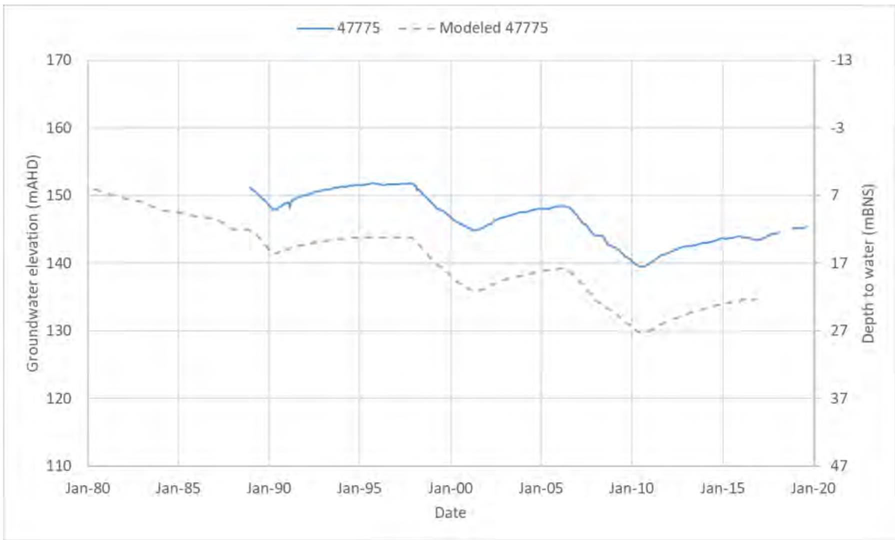


Figure H.11: Groundwater hydrograph – bore 82838

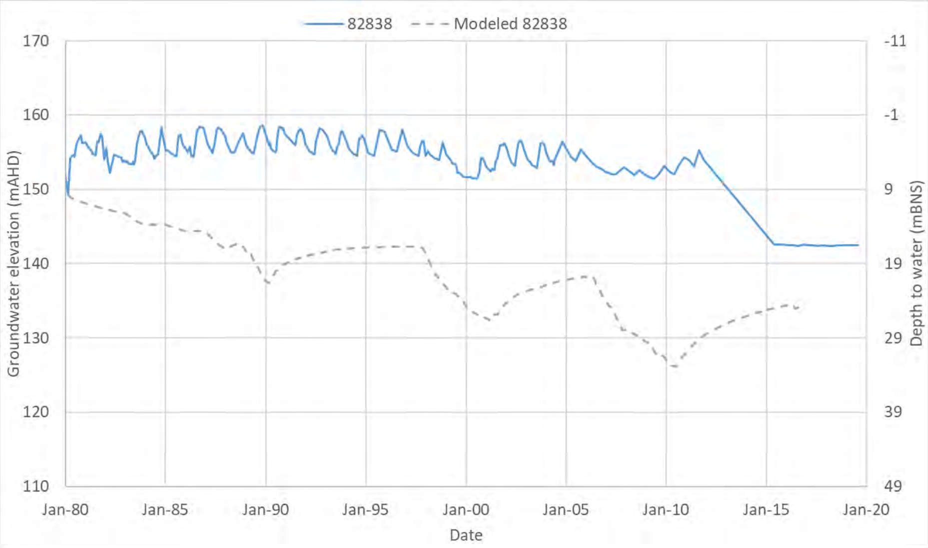


Figure H.12: Groundwater hydrograph – bore 82840

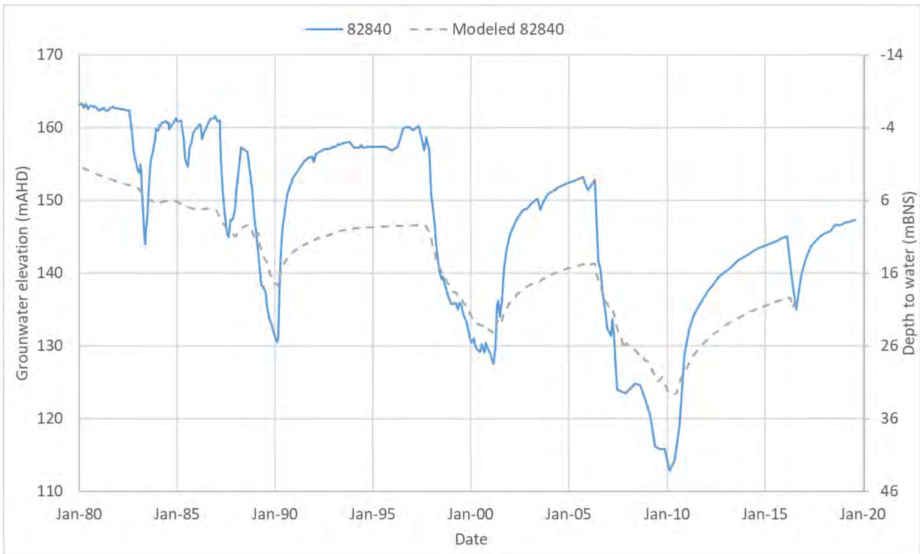


Figure H.13: Groundwater hydrograph – bore 82841

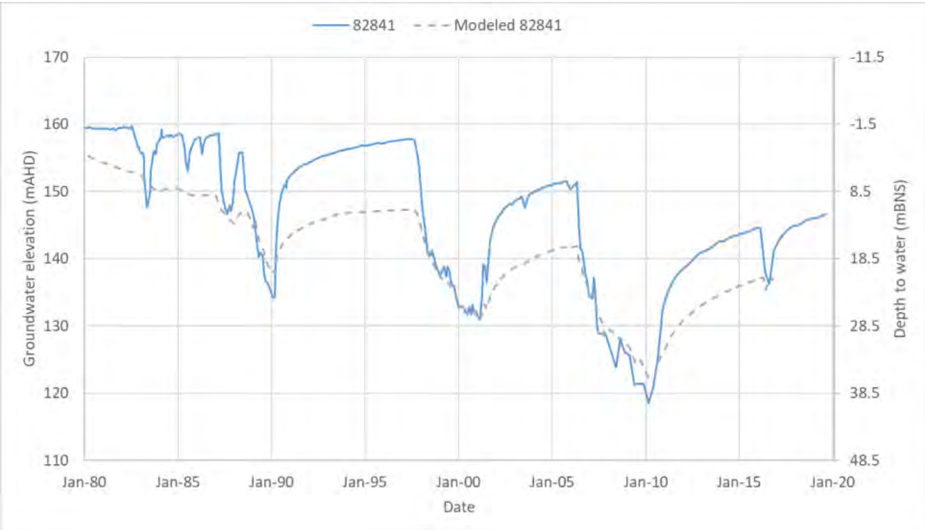


Figure H.14: Groundwater hydrograph – bore 82843

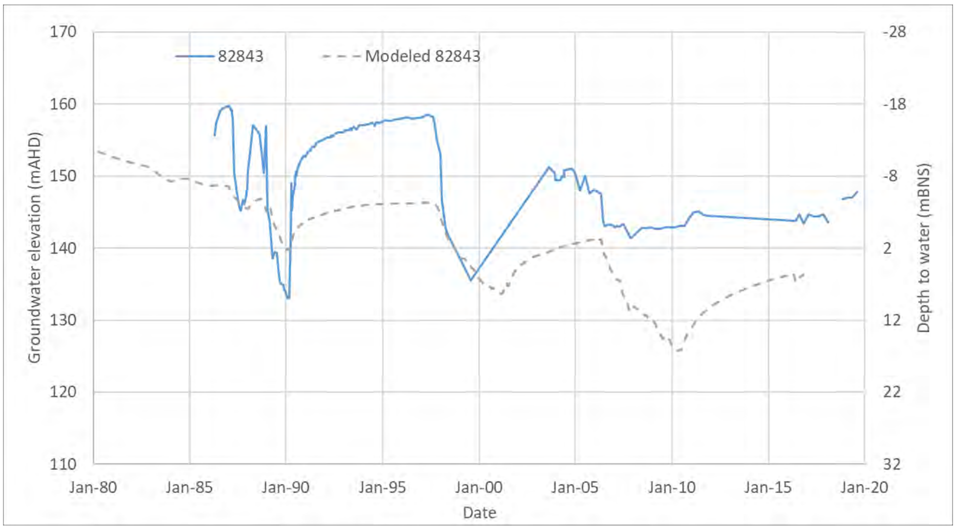


Figure H.15: Groundwater hydrograph – bore 82845

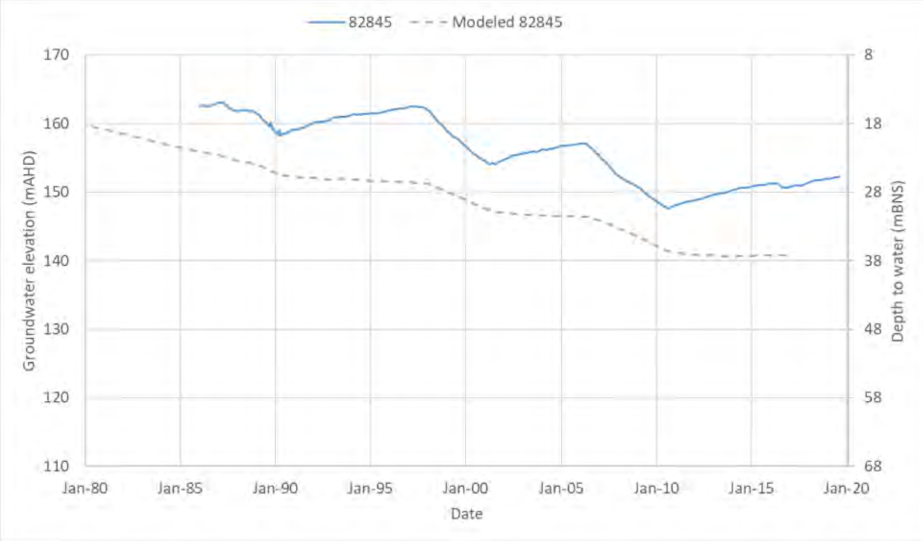


Figure H.16: Groundwater hydrograph – bore 82846

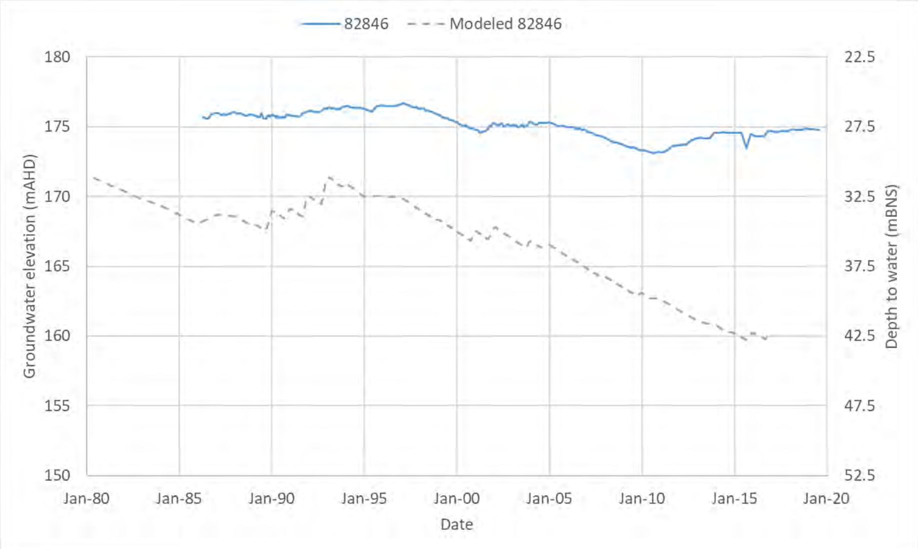


Figure H.17: Groundwater hydrograph – bore 82847

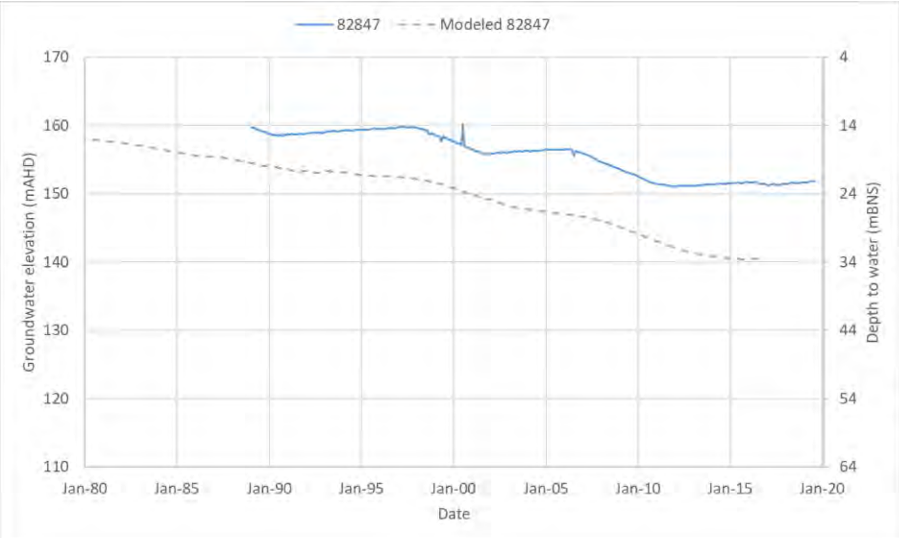


Figure H.18: Groundwater hydrograph – bore 102868

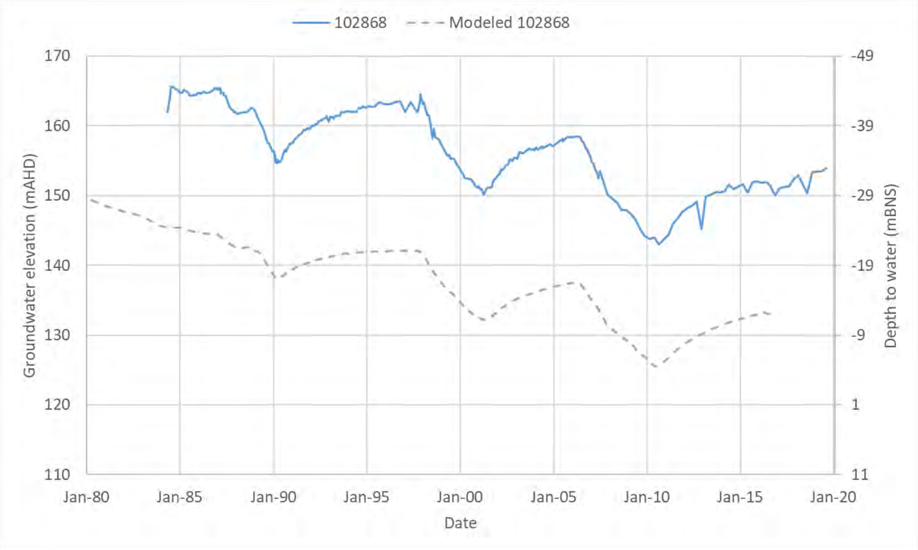


Figure H.19: Groundwater hydrograph – bore 102869

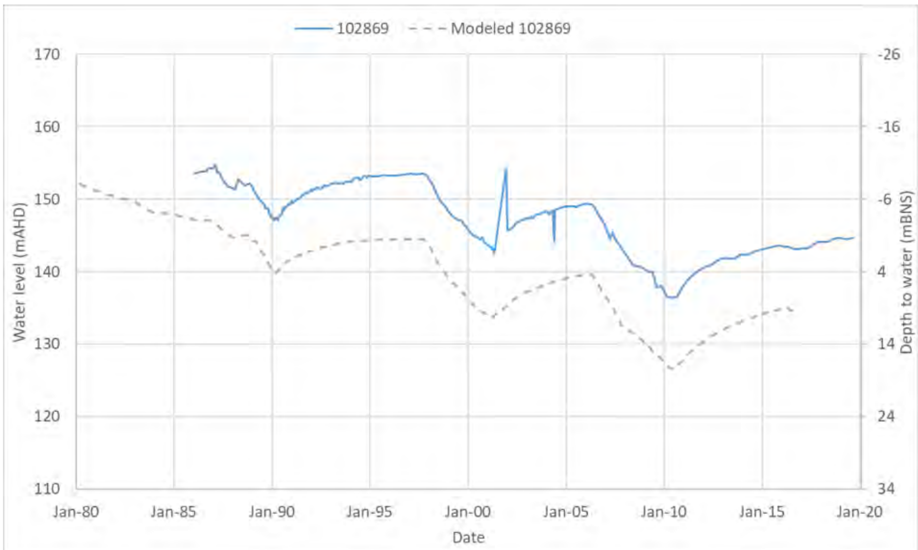
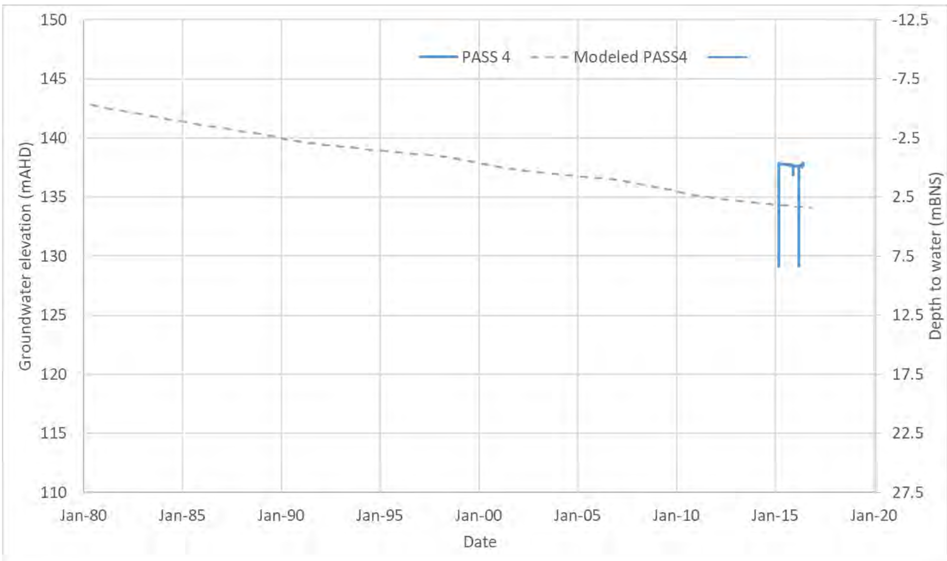


Figure H.20: Groundwater hydrograph – bore PASS 4



H.3 South of the graben

As previously noted in Appendix E, there is only one bore currently monitored on the northern side of the Gellibrand River. The waterlevels in this bore are influenced by seasonal fluctuations and show a marginal decline over the monitoring period. The groundwater model represents the waterlevel in this bore reasonably well.

Table H.3: Groundwater bores around Gellibrand (north and south of the river)

Bore	Aquifer monitored	Location	Bore depth	Monitoring record	Current status
108916	Shallow LTA*	North of river	14.9	1981 to 2011	Inactive
108917	Shallow LTA*	North of river	15.0	1981 to 2013	Inactive
108918	Shallow LTA*	North of river	15.3	1981 to 1994	Inactive
108919	Shallow LTA*	North of river	16.6	1981 to 2011	Inactive
108920	Shallow LTA*	North of river	18.0	1981 to 1998	Inactive
108898	LTA	North of river	272.0	1981 to 2013	Inactive
108899	LTA	North of river	34.0	1981 to 2013	Inactive
108958	Unknown	North of river	N/A	1979 to 1985	Inactive
108959	Unknown	North of river	N/A	1979 to 1983	Inactive
108960	Unknown	North of river	N/A	1979 to 1985	Inactive
108961	Unknown	North of river	N/A	1979 to 1985	Inactive
108907	Unknown	North of river	362.5	1982 to 2019	Active
116489	Unknown	North of river	210.0	1993 to 2011	Inactive
108897	Unknown	South of river	86.0	1981 to 2019	Active
108921	Unknown	South of river	19.7	1981 to 2000	Inactive
108922	Unknown	South of river	20.2	1981 to 2011	Inactive
108924	Unknown	South of river	16.7	1981 to 2016	Inactive
108925	Unknown	South of river	19.5	1981 to 2016	Inactive
108933	Unknown	South of river	11.7	1982 to 2011	Inactive
108934	Unknown	South of river	12.0	1982 to 2011	Inactive
108935	Unknown	South of river	11.8	1982 to 2011	Inactive
108945	Unknown	South of river	88.7	1979 to 2011	Inactive
108946	Unknown	South of river	40.0	1979 to 2016	Inactive
108947	Unknown	South of river	64.0	1979 to 2011	Inactive
108949	Unknown	South of river	79.0	1979 to 2009	Inactive
110737	Unknown	South of river	42.6	1980 to 2011	Inactive

Figure H.21: Groundwater hydrograph – bore 108907

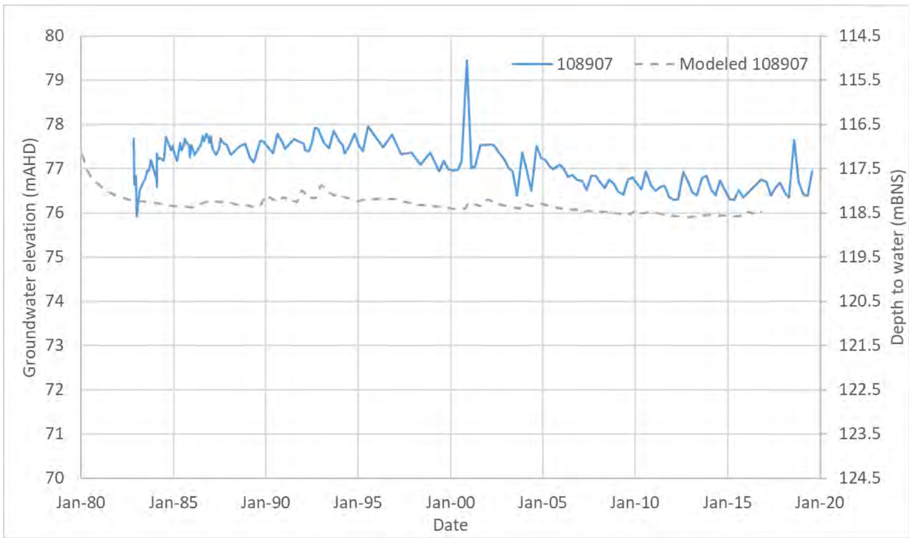


Figure H.22: Groundwater hydrograph – bore 108922

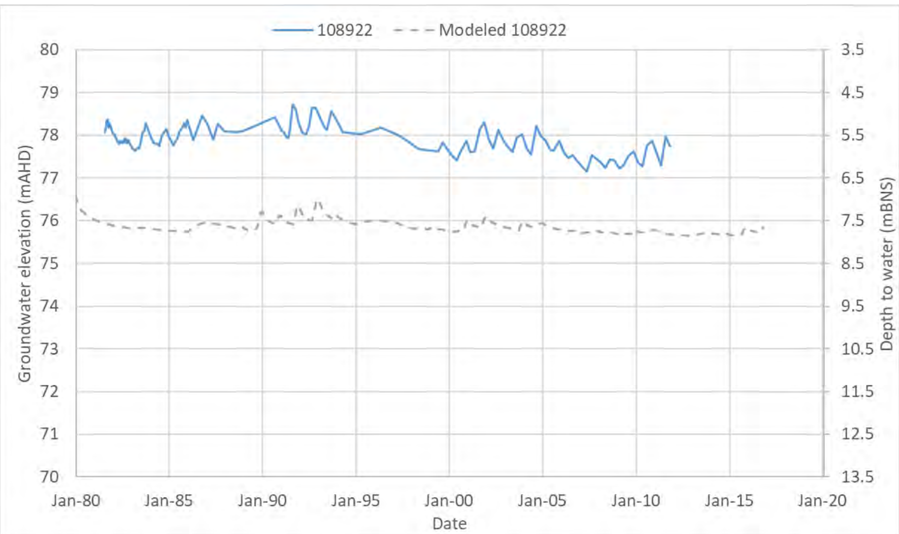


Figure H.23: Groundwater hydrograph – bore 108924

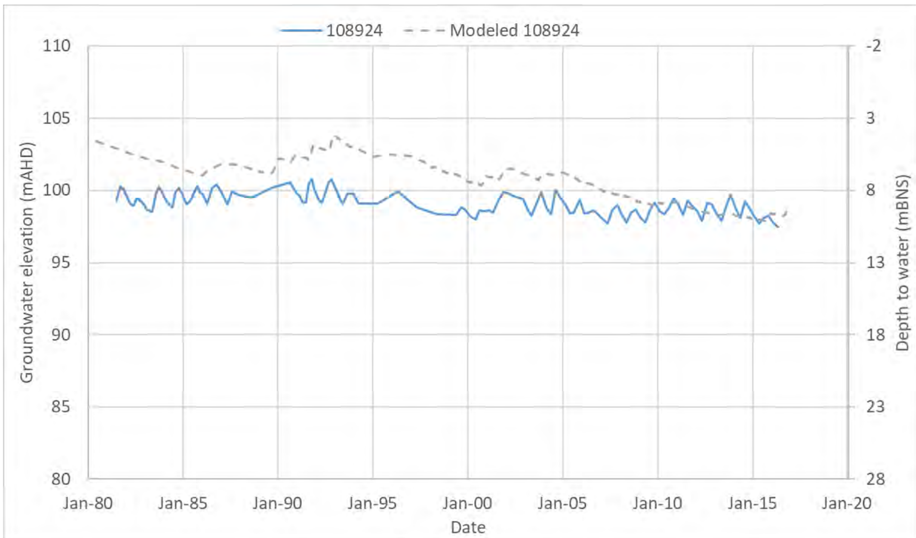


Figure H.24: Groundwater hydrograph – bore 108933

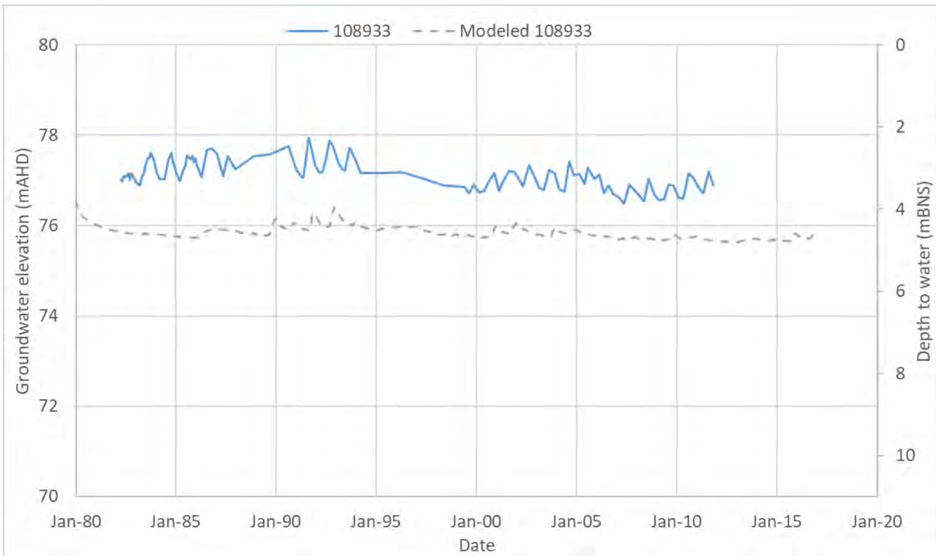


Figure H.25: Groundwater hydrograph – bore 108935

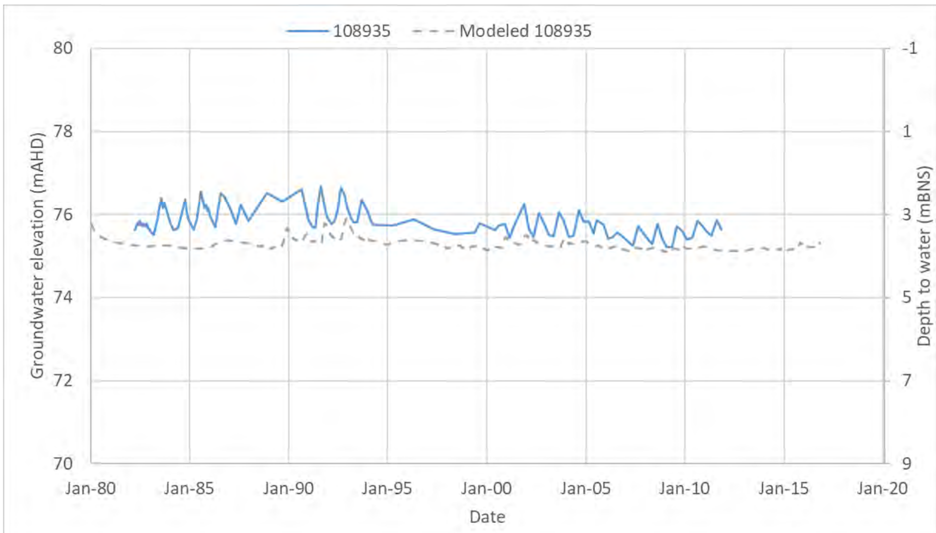


Figure H.26: Groundwater hydrograph – bore 108946

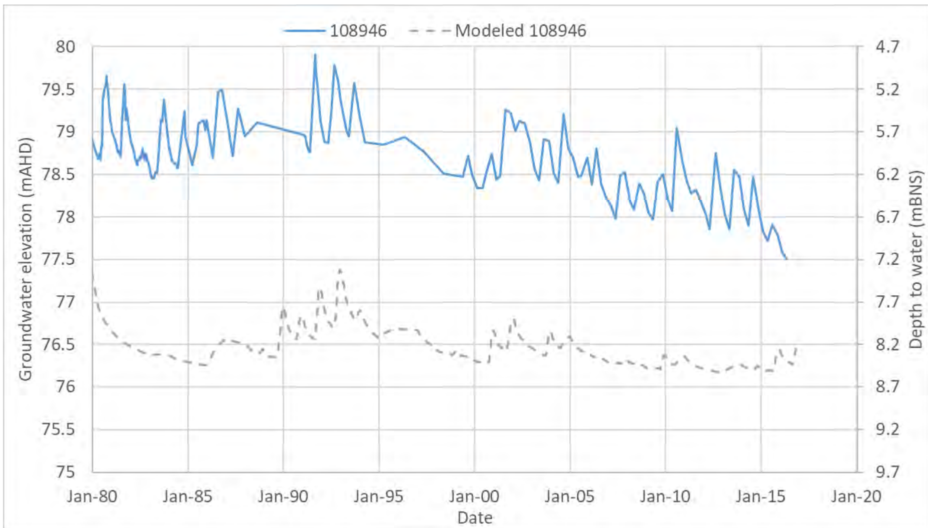


Figure H.27: Groundwater hydrograph – bore 108947

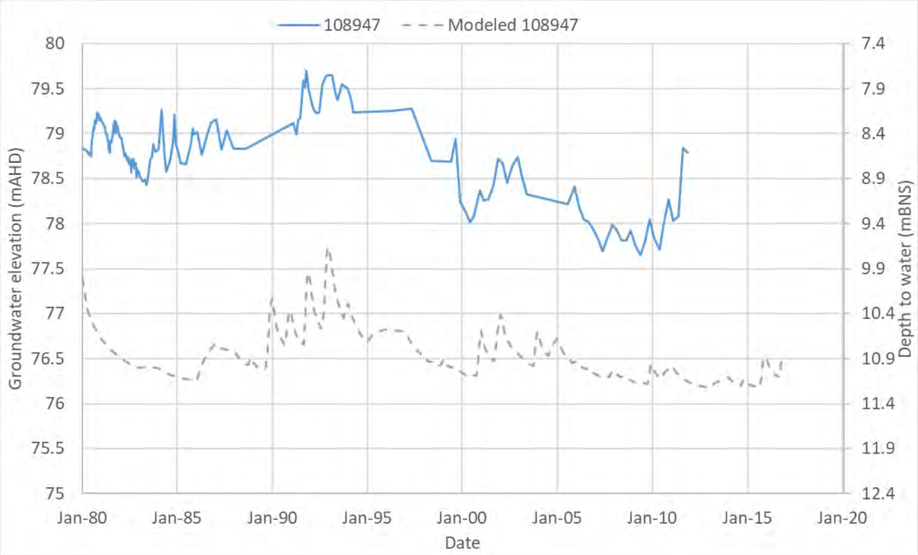
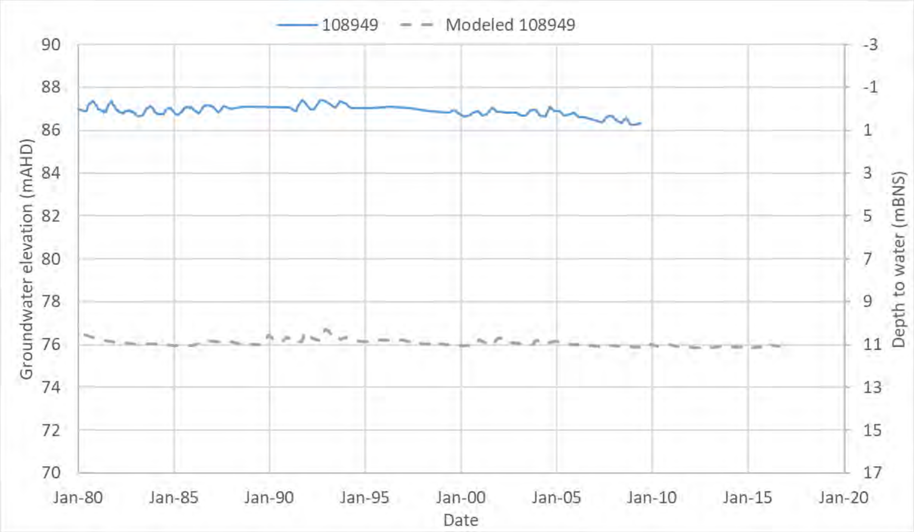


Figure H.28: Groundwater hydrograph - 108949



Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
Clear vision statement about the objectives of the remediation plan.	**Remediation and Environmental Protection Plan vision:** Implementation of practical remediation actions and controls that achieve an improvement to the environment and the community, where measurable and evidence-based scientific methodologies conclude that historical management of groundwater pumping at Barwon Downs Borefield has caused an environmentally significant adverse impact in that area. **Boundary Creek and Big Swamp Remediation vision:** Implementation of a practical remediation strategy that achieves an improvement to the environment and the community, so that: • Big Swamp and Boundary Creek have healthy and sustained ecological systems; • The impacts to the Barwon River are minimised and monitored; and • Fire risks/threats are mitigated **Priorities** were based on the protection of assets with the highest ecological values as well as consideration of the level of effort required to not only remediate damaged reaches but realise the benefits of remediation. Priorities agreed to by the Remediation Working Group and experts involved are: • **Protect** Barwon River (major asset) water quality and ecological values - one of the iconic river systems in Victoria, the Barwon begins in the Otway Ranges and flows through the heart of Geelong on its 160-kilometre journey to meet the sea at Barwon Heads. • **Improve** Boundary Creek stream flow and water quality. • **Improve** Big Swamp ecological values – vegetation communities within Big Swamp are transitioning to dry functional communities but ecosystem function is recoverable for wetland species to recolonise within Big Swamp. To assist in realising the vision for Boundary Creek and Big Swamp, the following six **objectives** were developed and agreed with the Remediation Working Group and experts involved: 1. Maintain groundwater levels above the top of the non-oxidised sediments in Big Swamp (to prevent oxidisation of deeper sediments within the swamp). 2. Control of the acid discharge (i.e. pH, sulfate and metals) from Big Swamp into Boundary Creek.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	3. Maintain at least minimum flows in Reach 3 of Boundary Creek all year round. 4. Manage potential formation of acidity downstream of Big Swamp, which may be triggered as a result of implementation of some remediation options (i.e. swamp inundation). 5. Preserve/improve the ecological values of Big Swamp and Boundary Creek. This objective is focused around addressing the changes to the vegetation assemblages within the swamp post the initial acidic event and fire. The result is a drying of the swamp, creating a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities. 6. Reduce the peat fire risk in Big Swamp.
"Remediation" to be defined	Definition of remediation that Barwon Water has adopted to align with the requirements of the s78 notice and scientifically recognised definitions is: Remediation refers to the controls and actions that could be practicably carried out to improve the ecological condition and function of areas confirmed to have been impacted by historical management of groundwater pumping at Barwon Downs, noting that this is likely to be different to the original condition due to the extent of change since European settlement.
The approach to remediate known issues and/or areas, investigate high risk areas and review moderate risk areas is reasonable, noting that CLG members expressed concern that this approach carries the risk of delaying remediation actions in areas currently identified for either investigation or review	The proposed approach to gather further information before undertaking remedial works is the same as that sought by members of the CLG in relation to remediation of confirmed impacts at Boundary Creek and Big Swamp, where it was requested that further data and modelling be undertaken to fill information gaps before proceeding with remediation. The approach to deliver the REPP under two parallel work packages allows for known impacts to be remediated and knowledge gaps to be filled for other areas before proceeding with remedial works if they are required. **This was supported by the Remediation Working Group as it recognises the need for immediate action to remediate the confirmed impacts within the Boundary Creek catchment and the need to investigate for impacts in the broader aquifer catchment.**

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
The Proposed investigation plans focus on groundwater level and surface water flow monitoring. If other approaches such as water quality, geochemistry or isotope monitoring have been considered (or conversely have not been considered) please provide commentary	The purpose of the Surrounding Environment Investigation is to address the following information gaps: • Has groundwater pumping caused a reduction in baseflow to rivers from the LTA (either directly or indirectly) in areas identified as high risk? If so, how much and is it significant? • Has groundwater pumping caused a decline in watertable in areas where there are high value GDEs? And if so, how much and is it significant? Barwon Water is proposing that five stream gauges and 22 monitoring bores be installed to determine groundwater levels and potential impacts on baseflow contribution to the five high risk rivers and creeks. This was deemed to be the most practicable way to confirm risk. Six vegetation monitoring sites were recommended on the same basis to confirm risk for groundwater dependent ecosystems near Yeodene, Deans Marsh and along the Gellibrand River. Regular review of the progress of the REPP will determine if there is need for additional monitoring such as water quality, geochemistry or isotope monitoring. At this stage, such investigations appear unwarranted until the risk has been confirmed and an estimate of the magnitude of environmental impact from historical groundwater pumping from Barwon Downs has been made. Once the presence and significance of any environmental impacts has been determined further monitoring may be required to inform any remedial actions that may be required.
The uncertainty around the groundwater model remains and as such the Remediation Plan should include actions to update and refine the conceptual and numerical models as more data become available	This point has been noted and refinement of the regional groundwater model and any local models developed has been factored into the REPP. Barwon Water recognises that while the numerical model was fit for purpose to <u>estimate</u> risk from historical management of groundwater pumping for the regional groundwater system, it is limited in its ability to represent detail of localised systems. For example, the numerical model does not include the alluvial aquifer as it is not continuous across the study area and the nature of the alluvial aquifer is highly variable where it is present.

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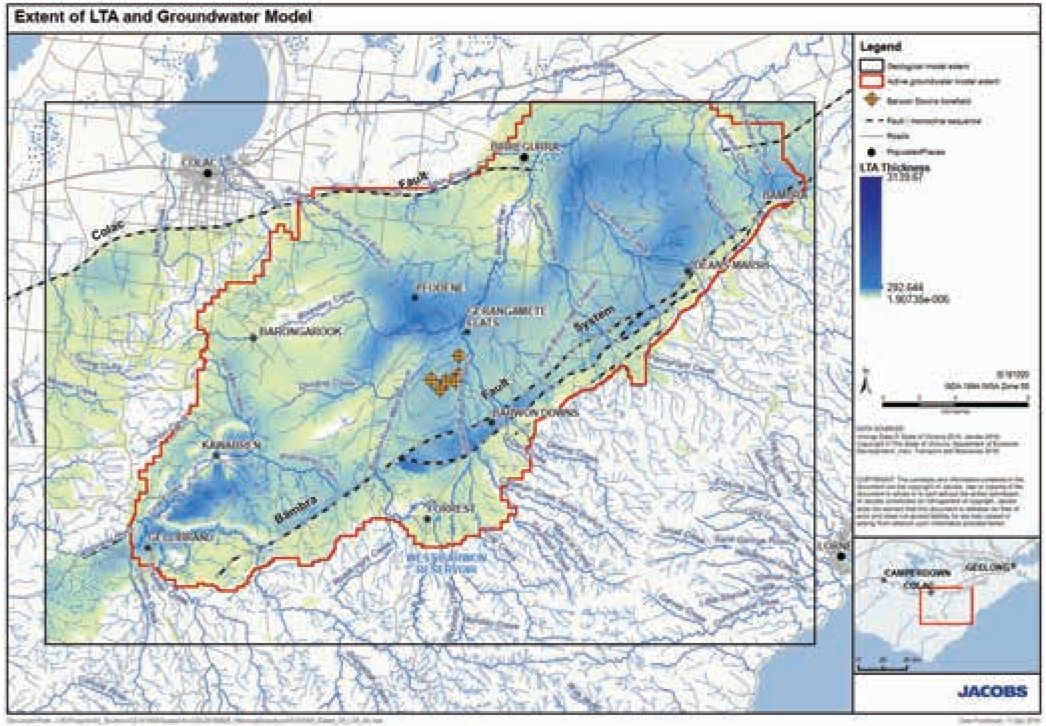
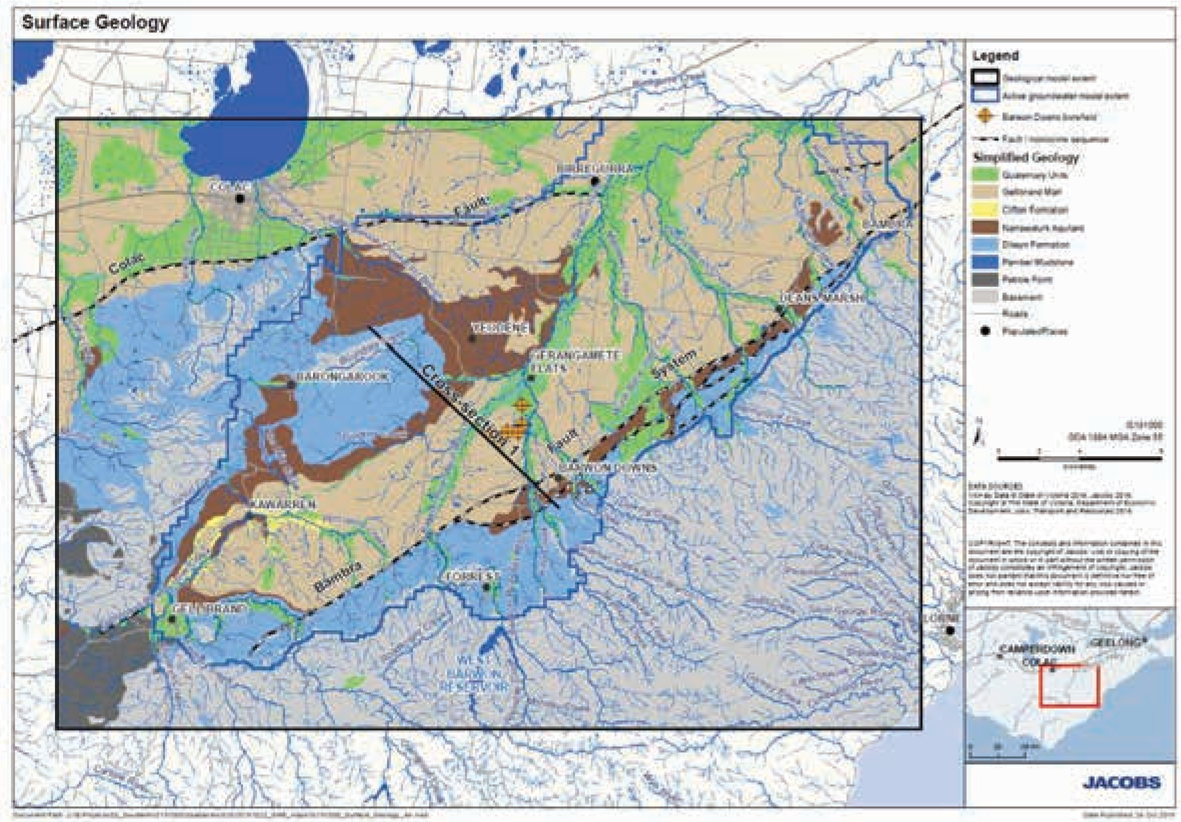
	Considering the feedback of SRW and the ITRP, Barwon Water developed groundwater, surface water and geochemical models to inform the Boundary Creek and Big Swamp Remediation Plan to better represent site specific conditions. Barwon Water does acknowledge that while the models that were developed have played a critical role in informing selection of a preferred remediation option, they are constrained by the limited data sets available for calibration which do not yet capture a full seasonal cycle due to their recent installation (field program concluded in June 2019). Likewise, hydrogeological information and groundwater and surface water monitoring data associated with the investigations proposed for the areas of high risk will be used to refine the conceptual understanding of these areas. Further, and if warranted, additional numerical groundwater modelling will be undertaken to better quantify impacts from historical groundwater extraction, if remediation is necessary and if so, what actions may be suitable. The REPP is based on an adaptive management approach. Under the monitoring and assessment program, Barwon Water proposes to update and calibrate the groundwater, surface water and geochemical models after a 12-month period of data collection (i.e. post May 2020) to capture a full season including the low flow period to inform the detailed design of the Remediation Plan (i.e. placement of hydraulic barriers to distribute surface water flows considering the secondary objective of reintroducing conditions for wetland species to recolonise). Beyond implementation of the Remediation Plan, Barwon Water proposes that the update and calibration of these models occur in line with recommendations as per the 2012 *Australian Groundwater Modelling Guidelines*.
Following the previous point, the risk assessment is based exclusively on the groundwater model and as such should be revisited when the model is updated	This point is noted and revisiting the risk assessment has been captured within the REPP. Barwon Water recognises that while the numerical model was fit for purpose to estimate risk from historical management of groundwater pumping for the regional groundwater system, additional monitoring data is required for potential high risk areas to confirm risks predicted by the regional groundwater model.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	After 12 months of data is collected, analysis will aim to confirm the following: • Presence and thickness of an alluvial aquifer • Surface water flows and levels in the river • Groundwater levels in the alluvial aquifer, LTA or MTD • Vertical gradients between aquifers and rivers. • Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers) • Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS) This information will feed into a decision as to whether the regional groundwater model is considered adequate for update and recalibration or if required, local hydrogeological models will be developed. Following this, a review of the risk assessment will be undertaken to verify that the current risk ranking of '**high**' allocated to the eight areas remain the same before proceeding with any investigations for potential '**medium**' risk areas. For further information, refer to Jacobs (2019) Investigation Plan for areas of Potential High Risk.
The ITRP strongly recommends that the delineation of the Boundary Creek reaches (in Figure 9) be revised to specifically match the geology and hydrogeology (i.e. Reach 1 should end at the eastern extent of the basement outcrop, where Reach 2 should start, contrary to the current arrangement)	Barwon Water understands and acknowledges the technical reasoning for this approach to defining the different reaches of Boundary Creek. Given the remediation of Boundary Creek and Big Swamp is based on management of surface water flows, for ease of explanation and understanding of the community Barwon Water will be defining the reaches of Boundary Creek based on surface water features.

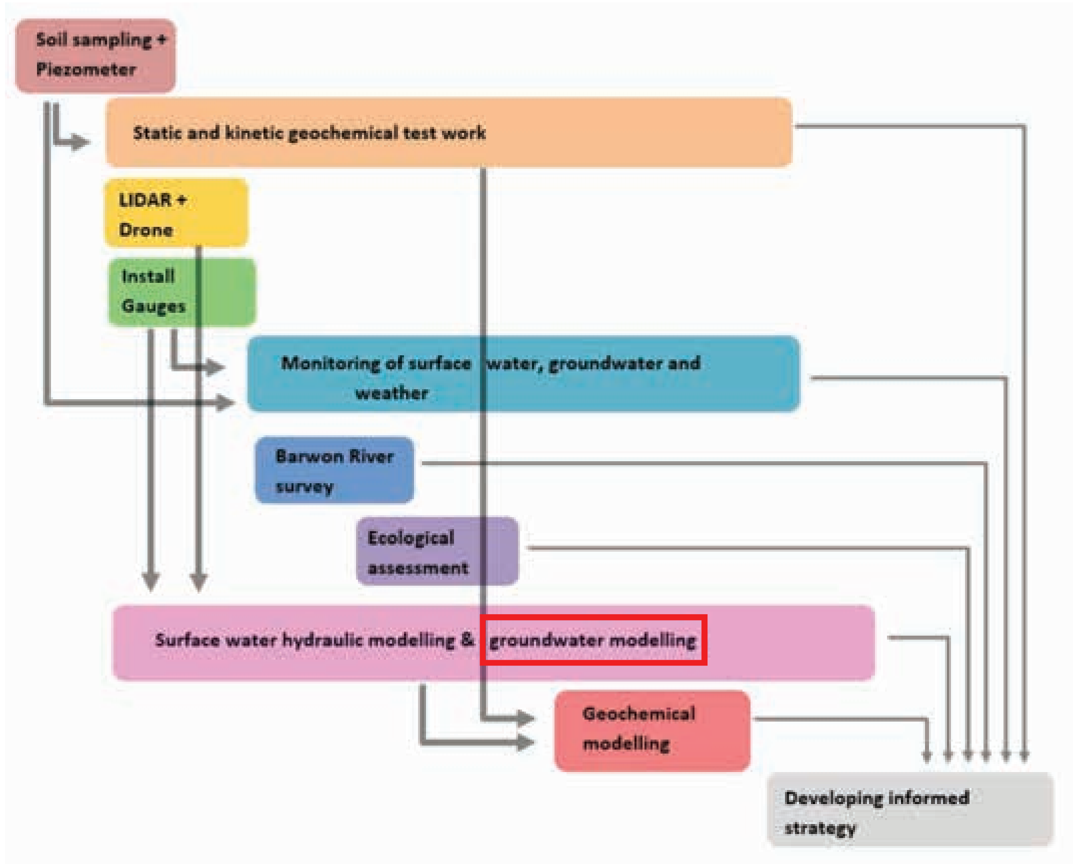
Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	While surface water reaches of Boundary Creek do not completely align with the underlying hydrogeological settings, for simplicity and to aid community understanding, the following classifications have been applied. **Reach 1** – This is the upper reach of the creek, flowing predominantly over outcropping bedrock which comprises impermeable Palaeozoic sandstone, siltstone and mudstone. The downstream end of Reach 1 is defined by 'McDonalds Dam', a large on-stream private irrigation water storage (160 ML capacity) that was constructed in 1979. Supplementary flows by Barwon Water are released into a small tributary that joins Boundary Creek in Reach 1, upstream of 'McDonalds Dam'. **Reach 2** – From the outlet of 'McDonalds Dam' to the downstream end of Big Swamp, flowing predominantly over the outcropping LTA comprising permeable sands of the Mepunga, Dilwyn and Pebble Point formations. This reach can be further subdivided into three sub-reaches: • Reach 2a, a likely artificial channelised section immediately downstream of 'McDonalds Dam'. • Reach 2b, a densely vegetated and marshy area known as the 'damplands' characterised by highly braided flow pathways and waterlogged conditions. • Reach 2c, corresponding to Big Swamp, a large peat swamp covering an area of approximately 11 hectares. **Reach 3**- Downstream of Yeodene Swamp to the confluence with the Barwon River, flowing over the outcropping Mid-Tertiary Aquitard (MTD) comprising the silty clays of the Gellibrand Marl. This reach has been modified to support agricultural activity. It is recognised that these reaches could equally be separated solely according to their hydrogeological characteristics. If this were the case, the boundary between Reach 1 and Reach 2 would be located approximately 600 m upstream of "McDonalds Dam", at the boundary between the outcropping LTA and Basement. However, to prevent confusion between naming conventions and remain consistent throughout reporting, formal revision to the reaches as defined above has not been adopted in this document, with the recognition that a proportion of Reach 1 overlies the LTA.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
The exclusion of the LTA near Deans Marsh from the groundwater model domain is not justified, given previous work indicated the impacts of pumping were measured by significant drawdown in this area.	The groundwater model domain was informed by the thickness and extent of the LTA. The reviewers correctly indicate that the LTA does extend beyond the numerical groundwater model domain, It also begins to thin considerably in this area and therefore at the time it was considered reasonable to bound the model accordingly (see figure below). In addition, a number of revisions to the hydrogeological conceptualisation of this area have been made since Witebslky (1995), based on more data and information, and subsequently the Dilwyn Formation is no longer considered to outcrop in this region (see second figure below). The reviewers also correctly point out that drawdown has been observed in the LTA in this area historically, with bore 107717 exhibiting groundwater levels up to 2.5 m lower than those observed in 1987. As a result, modelling has indicated medium and high risks to groundwater receptors in the Deans Marsh area. These have been prioritised for further investigation. If these investigations confirm that historical groundwater extraction has resulted in a high risk to groundwater receptors in this area, the regional groundwater model will be updated and recalibrated, or if required, a local hydrogeological model will be developed.

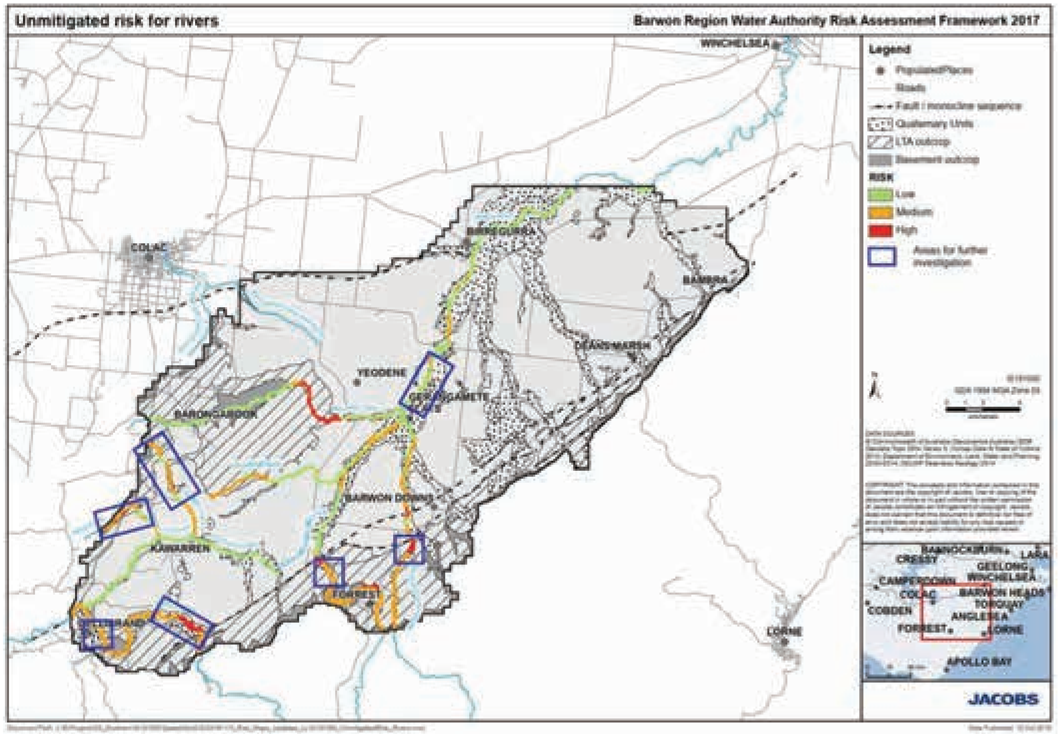
Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	
Groundwater modelling should be included as a key activity alongside monitoring in the adaptive management framework	Groundwater modelling was included in the scope of works and will be a critical component of the REPP. Groundwater modelling will be included in the REPP along with surface water modelling and geochemical modelling as activities alongside monitoring in the adaptive management framework. This includes consideration for additional groundwater modelling associated with the investigation of areas of high risk.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	The REPP is based on an adaptive management approach. Under the monitoring and assessment program, Barwon Water proposes to update and calibrate the local groundwater, surface water and geochemical models after a 12-month period of data collection (i.e. post May 2020) to capture a full season including the low flow period to inform the detailed design of the Remediation Plan (i.e. placement of hydraulic barriers to distribute surface water flows considering the secondary objective of reintroducing conditions for wetland species to recolonise). Beyond implementation of the Remediation Plan, Barwon Water proposes that the update and calibration of these models occur in line with recommendations as per the 2012 *Australian Groundwater Modelling Guidelines*.
Omission of groundwater modelling in the key activities (Figure 13, page 66)	Noted. Groundwater modelling was a key component of the scope of works that did not appear on the key activities figure included in the Scope of Works. The diagram has been rectified to show groundwater modelling as a key component. Refer to red box in revised diagram below.

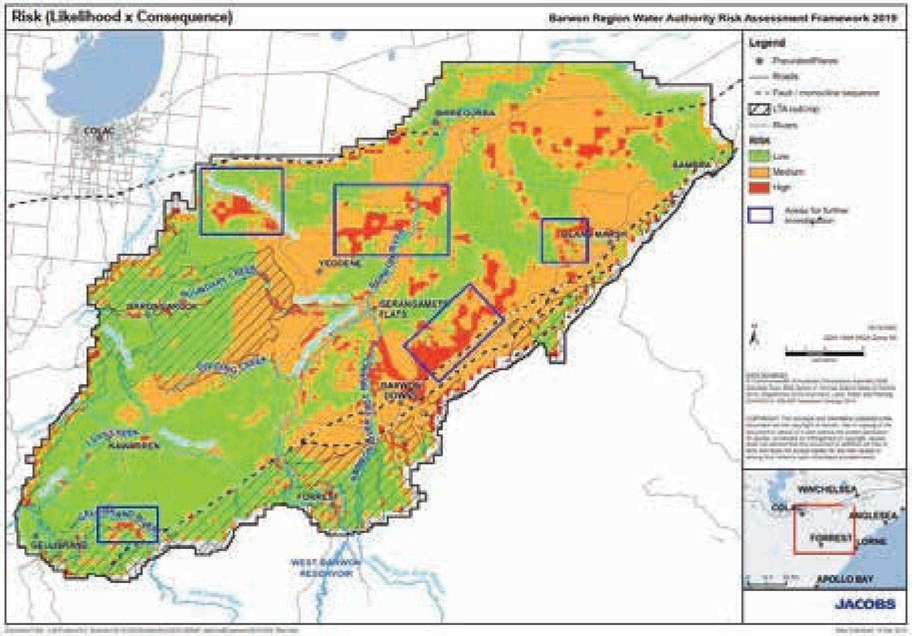
Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	
It is recommended that the consequences in the risk equation (page 43, table 6) be separated into two components, one for springs, seeps, or swamp vegetation (hydrophytes) and the other riparian and terrestrial vegetation (phreatophytes). Hydrophytes are considered sensitive to water table declines whereas phreatophytes can generally tolerate greater	The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) were used to assess the risk to vegetation and are specifically intended to be applied for high value GDEs.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
ranges depending on factors including the depth to watertable and its diurnal and seasonal variations, and the vegetation species, assemblages, rooting depths and abilities to respond to water table variations.	The different vegetation types will be assessed during the investigation of high risk GDE's and the outcomes will be used to inform re-assessment of risk and consideration of other areas for investigation.
It should be clarified whether only the sections of the waterways shown as high and medium risk on the map are the subject of investigation, or the entire stream as implied by the tables and later in Figure 12.	The investigations proposed include groundwater monitoring, the location at which has been specifically selected along high and medium risk reaches to verify the potential impacts historical groundwater extraction has had on groundwater levels in these areas. The locations for streamflow gauges have also been selected to characterise potential impacts on baseflow related to groundwater extraction, where the risks of impact related to extraction are greatest (see figure below). While the highlighted areas below indicate the locations at which groundwater and streamflow monitoring are proposed, the additional monitoring will also allow for broader characterisation of the system (i.e. streamflow monitoring on the Barwon River East Branch, Barwon River West Branch, Barwon River downstream of the Confluence and the Ricketts Marsh gauge will allow for baseflow contribution estimates to be made for all sub-reaches there within). Further, the outcomes of investigations in the high risk areas will be used to inform model calibration and re-assessment of risk and consideration of other areas for investigation.

Southern Rural Water / Technical Reference Panel recommendation	Barwon Water response
	
(With regard to prioritisation of at risk areas)…. assuming they are based on the maps (model outputs), then it is recommended that a buffer is included to account for the errors in the models. In other words, the areas adjacent to the high-risk areas should be included in the investigations.	The outcomes of the further investigation of the high risk areas identified through the risk assessment will be used to inform the need for broadening the areas to be captured for further action or investigation. The process outlined for the investigation of other areas will be outlined in the REPP.
For consistency, the Barwon River East Branch should be included, since it is listed in table 8 and 13.	The Barwon River East Branch is included as one of the eight '**high**' risk areas in the Surrounding Environment Investigation.

<table>
<tr><th>Southern Rural Water / Technical Reference Panel recommendation</th><th>Barwon Water response</th></tr>
<tr><td>Figure 12 implies that the entire length of the waterways will be subject to investigation. This needs to be clarified. A similar figure is strongly recommended for the prioritisation of catchment areas (based on Figure 10 and tables 14 & 15)</td><td>Clarification regarding the reaches for proposed investigation has been provided above.

A similar figure has been produced below, which highlights the catchment areas prioritised for further investigations.


</td></tr>
<tr><td>Some reference to quantifying the magnitude of potential treatment requirements (limestone dosing / hydrated lime dosing) as determined by the static and kinetic test-work would be helpful.

It would be helpful if the kinetic test work were able to provide some indication of the rate of remediation</td><td>The assessment of remediation options outlined in the REPP will consider various treatment options and requirements based on the soil and geochemical data available. Given the short period of data collection and incomplete soil incubation test results, information regarding timeframes and kinetic rates may be limited. The REPP will propose further data collection and geochemical modelling in conjunction with finalisation of the soil incubation to better inform requirements for treatment and rates of treatment.</td></tr>
</table>

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for one or more of the remediation options. Is it possible that the kinetic test-work, perhaps in combination with the static test-work, can assist with this request.	
Recommendation that the laboratory analytes for water samples (surface & groundwater) be expanded from those specified to include at least the following: • Cations: Ca, Mg, Na, K, Fe, Al, Mn, Cu, Pb, Zn, Ni, Co, Cd, Cr, As, Sb. • Anions: SO4 and Cl • Nitrogen speciation • Phosphorus speciation • Carbon speciation • Acidity/Alkalinity If thermodynamic modelling was to be employed as part of the hydro-geochemical modelling then the above list would be required.	Groundwater and surface water monitoring at all bores in the swamp and surface water gauges upstream and downstream of the swamp now also include monthly sampling and analysis for the analytes recommended. These are listed below (note, samples are also being analysed for speciated iron). Biochemical Oxygen Demand, 5 Day TDS at 180C Total Kjeldhal Nitrogen in Water Total Nitrogen (Calculation) MS Soluble Metals - Low Level Filtration Preparation fee Calcium Iron Potassium Magnesium Sodium OES Scan Preparation Fee Anions via IC Ammonia via FIA Nitrate via FIA Nitrite via FIA TON via FIA Chemical Oxygen Demand Alkalinity in Water Phosphorus, Reactive as P Phosphorus, Total as P Administration Charge Outsourced Acidity

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	Total Organic Carbon by SFA Dissolved Organic Carbon by SFA
Recommendation that assessment of baseflow contributions and hyporheic zone processes should be included in the survey of the Barwon River.	The intention of the Barwon River Survey was to gain a better understanding of the impact on the Barwon River as a result of the acidic discharge from Boundary Creek, not assess direct impacts on the Barwon River from groundwater extraction. The survey, whilst limited to one round of sampling initially, will also help to establish a baseline for ongoing monitoring of the Barwon River. It is acknowledged that whilst not ideal, macroinvertebrate sampling also allows some comparison to be undertaken with previous studies and understanding of macroinvertebrate health in the Barwon River. If the Surrounding Area Investigation confirms that historical groundwater pumping has directly impacted the Barwon River then assessment of baseflow contributions and hyporheic zone processes may be considered to help determine the type and magnitude of impact.
Consideration of other reports provided to SRW by their Community Leaders Group	The development of the REPP has been developed with input from the community through the Remediation Working Group. It has also considered the reports forwarded by SRW as provided to them by members of their Community Group. This included "Otway Water Book 31", "Otway Water Book 40 ASS Latest", and Wade (2017) Impacts of Barwon Downs Extraction on Groundwater and Surface water in the Kawarren Area. Otway Water Book 31 highlights areas of hydrologically sensitive areas that could have been impacted by historical groundwater pumping. These areas would have been captured through the risk assessment process undertaken to determine the areas within the surrounding environment requiring further investigation. Otway Book 40 ASS latest – raises concerns about the short period of time over which the 2017 ASS investigation took place. It also raises concerns around site selection and infers a broader area of impact needs to be considered. Again these areas of concern would have been captured through the

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	risk assessment process undertaken to determine the areas within the surrounding environment requiring further investigation. Wade (2017) recommends further assessment of impact to Loves Creek before further extraction of groundwater is permitted. The surrounding environment investigation has prioritised Ten Mile Creek and Yahoo Creek as "high" risks for further investigation as tributaries of Loves Creek. The outcomes of the investigation of these creeks will in turn inform requirements for further investigation of Loves Creek which was identified as "medium" risk during the risk assessment process. The Surrounding Environment Investigation will continue to consider this information and any other information forthcoming from the community that can assist to determine if environmentally significant adverse impacts have been caused by the historical management of groundwater extraction at Barwon Downs by Barwon Water