Barwon Water

Hydro-Geochemical Modelling

Design of Contingency Measure

Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan

31 July 2021

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Executive Summary

The submission of the hydrogeochemical modelling and detailed design for an active treatment contingency measure constitutes the final technical assessment milestone for the Boundary Creek and Big Swamp Remediation Plan in accordance with the current Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP).

The objectives of the hydrogeochemical modelling were to:

- Review the existing conceptual understanding of the hydrogeochemistry within Big Swamp
- Update the conceptual hydrogeochemical model for Big Swamp based on the new monitoring data and investigation outcomes.
- Review the current risks to the Barwon River associated with the quality of the water entering the Barwon River from Boundary Creek and Big Swamp.
- Assess the effect of proposed remediation actions on water quality leaving Big Swamp.
- Determine the requirements for possible active treatment contingency measures; and
- Inform the design of an appropriate active treatment contingency measure

Findings from the hydrogeochemical modelling

Hydrogeochemical modelling has analysed the volumes and sources of acidity within Big Swamp that have been generated by activation of naturally occurring acid sulphate soils through a combination of factors including groundwater extraction from the Barwon Downs borefield coupled with a drier climate.

The hydrogeochemical modelling has estimated the existing soil acidity across the swamp to be in the order of 3,900 tonnes ($CaCO_3$ equivalent) and with further drying of the swamp and activation of potential acid sulphate soils this could double.

Without supplementary flows and hydraulic barriers, this acidity is estimated to take 100 years to naturally dissipate from the swamp. The installation of the hydraulic barriers is able to reduce this to 35 years due to an increased rate of discharge as a result of increased movement of water through the swamp.

The reduction in time associated with remediation is related to a combination of:

- Reducing the mass of potential acidity available for oxidation via accelerated improvement in watertable levels in the swamp and stabilisation of the seasonal drying and wetting cycles

- An increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation

These results suggest that either a downstream contingency measure or introduction of a treatment system upstream of Big Swamp may be required to mitigate potential risks to the Barwon River. Upstream treatment combined with wetting of the swamp would assist to prevent further activation of potential acid sulfate soils whilst also treating the source of existing acidity and significantly reducing the timeframes for remediation.

Risks to the Barwon River

A review of the potential impacts on the downstream Barwon River using the modelling package PHREEQC highlighted that pH, iron and aluminium pose the greatest ecological risk. The highest risk is during the months of May and June when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase.

The analysis of the risks to the Barwon River showed that the conditions that led to the fish kill event in 2016 as a result of high acidity loads may be relatively infrequent. The review of the available water quality and flow data indicated that the conditions required in addition to low pH included:

- Greater than 40% of the flows in the Barwon River coming from Boundary Creek; **AND**
- Greater than 4 months of cease to flow events within Boundary Creek prior to a first flush event

Despite this, the results from the hydrogeochemical modelling outlined above suggests that either a downstream treatment contingency measure or upstream treatment with caustic magnesia would be required to mitigate potential risks to the Barwon River associated with the likely increase in the rate of discharge of acidity from the swamp.

Downstream active treatment contingency measure

The detail design of an active treatment contingency measure is to allow the procurement and construction of an appropriate mitigation measure to improve pH in Boundary Creek should the short term risk to the Barwon River be unacceptable while other remediation actions are implemented and take effect. The outputs from the hydrogeochemical modelling helped inform the design requirements for the active treatment contingency measure.

The contingency measure does not form part of the remediation actions for improved environmental outcomes for Big Swamp and Boundary Creek, but rather is designed as a last resort mitigation measure to reduce impacts on the downstream environment posed by high acidity loads leaving Big Swamp, if deemed to be required.

The downstream active treatment contingency measure has been designed to utilise a containerised pH adjustment – flow (PAF) dosing plant that can be easily procured and installed, and is a proven method for pH correction in similar applications. This plant would be located downstream of the swamp to allow treatment of water leaving Big Swamp with caustic soda should it be required. If deployed, the containerised system would also allow for easy removal should the contingency measure no longer be required.

The active treatment contingency measure would consist of the following:

- Containerised package treatment plant for dosing caustic soda for required level of pH correction
- Associated pipework to run water from the creek through the dosing system and discharge back to the creek
- Bunded chemical storage tanks for storage of caustic soda and diesel for operating of a generator as required
- Solar panels for provision of power when the generator is not required
- Installation of a silt barrier within the creek to capture sediment and floc that would be generated through the treatment of the water
- Telemetry control and monitoring systems with alarms to mitigate risk of dosing failures

The advantages of this active treatment contingency option include:

- Readily available and proven method of treatment
- Provides for treatment of water as it leaves the swamp and enters Boundary Creek
- Utilises a treatment method and chemical that is familiar to Barwon Water operational staff
- Can be easily removed if no longer required

The disadvantages of this method of treatment include:

- Resource intensive operation
- Potential for overdosing if automatic shut-downs fail during a dosing failure
- Increased chemical requirement when in operation
- Produces sludge and floc during the treatment process that requires capture and removal

Upstream treatment using caustic magnesia

In addition to the above, and in response to feedback received from the Independent Technical Review Panel, the hydrogeochemical analysis has also provided a preliminary assessment of the potential for treatment of existing acidity within Big Swamp using caustic magnesia (MgO) for pH correction as an additional remediation action.

This preliminary assessment has indicated that there is very little information publicly available on this method of treatment and further investigations are required to determine if this is a practical option that can be reliably implemented to reduce the acidity in the swamp. However, from the information that is available, upstream treatment using caustic magnesia does warrant further investigation.

The potential advantages of this upstream treatment option if determined to be reliable and feasible include:

- Treatment of the source of acidity within the swamp
- Lower volumes of treatment media required
- Passive application, no active dosing required
- Lower environmental risks and potential impacts compared to treatment with Caustic Soda
- Lower implementation costs
- Lower ongoing operational costs and resource commitments
- Shorter period of implementation/treatment required
- May significantly reduce the time taken to remove existing acidity from the swamp, which may take 35 years with just the barriers alone

The limitations include:

- Unproven method of treatment in this environment and therefore requires a trial to be undertaken as a proof of concept
- Potential for downstream contingency measure to be required if upstream treatment turns out to be unsuccessful or fails to achieve treatment required
- May require a delay in the installation of the hydraulic barriers to allow the trial to be undertaken and, if successful, implementation of full treatment

A trial would be required to investigate:

- If there is sufficient head to passively drive the water through the treatment media and distribute across the swamp

- If there is sufficient contact time between the water and treatment media to provide the required level of improvement in pH.
- How the treated water infiltrates the swamp soils and how this water can be distributed across the swamp to help neutralise acidity within the soils throughout the swamp
- Costs associated with this method of treatment based on the scale and infrastructure required as informed by the outcomes of the trial

Recommended approach to treatment of acidity

Based on the information available, Barwon Water believes that further investigation of upstream treatment with caustic magnesia is warranted as it has the potential to significantly improve remediation outcomes for Big Swamp and Boundary Creek. If this treatment method can be validated as a workable solution in this particular application, then it could:

- significantly reduce the volume of acidity within the swamp through treatment at the source
- reduce the ecological risks through reduced discharge of acidity and reduced risk of overdosing
- significantly reduce the timeframes for remediation

Barwon Water is therefore proposing to undertake the following actions:

- Begin the approvals process for installation of the **hydraulic barriers** with the option to install this summer or at a later stage pending outcomes from an upstream treatment (caustic magnesia) trial.
- Develop a trial plan for **upstream treatment** with caustic magnesia, including timelines and cost estimates. Following development of the trial plan, a decision would be made as to whether to proceed with the trial.

  If the trial is to proceed, Barwon Water would engage experts to begin the trial in line with the trial plan.

  Outcomes of the trial will then inform a decision as to whether to proceed with full implementation of the caustic magnesia treatment method, what implementation would look like and timeframes for implementation. This would also need to consider implications for installation of the hydraulic barriers.

- With the implementation of the caustic magnesia trial, Barwon Water would hold off on making any decision regarding the installation of the **downstream active treatment** contingency measure until after completion of the trial.

Purpose of this report

In accordance with the Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP), this document comprises Barwon Water's submission for the hydrogeochemical modelling and design of the active treatment contingency measure should it be deemed to be required.

This work has also attempted to assess the potential for treatment of acidity within Big Swamp using caustic magnesia as part of the remediation strategy in conjunction with the hydraulic barriers as proposed by the Independent Technical Review Panel. It is important to note that while there is limited information publicly available regarding this method of treatment, the information and advice that has been available indicates that this approach could warrant further investigation. Further information on this method of treatment is outlined below, however based on the advice that has been obtained it will require further investigation and a field trial before a decision could be made as to whether it is a viable treatment method that can be implemented as part of the remediation strategy.

This document is in addition to the detailed design of hydraulic barriers and success target review which was submitted to SRW on 1 July 2021.

What has informed the process?

The hydrogeochemical modelling and the design of the active treatment contingency measure has been informed by:

- The Boundary Creek, Big Swamp and Surrounding Environment Remediation & Environmental Protection Plan (REPP)
- The technical investigations undertaken to inform development of the REPP
- The data collected since acceptance of the REPP in February 2020
- Feedback received from our Remediation Reference Group (RRG) and their nominated experts regarding modelling outputs, draft hydraulic barrier designs, draft contingency measure design and remediation success targets
- Feedback received from the Independent Technical Review Panel (ITRP) and SRW regarding modelling outputs, draft hydraulic barrier designs, draft contingency measure design and remediation success targets
- The submission for the Detailed design of hydraulic barriers and success targets review

The feedback received from the RRG and their nominated experts, the ITRP and SRW has played an important role in shaping the hydrogeochemical modelling and the design of the contingency measures.

Background

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 supplementary flows not reaching the intended area, 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 participate in the design of 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 01 March 2020.

The section 78 notice defined remediation to be the controls and actions that could be practicably carried out to achieve improved environmental outcomes. In order to align this with an accepted scientific definition for remediation, the REPP further expanded the definition to be “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.”

In late February 2020, Southern Rural Water (SRW) accepted Barwon Water's REPP, which will be delivered under two parallel work packages:

- 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.

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

Based on a wide range of technical assessments and investigations, experts from various specialist fields and input from the community and stakeholder working group, the plan put forward the following remediation actions to be implemented for the remediation of Boundary Creek and Big Swamp.

- Continued delivery of a supplementary flow so that Boundary Creek is flowing all year round.
- Construction of barriers within the swamp to effectively distribute flow.
- Infilling of the existing fire trenches and the drain to allow the swamp to retain more water over the winter months.
- Prevention of the spread of some dry vegetation types so that wet vegetation species can recolonise.

- Collection of ongoing monitoring data to inform any changes needed so that the remediation plan can adapt to how the environment is responding.
- Assessment of contingency measures for implementation as required.

Objectives for remediation of Boundary Creek and Big swamp

Remediation has been defined in the s78 notice as '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'.

To provide focus and assist with decision making, Barwon Water, with input from the Remediation Working Group nominated experts, adopted a scientifically accepted definition of remediation (Edgar & Lovett, 2002) for the REPP based on the premise that the areas confirmed as requiring remediation have irreversibly changed due to factors notwithstanding groundwater extraction. For example, climate change, land clearing, farming and agricultural practices and the channelisation of rivers and creeks.

Return of these areas to pre-European conditions is neither practicable nor achievable given conditions have irreversibly changed. Remediation therefore recognises that the endpoint environmental outcomes are likely to be different to the original condition.

Therefore, without limiting the intent or extent of the s78 notice, the following definition of remediation was adopted for the REPP to provide further guidance for evaluating the appropriateness and practicality of proposed remediation actions for achieving improved environmental outcomes:

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.

In addition to developing an agreed definition of remediation for the REPP, a set of priorities to underpin remediation were also developed in consultation with the Remediation Working Group and their nominated experts during development of the REPP. The set of agreed priorities that were developed 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 the nominated experts were:

- **Protect** Barwon River 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 also 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.

Remediation strategy 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 would be required to meet the vision and priorities and respond to outcomes from further monitoring and technical assessments.

The actions outlined in the remediation plan to assist with rewetting the swamp included the:

- ***continued delivery of a supplementary flow*** *to meet the objective of maintaining 0.5ML/day 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*** *(e.g. '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.*

The information presented in the following section relate to the hydrogeochemical modelling and the design of contingency measures proposed for installation as part of the above remediation strategy.

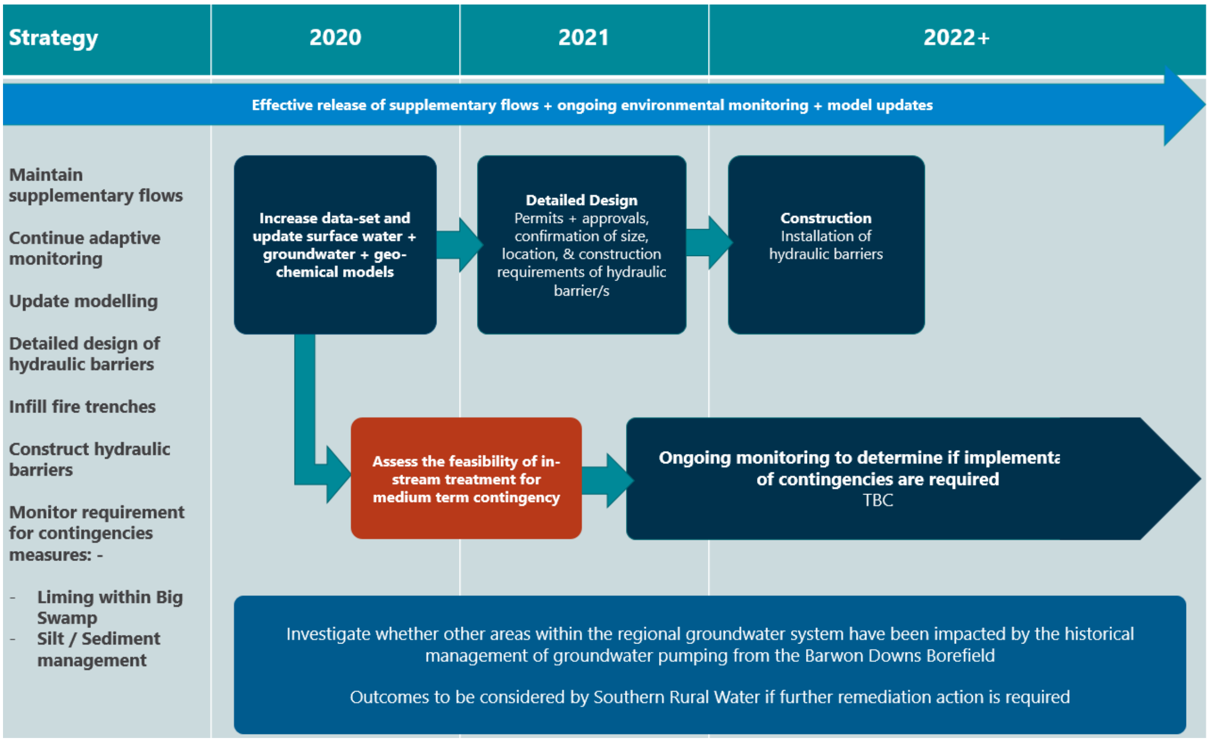

Figure 1: Timeframes for implementation of the proposed remediation strategy as presented in the REPP (Barwon Water 2020).

Objectives of the hydrogeochemical modelling and detailed design of contingency measure

Hydrogeochemical modelling

The objectives of the hydro geochemical modelling in this report was to build on the Basic Conceptual Geochemical Modelling for Big Swamp completed by GHD in 2019, and more specifically to:

1. Review and refine the hydrogeochemical conceptualisation of the Big Swamp and Boundary Creek System based on new monitoring data and investigations.
2. Undertake hydrogeochemical modelling of the system to assess the effect of remediation on water quality in Boundary Creek and if water quality targets can be met. Integration with updated groundwater-surface water model outputs will also need to be considered.
3. Provide recommendations as to the necessity of contingency measures (such as soil liming or water treatment) to improve water quality in Boundary Creek.
4. Analyse contingency treatment options and develop specifications for preferred option or options.

Detailed design of active treatment contingency measure

The detail design of an active treatment contingency measure is to allow the procurement and construction of an appropriate mitigation measure to improve pH in Boundary Creek should the short term risk to the Barwon River be unacceptable while other remediation actions are implemented and take effect. The outputs from the hydrogeochemical modelling helped inform the design requirements for the active treatment contingency measure.

The active treatment contingency measure does not necessarily form part of the remediation actions for improved environmental outcomes within Big Swamp, but rather is designed as a mitigation measure to reduce impacts on the downstream environment posed by high acidity loads leaving Big Swamp.

Further consideration of upstream treatment within Big Swamp using caustic magnesia may be warranted as part of the overall remediation strategy. This would require a field trial to determine its viability.

Hydrogeochemical Modelling

The following sections summarise the hydrogeochemical analysis and modelling that has been undertaken and which is outlined in more detail in the full report provided in Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek

The hydrogeochemical analysis and modelling focussed on the following key aspects:

- Review a 1-day surface water monitoring event in Big Swamp undertaken on April 7th 2021
- Develop a hydrogeochemical conceptual site model (CSM) based on the results of groundwater-surface water monitoring (including the results of the 1-day monitoring event)
- Understand the risks to fish in the Barwon River
- Build a hydrogeochemical model using PHREEQC based on the CSM that is capable of simulating the chemistry of water monitored at the surface water gauge 233276 downstream of Big Swamp
- Use the model to simulate the potential changes in water chemistry of water discharging from big swamp in the presence and absence of remediation (i.e. inundation)
- Undertake modelling simulations using PHREEQC to assess the potential ecological risks and the risk of fish kills in the Barwon River in response to the discharge of water from Boundary Creek and hence, if contingency measures such as downstream treatment may be required to mitigate risks and ultimately improve remediation outcomes.
- Undertake modelling simulations using PHREEQC to assess the magnitude of potential contingency measures to inform subsequent design

Surface Water Monitoring Event

To help inform the hydrogeochemical conceptual site model, a one-day field sampling event was undertaken on the 7th of April 2021 to assess changes in water chemistry along surface water flow paths through Big Swamp. Two flow paths were observed during the event including the northern "primary" channel and a southern flow path which diverts through the interior of the swamp. Field water quality parameters were collected at 17 locations on the day and water samples collected for detailed laboratory analysis at 10 representative locations. These locations are illustrated in Figure 2 below.

Figure 2: Location of surface water monitoring and sampling locations in Big Swamp on April 7th

During the sampling event, flowing surface water was apparent in the interior of the swamp along the entirety of its length (at BH15, BH10, BH07 and BH01). However, flowing surface water was only observed in the northern channel between the gauge upstream of Big Swamp (233275) and the surface water sample point BC02. Surface water monitoring points in the northern channel downstream of this represented discrete pools of surface water that were either remaining from higher flow conditions during January and early February when the pools may have been connected; accumulated rainfall; or the surface expression of groundwater in topographic low points.

These observations suggest that the northern channel does not represent the primary flow path through Big Swamp to the east of BC02 and that flows through the interior of the swamp are likely to predominate. As a result, the representation of flows paths through the swamp will need to be re-considered during future iterations of groundwater-surface water modelling.

The acidity and pH within the swamp based on the results of the sampling event have been illustrated in figures Figure 3 and Figure 4 below.

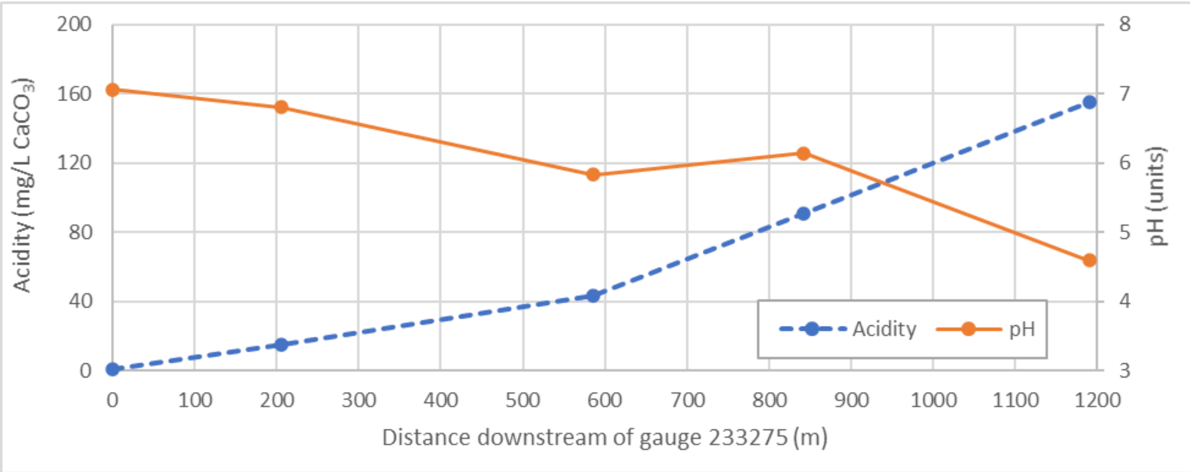

Figure 3: Trends in acidity and pH downstream of gauge 233275 in the northern channel

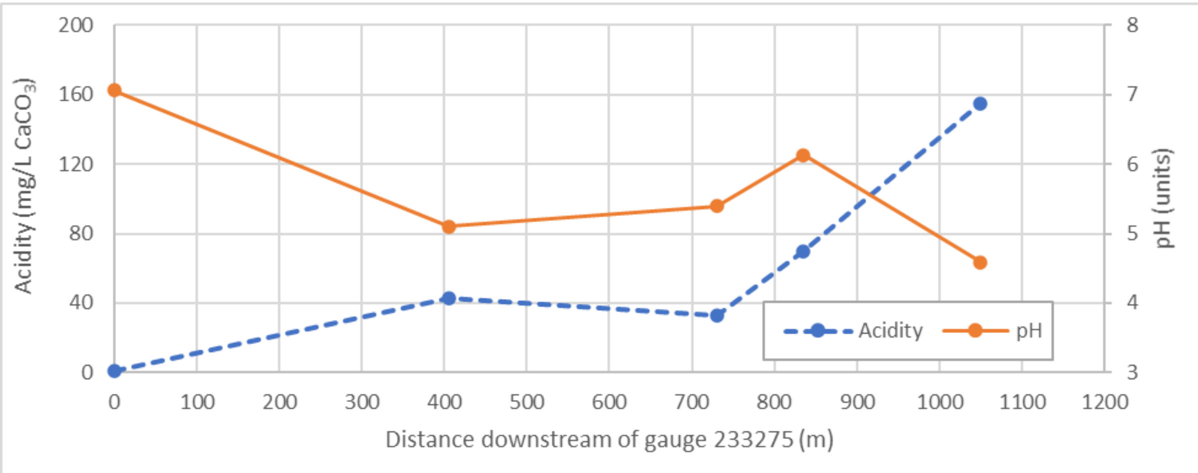

Figure 4: Trends in acidity and pH downstream of gauge 233275 in the interior of the swamp

Conceptual Site Model

Approach for hydrogeochemical conceptualisation of Big Swamp

While the formation and oxidation of sulfides represent a natural process, the conceptualisation of the hydrogeochemical process within Big Swamp has been based on a source-pathway-receptor model that is more commonly used for assessment of contaminated sites. This is because understanding the potential sources and pathways by which acidic and metalliferous water mobilises to Boundary Creek can aid assessment of potential remediation strategies. As such, the below conceptual site model (CSM) has been developed using a source-pathway-receptor model, which considers the following:

- The potential sources of acidity including that stored as solid phase minerals in surface soils; that stored in pore water in the unsaturated zone; and that stored in groundwater in the saturated zone.

- The potential pathways by which this can move into Boundary Creek including acidic runoff from surface soils, unsaturated zone flow and groundwater discharge.

- The effects of acidic and metalliferous discharge on water quality at the receptor, which in this case is Reach 3 of Boundary Creek.

For the purpose of the Big Swamp CSM, the primary “contaminant” that has been considered is acidity. This is because, while other analytes (such as dissolved metals) may also be considered as contaminants of concern in the system, these are secondary in nature and their concentration is typically related to the concentrations of acidity and the pH of the water in Big Swamp.

A brief outline of the source-pathway-receptor CSM for Big Swamp is provided below. More comprehensive information can be found in Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek.

Source of acidity

The primary source of acidified water in Boundary Creek could be simplistically described as oxidised sulfides in Big Swamp. However, for the purpose of this CSM this has been considered an overly simplistic conceptualisation, as the oxidation of sulfides over the last 30 years has resulted in the movement of this acidity into different secondary stores. This includes:

- Acidity stored in solid phase as minerals in the soils themselves
- Acidity stored in groundwater resulting from the infiltration of acidic recharge/seepage
- Acidity stored in the pore water of soils in the unsaturated zone

The results of the analysis undertaken as part of the conceptualisation estimated that there are approximately 810 tonnes acidity as $CaCO_3$ in the top 0.24m of surface soils, 126 tonnes of acidity as $CaCO_3$ in groundwater and 11 tonnes of acidity as $CaCO_3$ equivalent stored in the unsaturated zone. The hydrogeochemical modelling further investigates the total existing and potential soil acidity.

Pathways for mobilisation

Based on the above described sources, there are three potential pathways by which acidity may move into Boundary Creek. This includes:

- Acidic runoff from surface soils

- Groundwater discharge to surface water
- Flushing of acidity from the unsaturated zone

These have each been considered in more detail in the full report in Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek.

Influence on the Receptor – Reach 3 of Boundary Creek
This section considers the effect of acidic and metalliferous discharge from Big Swamp on water quality in the receptor (Reach 3 of Boundary Creek) by assessing 3 key surface water quality characteristics:

- Surface water quality entering and exiting the swamp and temporal trends in surface water quality in response to flow;
- Acidity discharging from the swamp, the dominant forms of acidity and the total loads discharging from the swamp to help inform modelling scenarios; and
- Surface water quality compared to water quality objectives to better understand which physical and chemical analytes may have a negative impact on aquatic ecosystems.

Summary of the conceptual understanding of Big Swamp

- The greatest store of acidity in Big Swamp appears to be soil acidity in the upper soil profile, which has been estimated to contain 810 tonnes of $CaCO_3$ equivalent within the top 0.24m. However, the timing of acidic discharge with respect to periods of high and low runoff suggest this is not the primary mechanism by which acidity is discharged to Boundary Creek.
- Groundwater acidity stored in the shallow alluvial aquifer represents the second largest store of acidity in Big Swamp (126 tonnes of acidity as $CaCO_3$ equivalent) and the modelling suggests that this is the primary mechanism by which acidity is discharged into Boundary Creek (though this would be sustained by the infiltration of acidity from the upper soils). As such, the recharge of acidity to groundwater via overlying soils and subsequent movement of groundwater into Boundary Creek should represent the focus of subsequent hydrogeochemical modelling.
- Pore water acidity in the unsaturated zone represents a minor store of acidity in Big Swamp (estimated to represent 11 tonnes of $CaCO_3$ equivalent) and leaching of soil moisture from the unsaturated zone appears to be a negligible process for further consideration as part of hydrogeochemical modelling (though movement of recharge through this zone into groundwater would occur).
- By combining the groundwater surface water model (GHD, 2020) with the monitored groundwater acidity, it is possible to characterise the discharge of acidity from Big Swamp into Boundary Creek under current conditions and assess how this may change in response to barrier installation.
- Uncertainty in the groundwater model, adopting appropriate groundwater acidity concentrations, temporal variations in groundwater acidity concentrations and losses of acidity to the groundwater system are processes which should be interrogated as part of designing and calibrating the hydrogeochemical model.

Risks to the Barwon River

While the discharge of acidic water from Boundary Creek into the Barwon River is relatively well documented, to date there has been little investigation into how this translates into risk of a fish kill event occurring in the Barwon River. The hydrogeochemical modelling report has attempted to investigate this further through:

1. Reviewing the available surface water quality data available for Boundary Creek and the Barwon River upstream of its confluence with Boundary Creek.
2. Identifying key analytes of concern which pose the greatest risk of toxicity to fish.
3. Estimating the conditions under which the contribution of key analytes of concern from Boundary Creek are likely to result in a high risk of fish mortality in the Barwon River
4. Assessing the flow conditions under which this is likely to occur

The below summarises the outcomes of this analysis and the risk posed to aquatic ecology (principally fish) in the Barwon River related to the discharge of acidic water from Boundary Creek:

- pH, iron and aluminium pose the greatest ecological risk to the Barwon River, including the greatest risk of fish kills related to acute toxicity associated with respiratory failure due to low pH conditions and high aluminium concentrations.
- Simulations via the modelling package PHREEQC and comparison of flows in Boundary Creek to those in the Barwon River suggest that under typical conditions, ecological risks to the Barwon River are highest during May and June, when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase. Higher flow periods (July-August) tend to represent lower risks to the Barwon River due to the reduced concentration of parameters of concern under these conditions while lower flow periods (December-March) tend to represent lower risks to the Barwon River due to the reduced contribution of flows from Boundary Creek. This is consistent with sampling undertaken to date by Austral (2020).
- The only recorded fish kill event in the Barwon River occurred in June 2016 when flows from Boundary Creek represented ≥40% of those in the Barwon River. This period represents a flow event following flow cessation in Boundary Creek (known as a first flush). While other first flush events have yielded a similar contribution of flows to the Barwon River, these were preceded by 4 months or less of flow cessation in Boundary Creek, whereas the June 2016 event was preceded by more than 8 months of flow cessation in Boundary Creek. This suggests that the Barwon River is at the greatest risk of a fish kill event following an extended period of flow cessation in Boundary Creek (>4 months) when flows from Boundary Creek represent ≥40% of those in the Barwon River.

Predicted water quality outcomes of hydraulic barrier remediation option

The predicted water quality outcomes of the hydraulic barriers were informed by the conceptual site model, the groundwater-surface water model (GDH, 2020) and the hydrogeochemical modelling software PHREEQC. The hydrogeochemical modelling also aims to validate the CSM and groundwater-surface water model.

The outcomes of the CSM, GW-SW model and hydrogeochemical model are combined to estimate the potential water quality outcomes in Boundary Creek downstream of Big Swamp in the presence and absence of the proposed barriers and comment on the potential implications for treatment options.

It is recognised that this approach will not generate a fully parameterised reactive solute transport model but instead, represents the first step in understanding the implications of barrier installation versus doing nothing. In this respect, the ultimate aim of the model is to provide a first order estimate of how long it may take (months, years, decades) for water quality in Boundary Creek to improve in the presence or absence of the proposed hydraulic barriers. By doing so, the modelling aims to determine whether there is sufficient benefit to water quality outcomes associated with the proposed barriers to warrant installation, whether there is sufficient confidence to directly proceed with remediation or whether further investigations and detailed modelling is required to inform further decision making.

A full report on the modelling activities can be seen in Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek.

Summary

The calibrated hydrogeochemical model was used in conjunction with the CSM presented in Section and the groundwater surface water model (GHD,2020) to predict the water quality changes with the installation of the hydraulic barrier. The key outcomes from this modelling are:

- Approximately 56 tonnes per year of acidity $CaCO_3$ equivalent is added to the groundwater system via rainfall recharge, compared to 80 tonnes per year of acidity $CaCO_3$ equivalent being discharged. This suggests that the Swamp may have established a dynamic equilibrium over the last 30 years since acidification processes began.

- The hydrogeochemical modelling has estimated the existing soil acidity across the swamp to be in the order of 3,900 tonnes ($CaCO_3$ equivalent) and with further drying of the swamp and activation of potential acid sulphate soils this could double.

- In the absence of remediation, the mass of acidity in the swamp (both existing and potential acidity) could take approximately 100 years to naturally dissipate from Big Swamp.

- Modelling indicates that concentrations of acidity discharging from Big Swamp are likely to increase following remediation in response to enhanced groundwater discharge from the western portion of the swamp, where concentrations of groundwater acidity are higher than those in the east.
- The reduction in time associated with remediation is related to a combination of:
    - Reducing the mass of potential acidity available for oxidation via accelerated improvement in watertable levels in the swamp and stabilisation of the seasonal drying and wetting cycles
    - An increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation.
- The rate of discharge of acidity from the swamp may also be increased in the absence of remediation through recovery of groundwater levels in the LTA in the western end of the swamp. This may subsequently reduce estimated timeframe for removal of acidity from the swamp in the absence of remediation.
- These results suggest that either a downstream contingency measure or introduction of a treatment system upstream of Big Swamp may be required to mitigate potential risks to the Barwon River. Upstream treatment combined with wetting of the swamp would assist to prevent activation of potential acid sources whilst also treating the source of existing acidity and reducing the timeframes for improved environmental outcomes.

Downstream Contingency Measure

The objective of the contingency measure is to improve water quality in Reach 3 of Boundary Creek and reduce the risk to ecology in the Barwon River. If required, the contingency measure could be implemented whilst the ultimate long term remediation option is constructed and proven to be effective in controlling the release of acidity from the Swamp.

The contingency measures that have been considered for implementation have been selected from several remedial actions that were assessed as potential remediation options in the Remediation and Environmental Protection Plan (REPP) to improve water quality in Boundary Creek. CDM Smith (2019) completed an options assessment as part of development of the REPP and recommended aerial liming and an active treatment system be investigated as contingency measures.

In addition to this work, the hydrogeochemical modelling also considered the ability to treat acidity within Big Swamp using caustic magnesia, as was recommended by the Independent Technical Review Panel. Upstream treatment could potentially reduce the need for implementation of an active treatment contingency measure, however field trials are required to confirm the feasibility. Further detail on this option is provided in the next section.

The options assessment was further refined through assessment of key aspects including implementation, constructability and operation and maintenance. Jacobs investigated the range of potential locations, application methods and chemicals that could be adopted as a contingency measure.
A chemical dosing system located on the downstream (Eastern) end of the Big Swamp using sodium hydroxide ($NaOH$) as a pH correction chemical was recommended as the preferred option for the contingency measure.

A summary is provided below, with detailed information provided in Appendix B: Design of Downstream Contingency Measure

Initial Screening of treatment options

The selection of the contingency measure type consisted of an initial screening process followed by more detailed assessment of the remaining options.

A range of options were identified and considered as part of the initial option development and these were screened based on the functional requirements. The initial screening process was influenced by the practicability of installation, assuming that the contingency measure could be installed over summer 2021/22 if deemed to be required. The short timeframe for installation (if required) favours conventional approaches with known outcomes ahead of more novel methods with uncertain outcomes.

The options considered for the contingency measure were reviewed against three key functional aspects, which were:

- Location of the works,

- Method of treatment/application and
- Chemical used to improve pH in the water.

Treatment location

The location of the contingency measure to improve the pH of the water entering the Barwon River could be situated in the following locations:

- Upstream of Big Swamp to pre-treat Boundary Creek flows entering the Big Swamp,
- Within the swamp to treat surface water before it leaves the swamp, or
- Downstream of the swamp treatment of the flow leaving the swamp.

The location of the contingency measure is proposed to be downstream of Big Swamp, due to ease of access and certainty around ability to mix and therefore treat all flows leaving the Swamp.

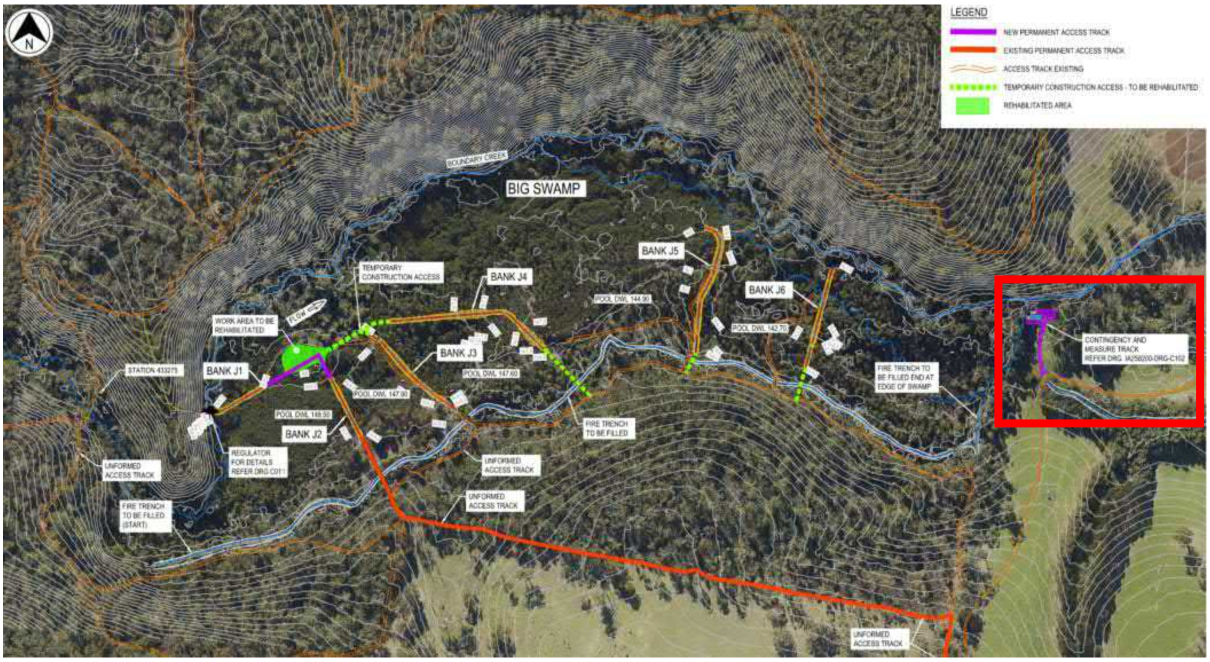

Figure 5: shows the location of the contingency measure downstream of the swamp and proposed hydraulic barriers.

Treatment methods considered

The different treatment methods that have been considered for pH correction are outlined below.

Manual Chemical Application within Big Swamp

Periodic manual chemical treatment to the Boundary Creek system in Big Swamp to correct the pH is a potential option for the contingency measure. This could be done with dosing chemicals to the waterway from chemical containers to the required volume in response to pH levels of the Big Swamp. The dosing is proposed to be at the existing weirs as a mixing point for flows.

This method is labour intensive and is likely to provide pH spikes into the waterway. The operational cost of the labour is expected to be high and operation would be challenging to staff for long periods of time. The management of chemicals with resupply, staff facilities such as toilets and lunch room are likely to be required to support the onsite team. Risk management of chemical use is further unlikely to support this method. Chemical dosing at night is unlikely to be acceptable, leaving the Boundary Creek system vulnerable to low pH events outside of business hours.

Lime Bed

Lime could be placed within the Boundary Creek system, potentially downstream on a weir to provide a pH correction for passing flows. This method does not allow for variable control of the pH and risks creating high alkaline water within the system. It is expected to be difficult to manage replacement lime and to achieve a desired pH level consistently in the waterway. Lime beds are also likely to coat with iron and aluminium hydroxides rapidly and may require frequent ongoing maintenance and re-supply.

Chemical Dosing System

A chemical dosing system would draw flow from the Big Swamp system via a feed pump from upstream of a weir where a pool of water is formed. The flow would be dosed with chemical for return to Big Swamp or Boundary Creek. This operation allows for consistent dosing, chemical storage and operation throughout the day and night. The system would provide for capacity to monitor dosing rates and volumes and responding pH levels during dosing, allowing for potential adjust by the system in response to pH changes in the discharge water.

This method has a greater capital cost, however, provides for reduced operational labour costs and greater level of control on chemical application to waterway.

Chemical Options

Common chemicals used for pH correction for increasing alkalinity are provided in Table 1, together the amount required. All these chemicals will neutralize acidity, so the selection of chemical to be used at Big Swamp was informed by Barwon Water's current experience with chemicals to leverage off existing supply chains and Barwon Water current capacity. Preliminary discussions with Barwon Water indicated that Caustic Soda is a common chemical in use within their water treatment plants.

Table 1: Alkalinity contributed per mg of pure product – Practical guide to the optimisation of chemical dosing, coagulation, flocculation, and clarification.

Chemical Agent	Alkalinity Added (mg $CaCO_3$ equivalent /mg pure chemical)
Soda Ash (Na_2CO_3)	0.94
Hydrated Lime ($Ca(OH)_2$)	1.35
Caustic Soda (NaOH)	1.25
Magnesium Hydroxide ($Mg(OH)_2$)	1.72
Sodium Bicarbonate ($NaHCO_3$)	1.19

Preferred treatment contingency option

A review of the options considered above indicate a chemical dosing system located on the discharge end of the Big Swamp (Eastern) using Caustic Soda as a pH correction chemical would be recommended for the following reasons:

- Preferred location due to accessibility, limited modifications and vegetation removal, reduced fire risk
- Certainty of the achieving the desired water quality outcomes downstream of the swamp and minimizing risk to the Barwon River
- Caustic soda is readily available and aligns with the Barwon Water current experience.

Figure 6: Chemical dosing system and associated components

A number of different chemical dosing systems such as a containerised pH Adjustment - Flow (PAF) plant are available commercially for purchase. The design in Appendix B: Design of Downstream Contingency Measure shows one such plant and the componentry that would be required. Exact specifications and instrumentation shall be determined between Barwon Water Technical Services team and the preferred supplier at the time of purchase, an example of this plant is shown in Figure 7 below.

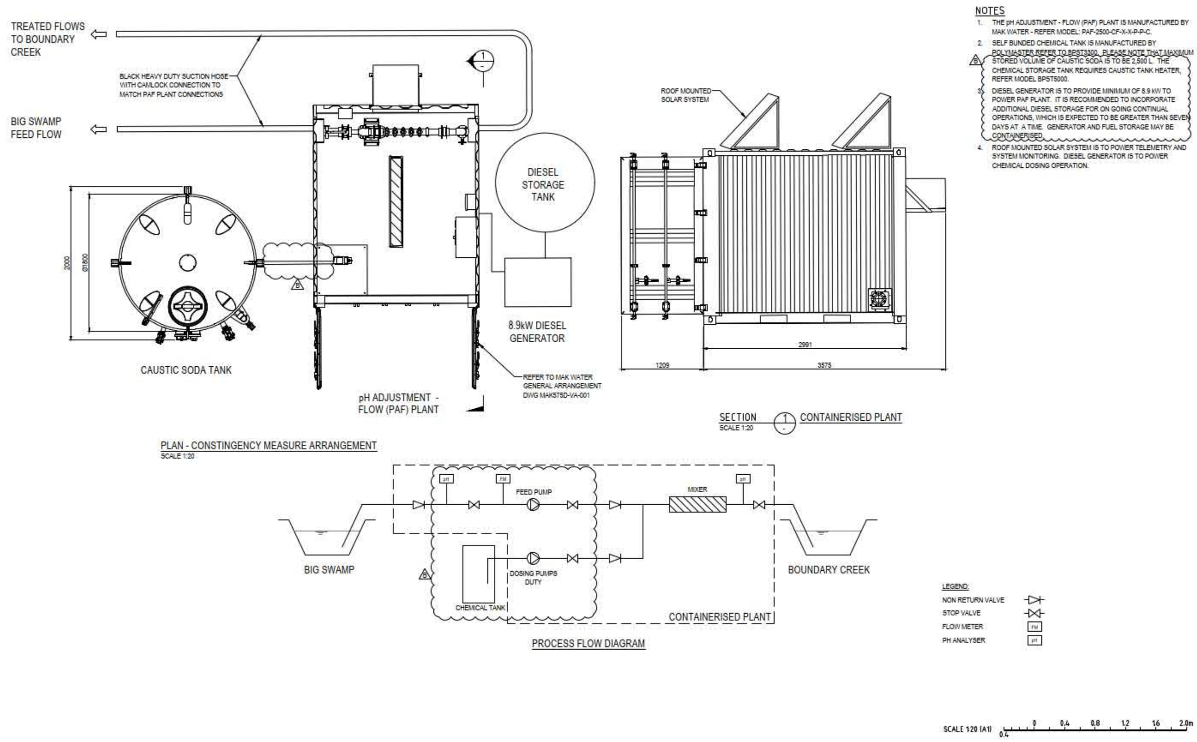

Figure 7: Containerised pH adjustment – flow (PAF) plant.

Chemical dosing requirements

The objective of the contingency measure is to chemically neutralise low pH flows leaving the Big Swamp in the short term if determined to be required until other remedial actions including the installation of the hydraulic barriers can take effect. Work undertaken as part of the Hydrogeochemical modelling calculated the dosing requirements of the downstream contingency measure using caustic soda, which was estimated to be up to 800L per day to achieve a pH of 7.

The chemical dosing requirements will vary depending on the flow conditions. A range of different flow rates and acidity concentrations were used to reflect the range in conditions which may occur in a given year and estimate the dosing requirement:

- **Initial flush:** represents higher concentrations of acidity discharging from Big Swamp as flows return following summer low flow conditions or flow cessation.
- **Ongoing flush:** represents higher loads of acidity discharging from Big Swamp as flows continue to increase while concentrations remain moderately high.
- **Winter-Spring high flow:** represents higher flow rates in which concentrations of acidity decline through flushing and or dilution, though loads remain relatively high due to high flow rates.
- **Summer low flow:** represents lower flow rates during summer when concentrations of acidity tend to increase while flow rates decline.

The contingency measure is proposed to have a self-priming pump to provide feed water and to dose caustic soda at a rate of up to 800L day.

The caustic soda 40% storage will require a heating element to prevent freezing at temperature below 15 degrees Celsius. Consideration could be given to using caustic soda 25% to reduce the potential for freezing, however this will increase the required storage of chemical on site.
The sampling periods selected to represent the above described range in conditions were April 2020, May 2020, October 2020 and December 2019, respectively, as illustrated in below in Figure 8.

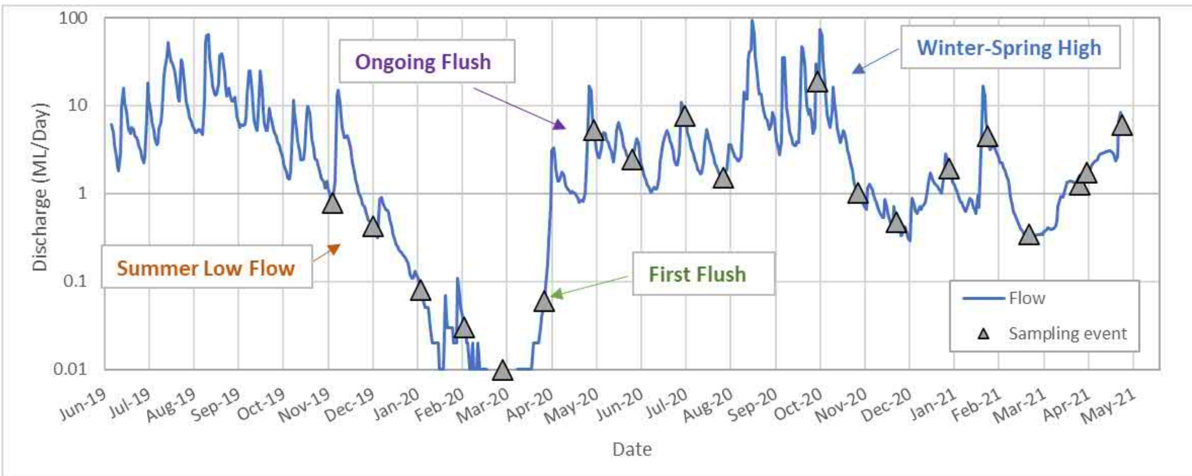

Figure 8: Sampling periods used to inform treatment rates (Jacobs 2021)

Dosing rates

The estimated monthly and annual volumes of sodium hydroxide required to yield a pH of 5 and 6 downstream of Big Swamp are illustrated in Figure 9 and Figure 10 respectively. These indicate that based on the typical flow conditions and the concentrations of analytes observed during 2019-2020, monthly treatment rates to achieve a pH of 5 downstream of Big Swamp range from as little as 22 L in March to as much as 6,600 L in July. The total annual volume required to achieve a pH of 5 is approximately 28,000 L, with the majority (21,000 L) required between the months of May and September.

To achieve a pH of 6 downstream of Big Swamp, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. The total annual volume required to achieve a pH of 6 is approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.

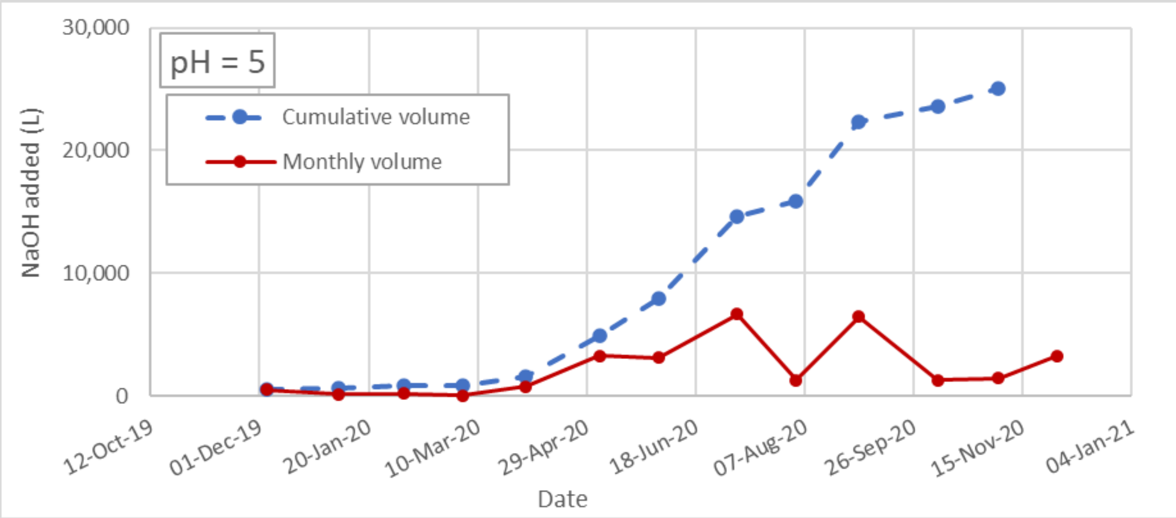

Figure 9: Estimated monthly and annual NaOH treatment volumes to yield a pH of 5 downstream of Big Swamp

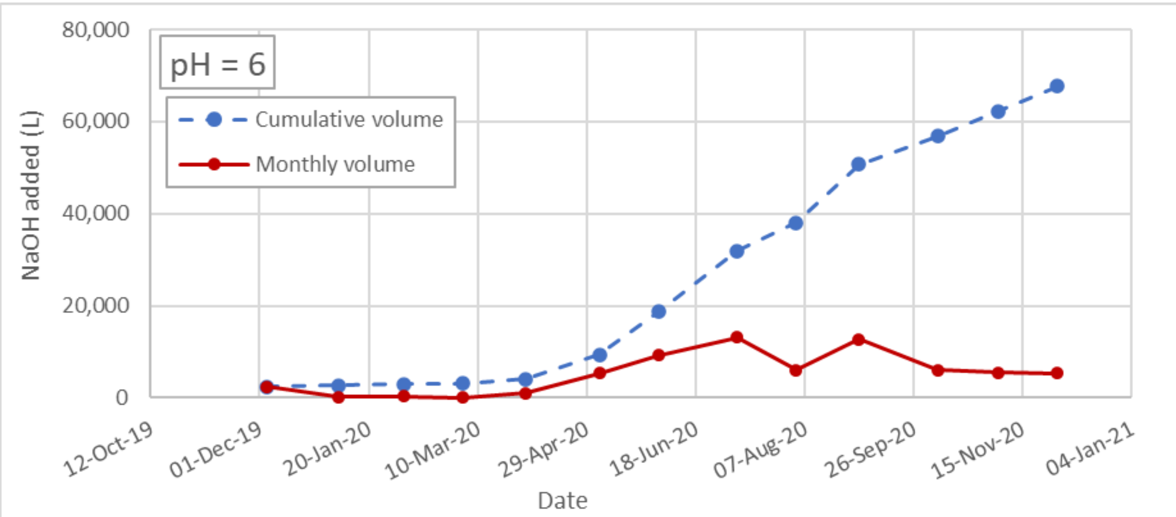

Figure 10: Estimated monthly and annual NaOH treatment volumes to yield a pH of 6 downstream of Big Swamp

A summary of the dosing requirements for the downstream contingency measure using sodium hydroxide is outlined below:

- To achieve a pH of 6, dosing rates range between less 80 L/day under summer low flow and initial flushing conditions, to 200 L/day during winter-spring high flows conditions and 700 L/day during ongoing flushing conditions.
- To achieve a pH of 6, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. The total annual volume required to achieve a pH of 6 is approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.
- The annual build-up of aluminium and iron hydroxide sludge in response to sodium hydroxide dosing is estimated to be 24 m3 assuming treatment to pH of 6.

Upstream treatment with caustic magnesia

The hydrogeochemical modelling undertaken to inform the potential outcomes of installation of hydraulic barriers as a remediation action for Big Swamp indicates the water quality benefits could take 35 years to be realised. This highlights the importance of either a downstream contingency measure or a potential upstream treatment solution to advance remediation.

On June 17 2021, the Independent Technical Review Panel (ITRP) recommended that an upstream treatment system using magnesia (magnesium oxide, MgO) as a pH correction chemical be considered. The focus of this system would be to treat the acidity stored in soils and pore water throughout the swamp. There is limited information available in the public domain regarding this treatment option and therefore it was not possible for Jacobs (2021) to consider it in detail, as the advice that was able to be sourced on the this treatment method recommended that a field trial would need to be undertaken to confirm the viability of the option.

Chapter 7 in Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek describes the seasonal variability in treatment rates and annual treatment loads for the upstream treatment option involving magnesium oxide.

Summary
The input of alkalinity into surface water upstream of Big Swamp is likely to be more effective in the longer term by treating acidic surface soils in the swamp which would limit the ongoing leaching of acidity from those soils into groundwater (provided the alkaline water could be effectively distributed across acidic soils).

The dosing requirements for the potential upstream treatment option using magnesium oxide is below:

- To achieve a pH of 6, mass ranges between less 16 kg/day under summer low flow and initial flushing conditions, to 40 kg/day during winter-spring high flows conditions and 80 kg/day during ongoing flushing conditions.
- To achieve a pH of 6, the mass ranges from 13 kg in March to as much as 2,700 L in July. The total annual mass required to achieve a pH of 6 is approximately 14,000 kg, with the majority (9,500 kg) required between the months of May and September.

Summary, conclusion and next steps

Conclusions

The key conclusions drawn from the Hydrogeochemical analysis and modelling, detailed design of the downstream treatment contingency measure and investigation of upstream treatment with caustic magnesia are as follows:

- Hydrogeochemical modelling has analysed the volumes and sources of acidity within Big Swamp that have been generated by activation of naturally occurring acid sulphate soils through a combination of factors including groundwater extraction from the Barwon Downs borefield coupled with a drier climate.
- The hydrogeochemical modelling has estimated the existing soil acidity across the swamp to be in the order of 3,900 tonnes ($CaCO_3$ equivalent) and with further drying of the swamp and activation of potential acid sulphate soils this could double.
- Without supplementary flows and hydraulic barriers, this acidity is estimated to take 100 years to naturally dissipate from the swamp. The installation of the hydraulic barriers is able to reduce this to 35 years due to an increased rate of discharge as a result of increased movement of water through the swamp.
- The reduction in time associated with remediation is related to a combination of:
    - Reducing the mass of potential acidity available for oxidation via accelerated improvement in watertable levels in the swamp and stabilisation of the seasonal drying and wetting cycles
    - An increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation.
- These results suggest that either a downstream contingency measure or introduction of a treatment system upstream of Big Swamp may be required to mitigate potential risks to the Barwon River.
- Upstream treatment combined with wetting of the swamp would assist to prevent further activation of potential acid sulfate soils whilst also treating the source of existing acidity and significantly reducing the timeframes for remediation.
- There is very limited information publicly available on treatment methods using caustic magnesia, particularly in this type of environment.
- The expert advice that was available recommended that a trial of upstream treatment using caustic magnesia would be required to confirm its viability.

Given the above, Barwon Water is proposing to:

- Continue with seeking approvals for installation of the hydraulic barriers as proposed
- Hold off on implementation of the downstream active treatment contingency

- Conduct a trial of upstream treatment with caustic magnesia over the next 3-6 months to confirm viability
- Confirm requirements for installation of the hydraulic barriers and downstream contingency measure based on the outcomes of the trial of upstream treatment with caustic magnesia.

Further detail on the recommended path forward is provided below:

Hydraulic Barrier Installation
The planning permit and approvals process for the hydraulic barrier installation should still commence as soon as possible to allow construction to occur over summer 2021/22 if it is decided not to proceed with the trial or upstream treatment

Should the outcome of the trial show the upstream treatment method is worth pursuing and requires the delay of the installation of the hydraulic barrier then the planning approvals will still be prepared and would be valid for 2-years. This would still allow construction to commence the summer of 2022/23.

Upstream treatment investigations
Further investigations are required to determine if an upstream treatment method using caustic magnesia can be practicably implemented to reduce the acidity in the swamp. From the information available on the caustic magnesia treatment method, it appears to warrant further investigation. The required daily treatment rates appear much lower than downstream treatment (noting that downstream treatment may not need to be operated full time) and there is less risk associated with overcorrection of pH as the solution cannot go higher than approximately pH 10.

The potential benefits of this upstream treatment option if determined to be feasible include:

- Treatment of the source of acidity within the swamp
- Lower volumes of treatment media required
- Passive application, no dosing required
- Lower environmental risks and potential impacts compared to treatment with Caustic Soda
- Lower implementation costs
- Lower ongoing operational costs and resource commitments
- Shorter period of implementation/treatment required
- May significantly reduce the time taken to remove existing acidity from the swamp, which may take 35 years with just the barriers alone.

The potential limitations:

- Unproven method of treatment in this environment and therefore requires a trial
- Potential for downstream contingency to be required if upstream treatment turns out to be unsuccessful

- May require a delay in the installation of the hydraulic barriers to allow the trial and full treatment to be implemented

A trial would be required to investigate:

- If there is sufficient head to passively drive the water through the treatment media
- If there is sufficient contact time between the water and treatment media to provide to be required level of improvement in pH
- How the treated water infiltrates the swamp soils and how this water can be distributed across the swamp to help neutralise acidity within the soils around the swamp.
- Costs associated with this method of treatment based on the scale and infrastructure required as informed by the outcomes of the trial.

Before a decision is made to proceed with a trial, the first step would be to develop a trial plan to determine what needs to be tested and monitored, how the trial should be implemented, what infrastructure is required, and how long the trial should be implemented. It is envisaged that a trial would be conducted in a section of the swamp to test the effectiveness and if successful scaled up.

If successful, the size of the treatment infrastructure could be scaled up to meet the requirements of the swamp and the head pressure from the stock pipeline would be used spread the solution around the swamp. Pipework through the swamp could spread the solution to the required location following the paths used for the bore installations and future installation of the hydraulic barriers.

Downstream Contingency Measure

With the implementation of an upstream treatment trial Barwon Water would hold off on making any decision regarding the installation of the downstream active treatment contingency measure. This is based on the analysis of the risks to the Barwon River that indicates that the conditions that led to the fish kill event in 2016 as a result of high acidity loads may be relatively infrequent. The review of the available water quality and flow data indicated that the conditions required in addition to low pH included:

- Greater than 40% of the flows in the Barwon River coming from Boundary Creek; and
- Greater than 4 months of cease to flow events within Boundary Creek prior to a first flush event.

The following is also assisting to reduce this risk further:

- Continuing to provide supplementary flows to Boundary Creek during dry periods to help mitigate against cease to flow events in Boundary Creek.
- The recovering LTA levels have indicated that more of the bottom end of the swamp are inundated more of the time, helping to prevent further acidification of soils during summer.

Should the downstream active treatment contingency be required, the detailed design that has been developed allows for procurement of a containerised chemical dosing system that could be easily procured and deployed.

Plan for next steps:

- Begin approvals process and commercial agreements for hydraulic barrier with the option to install this summer or at a later stage pending outcomes from the upstream treatment trial
- Develop trial plan and cost estimates of the upstream treatment - hold point / decision point as to whether to proceed
- Decision will be informed by consideration of and communication of implications for broader timeframes for implementation of other remediation actions
- If trial is to proceed, engage experts to begin trial of upstream treatment option, in line with the trial plan.
- Outcomes of the trial will then inform another hold point / decision point regarding full implementation of the caustic magnesia treatment in conjunction with installation of the hydraulic barriers

Timelines

Given the proposed next steps, at this stage it is not possible to provide a detailed action plan with timeframes for implementation of remediation actions. A detailed action plan may only be finalised once the trial plan has been developed for upstream treatment with caustic magnesia and the trial has been completed. The time needed to complete the trial is currently unknown but will be informed by the trial plan. Time frames for implementation of upstream treatment if the trial is successful can only be determined once the trial has been completed. Once the trial has been completed it will then be feasible to confirm timeframes for installation of the hydraulic barriers and downstream treatment contingency measure if required.

The updated actions and timeframes for competition (as they are determined) will continue to be tracked and reported in the task tracker included in quarterly updates and annual report.

Appendices

Appendix A: Hydrogeochemical modelling of Big Swamp and Boundary Creek

Hydrogeochemical modelling of Big Swamp and Boundary Creek

| Final

July 30

Barwon Water

Hydrogeochemical modelling of Big Swamp and Boundary Creek

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Executive Summary

Big Swamp is an acid sulfate soil swamp located on Boundary Creek that has become acidic through a combination of factors including groundwater extraction from the Barwon Downs borefield coupled with a drier climate and the ineffective regulation of passing flows along Boundary Creek. This has resulted in the ongoing discharge of acidic and metalliferous water from Big Swamp to the lower reaches of Boundary Creek and the Barwon River.

In response to this, Barwon Water have commissioned numerous studies and investigations to assess potential options for remediating the Big Swamp and Boundary Creek system. These studies have indicated that the inundation of Big Swamp via the installation of hydraulic barriers and enhancing flow supplementation is the most effective long-term mechanism for limiting ongoing sulfide oxidation and acidification.

This report builds on these previous studies to understand the potential hydrogeochemical outcomes associated with the implementation of such a remedial strategy to help inform subsequent decision making. It does so by:

- Reviewing groundwater and surface water monitoring data and a 1-day surface water monitoring event in Big Swamp to develop a robust hydrogeochemical conceptual model of Big Swamp,

- Undertaking modelling simulations to assess the potential risk of fish kills in the Barwon River in response to the discharge of water from Boundary Creek and hence, if contingency measures such as downstream treatment may be required to mitigate risks and ultimately improve remediation outcomes,

- Building a hydrogeochemical model based on the conceptual site model that is capable of simulating the chemistry of water monitored downstream of Big Swamp and using the model to simulate the potential changes in water chemistry discharging from Big Swamp in the presence and absence of remediation (i.e. inundation),

- Undertaking modelling simulations to inform the requirements of potential contingency measures to inform subsequent design,

- Assessing the duration over which remediation may take to occur in response to inundation and whether additional measures to increase the rate of remediation warrant further consideration.

The outcomes of the report can be summarised as follows.

Surface water monitoring event

A one-day sampling and field monitoring event was undertaken on the 7th of April 2021 to assess changes in water chemistry along surface water flow paths through Big Swamp. Two flow paths were observed during the event including the northern “primary” channel and a southern flow path which diverts water through the interior of the swamp. Surface water quality was monitored at 17 locations on the day using a field water quality meter and water samples were collected at 10 representative locations for detailed laboratory analysis. Field observations indicated that the northern flow path was not flowing on the day in question, suggesting that it is not the primary flow path through Big Swamp. This was a key assumption in the groundwater surface model by GHD (2020) and future updates to the groundwater surface water model should consider this.

Surface water quality results indicated that the greatest increase in surface water acidity occurred in the eastern portion of the swamp, suggesting that increased groundwater discharge in the eastern end of the swamp was the primary pathway for acidity mobilisation into surface water during the sampling event. Further, it was observed that surface water pH declined as water moved through the swamp and continued to decline in Reach 3 of Boundary Creek as the groundwater discharge from the swamp was oxidised.

Conceptual site model

The hydrogeochemical conceptual site model adopts a source, pathway, receptor approach to assess the primary mechanisms by which acidity is discharged to Boundary Creek. To do this, it combines groundwater and surface water monitoring data with static soil laboratory test work undertaken by Cook et al (2020) to characterise the relative stores of acidity and timing at which acidic discharge is observed in Boundary Creek.

The model highlights that the greatest store of acidity in Big Swamp appears to be soil acidity followed by groundwater acidity, while pore water acidity in the unsaturated zone appears to be negligible. Despite this, while the upper portion of the soil profile represented the greatest store of acidity in Big Swamp (810 tonnes of $CaCO_3$ equivalent), periods of high runoff over these soils when groundwater discharge modelled by GHD (2020) was low suggest that acidic runoff provides a negligible inputs of acidity into Boundary Creek.

Conversely, by applying a reasonable range in groundwater acidity concentrations based on monitoring data to the estimated groundwater discharge volumes provided by GHD (2020), the discharge of acidity from groundwater can account for all of the acidity observed in discharge from Big Swamp. This suggests that while soil acidity may represent the greatest primary source of acidity in Big Swamp, groundwater discharge represents the primary pathway by which acidity is discharged to Boundary Creek.

As such, the hydrogeochemical conceptual site model indicates that combining the groundwater-surface water model with monitoring of groundwater chemistry can be used to characterise the discharge of acidity from Big Swamp into Boundary Creek under current conditions and assess how this may change in response to barrier installation.

Hydrogeochemical Modelling

The modelling package PHREEQC was used to estimate the following:

- Potential ecological impacts of acidic water in Boundary Creek to the Barwon River
- Dosing requirements of a potential downstream contingency measure
- The timeframe associated with water quality changes with remediation involving the installation of hydraulic barriers
- Requirements of a potential upstream treatment system.

Potential impacts to the Barwon River

The discharge of acidic waters from Big Swamp have been documented to cause a fish kill event in the Barwon River downstream of its confluence with Boundary Creek in 2016 (Barwon Water, 2019). While the discharge of acidic water from Boundary Creek into the Barwon River is relatively well documented, to date there has been little investigation into how this translates into a risk of a fish kill event occurring in the Barwon River.

To assess this risk, surface water monitoring data from Boundary Creek upstream of Big Swamp, downstream of Big Swamp and in the Barwon River upstream of its confluence with Boundary Creek were reviewed to assess the key analytes which pose the greatest risk of causing a fish kill in the Barwon River. These were identified as pH, aluminium and iron.

To better understand the conditions under which these risks could be realised, a series of mixing simulations using the hydrogeochemical modelling package PHREEQC were undertaken to establish the proportion of flow from Boundary Creek relative to the Barwon River required to yield such risks. These results were subsequently compared to typical monthly flow conditions in both Boundary Creek and the Barwon River. This indicated that risks to the Barwon River are highest during May and June, when discharge from Boundary Creek contains higher concentrations of parameters of concern and flows from the creek begin to increase. Higher flow periods (July-August) tend to represent lower risks to the Barwon River due to lower concentrations of parameters of concern becoming diluted. Lower flow periods (December-March) also tend to represent lower risks to the Barwon River due to the reduced flow contribution from Boundary Creek. These results were consistent with sampling undertaken to date by Austral (2020).

The only recorded fish kill event in the Barwon River occurred in June 2016 when flows from Boundary Creek represented ⩾40% of those in the Barwon River. This period represents a flow event following flow cessation in Boundary Creek (known as a first flush). While other first flush events have yielded a similar contribution of flows to the Barwon River, these were preceded by 4 months or less of flow cessation in Boundary Creek, whereas the June 2016 event was preceded by more than 8 months of flow cessation in Boundary Creek. This suggests that the Barwon River is at the greatest risk of a fish kill event following an extended period of flow cessation in Boundary Creek (>4 months) when flows from Boundary Creek represent ≥40% of those in the Barwon River.

Downstream contingency measures

A number of potential contingency measures to improve water quality in Reach 3 of Boundary Creek and reduce risks to the Barwon River have been considered as part of the Remediation and Environmental Protection Plan (REPP). CDM Smith (2019) completed an options assessment as part of the development of the REPP and recommended aerial liming and an active treatment system be investigated as contingency measures. Jacobs (2021b) further refined the options assessment for the contingency measures, focusing on the implementation, constructability and operation and maintenance. Jacobs investigated the range of potential locations, application methods and chemicals that could be adopted as a contingency measure. A chemical dosing system located on the downstream (Eastern) end of the Big Swamp using sodium hydroxide (NaOH) as a pH correction chemical was recommended as the preferred option for the contingency measure.

To inform the potential design requirements of such a system, a series of simulations using PHREEQC were undertaken to achieve a variety of different pH outcomes in Boundary Creek based on the range of historically observed water quality analysis and flow rates. The modelling indicates that to achieve a pH of 6, NaOH dosing rates range from less than 80 L/day under summer low flow and initial flushing conditions, to 200 L/day during winter-spring high flows conditions and 700 L/day during ongoing flushing conditions. On a monthly basis, to achieve a pH of 6, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. On an annual basis, the total volume required to achieve a pH of 6 is estimated to be approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.

Model runs were also undertaken to assess the potential build-up of aluminium hydroxide and iron hydroxide precipitates which may need to be managed as part of contingency operation and maintenance. The annual build-up of aluminium and iron hydroxide sludge in response to sodium hydroxide dosing is estimated to be 24 m^3 assuming treatment to pH of 6.

Predicted water quality outcomes from inundation

The installation of hydraulic barriers through Big Swamp is one of several remedial actions recommended in the Remediation and Environmental Protection Plan (REPP) to improve the flows and water quality, as well as the vegetation and ecology in Boundary Creek and Big Swamp. The predicted water quality outcomes of the hydraulic barriers were assessed by combining the conceptual site model, the groundwater-surface water model (GDH, 2020) and the hydrogeochemical modelling software package PHREEQC to estimate the magnitude and timing of these changes.

Potential water quality outcomes following inundation were assessed by developing a hydrogeochemical model in PHREEQC and calibrating it to the observed water quality downstream of Big Swamp. This was subsequently used to, predict the change in water quality associated with enhanced groundwater discharge from the western end of the swamp as predicted by the groundwater-surface water model (GHD, 2020). This was used to estimate changes in the load of acidity discharging from Big Swamp. Results indicate that following inundation, the annual load of acidity discharging from Big Swamp may increase from approximately 80 tonnes $CaCO_3$ equivalent per year to approximately 160 tonnes $CaCO_3$ equivalent per year as a result of the enhanced discharge of acidic groundwater.

The mass of acidity available for contribution to the groundwater and surface water system (both existing and potential) was estimated by combining the static soil test results from Cook et al. (2020) with the modelled depth to watertable predicted in the presence and absence of inundation by GHD (2020). The results indicate that while the existing acidity remains unchanged between these two scenarios (approximately 3,900 tonnes $CaCO_3$ equivalent), the amount of potential acidity which may be released via oxidation is estimated to reduce from approximately 4,000 tonnes $CaCO_3$ equivalent to 1,600 tonnes $CaCO_3$ equivalent via watertable rise following inundation.

Accordingly, the results indicate that in the absence of inundation, water quality improvements in Boundary Creek would not be expected for approximately 100 years, while improvements following inundation may occur in approximately 35 years (noting that this does not take into account recovery of groundwater levels in the Lower Tertiary Aquifer which have not been modelled by GHD (2020) due to the absence of groundwater level information in the LTA in the western portion of the swamp prior to the undertaking of this report). This highlights that a potential upstream treatment may be required to improve the timeframe for remediation.

Potential upstream treatment option

As water quality improvement in Boundary Creek via inundation was estimated to take decades, and the Independent Technical Review Panel (ITRP) recommended that an upstream treatment system using caustic magnesia (MgO) be considered, further investigation into accelerating remediation via the introduction of alkalinity (via and upstream treatment option) was deemed warranted. However, there is little information publicly available on this particular method of treatment and the expert advice sought recommended that an onsite trial would be required to determine the viability of this method of treatment.

To inform the potential design requirements of such a system, a series of simulations using PHREEQC were undertaken to achieve a variety of different pH outcomes in Boundary Creek based on the range of historically observed water quality analysis and flow rates.

The results indicate that to achieve a pH of 6, dissolution rates range from less than16 kg/day under summer low flow and initial flushing conditions, to 40 kg/day during winter-spring high flows conditions and 80 kg/day during ongoing flushing conditions.

On a monthly basis, to achieve a pH of 6, dissolution rates range from 13 kg in March to as much as 2,700 kg in July. The total annual mass required to achieve a pH of 6 is approximately 14,000 kg, with the majority (9,500 kg) required between the months of May and September.

The upstream treatment option provides benefits by way of reduced sludge management and environmental risks associated with overdosing, however dissolution rates, alkalinity loads and the ability for alkalinity to reach areas of acidic discharge need to be proofed with field trials.

1. Introduction

1.1 Background

The hydrogeochemical evolution of the Boundary Creek and Big Swamp system reflects the culmination of numerous events throughout the catchment's convoluted history. This includes:

1- The initial deposition of acid sulfate soils in the swamp,

2- The construction of nearby agricultural drains and farming in the area over 100 years ago,

3- Step changes in climate (including the Millennium Drought),

4- The construction of an on-stream dam upstream of the swamp,

5- Groundwater extraction by Barwon Water and the release of supplementary flows to Boundary Creek, and

6- Peat fires in the swamp and the excavation of trenches by CFA to control these fires.

There have been numerous studies undertaken in the Boundary Creek Catchment that have focussed on characterising its hydrogeochemistry. A timeline of these studies and their implication for the remediation of Boundary Creek and Big Swamp are summarised below and in Figure 1-1.

Davidson and Lancaster (2011) undertook a preliminary inland Acid Sulfate Soil (ASS) assessment via a structured sampling program. While preliminary in nature, this study represented the first ASS site investigation at the swamp and in doing so, was the first to identify ASS in the swamp. The program identified the occurrence of both actual and potential ASS in the swamp and thus, that sulfide oxidation was currently active in the swamp.

Subsequently, Hirst et al. (2012) undertook a site investigation that specifically focussed on the effect of bushfires on soil geochemistry in a peat rich ASS environment. The study highlighted the formation of minerals a-typical to unburnt ASS environments, including maghemite and magnetite. Of interest to remediation, these minerals are relatively stable and less likely to participate in remedial geochemical reactions upon inundation.

Further geochemical analysis of soils in Big Swamp were completed by Glover (2014), who characterised the occurrence of an oxidation profile in certain areas of the swamp (i.e. that soils higher in the profile were acidic, though deeper in the profile high concentrations of sulfides remained with the potential for further drying to cause ongoing acidification).

In 2017, Jacobs undertook the Yeodene Swamp study. This focussed on reviewing the catchment history in concert with a soil, groundwater and surface water monitoring program to develop a conceptual model of the swamp, characterise its current hydrogeochemical state and assess the drivers of acidification in the swamp. The study found that the processes contributing to flow reductions in Boundary Creek (low rainfall and groundwater extraction) in 1990 and since 1999 were the key factors driving acidification.

Upon recognition of this, and in response to ongoing community concern, Barwon Water sought to remediate Big Swamp and Boundary Creek (which was subsequently enshrined in a section 78 notice) via the Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan (REPP). This lead to the undertaking of numerous studies including a comprehensive soil sampling program aimed at refining the soil geochemistry in the swamp (Jacobs, 2019a), soil incubation tests which simulated the soils geochemical response to inundation (Monash University, 2020), the development of a basic conceptual geochemical model of Big Swamp (GHD, 2019) and a preliminary groundwater-surface water model of Boundary Creek and Big Swamp (Jacobs, 2019b) to assess the viability of maintaining inundation in the swamp as a remediation strategy.

Through the undertaking of these studies, the spatial distribution and concentration of ASS (both in acidified and potential states) in the swamp was characterised, allowing for proposed inundation to target key areas of concern which are susceptible to further acidification upon oxidation. Further, it was found that while inundation may initially raise water pH in the swamp (via iron reduction), increases in pH would not be expected downstream of the swamp immediately following inundation. This is because the system appears to be sulfate limited with respect to sulfide formation and thus, the discharge of ferrous water from the swamp into Boundary Creek and its subsequent oxidation is likely to release any stored acidity, until all acidity in the system has been removed or treated.

Despite this, the primary remediation strategy for Boundary Creek and Big Swamp remains inundation as the most effective long-term mechanism for limiting ongoing sulfide oxidation and acidification. Further refinement of the groundwater-surface water model was undertaken during 2020 to determine the optimal combination of flow delivery and augmentation (via hydraulic barriers or flow diversions) to achieve inundation in areas susceptible to generating further acidity upon drying.

In parallel with groundwater-surface water modelling, ongoing groundwater and surface water chemistry have been monitored at monthly time intervals at 17 shallow (<6 m) bores within Big Swamp, 3 deeper nested bores immediately to its south east and surface water upstream-downstream of the swamp since late 2019.

The focus of this report is to combine monitoring data with the current understanding of hydrogeochemical processes occurring in the swamp and the results of the groundwater surface water modelling to undertake predictive hydrogeochemical modelling to estimate the changes in water quality in Boundary Creek in response to remediation. This exercise will be key to informing:

1- Whether the proposed remediation strategy will achieve the desired water quality outcomes

2- The timing associated with water quality changes

3- If additional (contingency) measures are necessary during remediation

This study was undertaken in conjunction with the following studies as required by the Remediation and Environmental Protection Plan (REPP):

- Detailed Design of the Hydraulic Barriers (Jacobs, 2021a)
- Big Swamp Contingency Measures Design Report (Jacobs, 2021b)

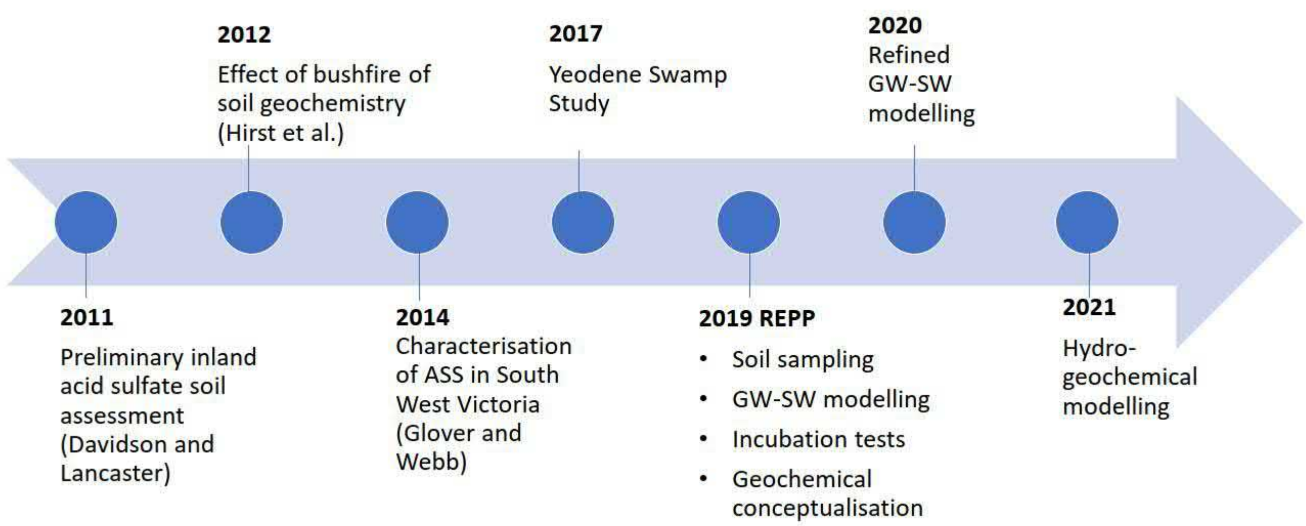

Figure 1-1 Summary of hydrogeochemical investigations of Boundary Creek and Big Swamp

1.2 Scope

Based on the above, this report aims to:

- Review a 1-day surface water monitoring event in Big Swamp undertaken on April 7th 2021
- Develop a hydrogeochemical conceptual site model (CSM) based on the results of groundwater-surface water monitoring (including the results of the 1-day monitoring event)
- Undertake modelling simulations using PHREEQC to assess the potential ecological risks and the risk of fish kills in the Barwon River in response to the discharge of water from Boundary Creek and hence, if contingency measures such as downstream treatment may be required to mitigate risks and ultimately improve remediation outcomes.
- Build a hydrogeochemical model using PHREEQC based on the CSM that is capable of simulating the chemistry of water monitored at the surface water gauge 233276 downstream of Big Swamp
- Use the model to simulate the potential changes in water chemistry discharging from big swamp in the presence and absence of remediation (i.e. inundation)
- Undertake modelling simulations using PHREEQC to assess the magnitude of potential contingency measures to inform subsequent design
- Assess the duration over which remediation may take to occur in response to inundation and whether additional measures to increase the rate of remediation warrant further consideration

1.3 Report Structure

- Chapter 2 describes the outcomes from the surface water monitoring event undertaken to inform the conceptual site model.
- Chapter 3 outlines the current understanding of the source of acidity, mobilsation pathways and impacts on the receptor (Reach 3 of Boundary Creek which discharges to the Barwon River)
- Chapter 4 discusses the potential conditions under which the Barwon River may be at greatest risk of ecological risks (primarily fish kills) as a result of acidic discharge from Boundary Creek
- Chapter 5 undertakes a series of modelling simulations to inform the potential requirements (dosing rates, and storage volumes) which a downstream dosing plant may need to meet to mitigate risks (primarily fish kills) to the Barwon River.
- Chapter 6 builds upon the conceptual site model and the groundwater surface water model developed by GHD (2020) to predict the water quality outcomes in Boundary Creek which may occur in response to remediation (barrier installation and flow supplementation) and subsequently, assess the duration over which remediation may take to occur.
- Chapter 7 provides an initial review of an upstream treatment solution which may enhance remediation.
- Chapters 8 and 9 summarise the reports conclusions and recommendations, respectively.

2. Surface water monitoring event

To help inform the hydrogeochemical conceptual site model, a one-day sampling and field monitoring event was undertaken on the 7th of April 2021 to assess changes in water chemistry along surface water flow paths through Big Swamp. Two flow paths were observed during the event including the northern "primary" channel and a southern flow path which diverts water through the interior of the swamp.

Field water quality parameters were collected at 17 locations on the day and water samples collected at 10 representative locations for detailed laboratory analysis. The sampling locations are illustrated in Figure 2-1 below. The surface water flow rate at gauge 233276 (downstream of Big Swamp) was 1.27 ML/day on the day of sampling and represents a period of moderate to low flow in the Boundary Creek system that was preceded by 7 days of no rainfall (see Figure 2-2).

Figure 2-1 Location of surface water monitoring and sampling locations in Big Swamp on April 7th

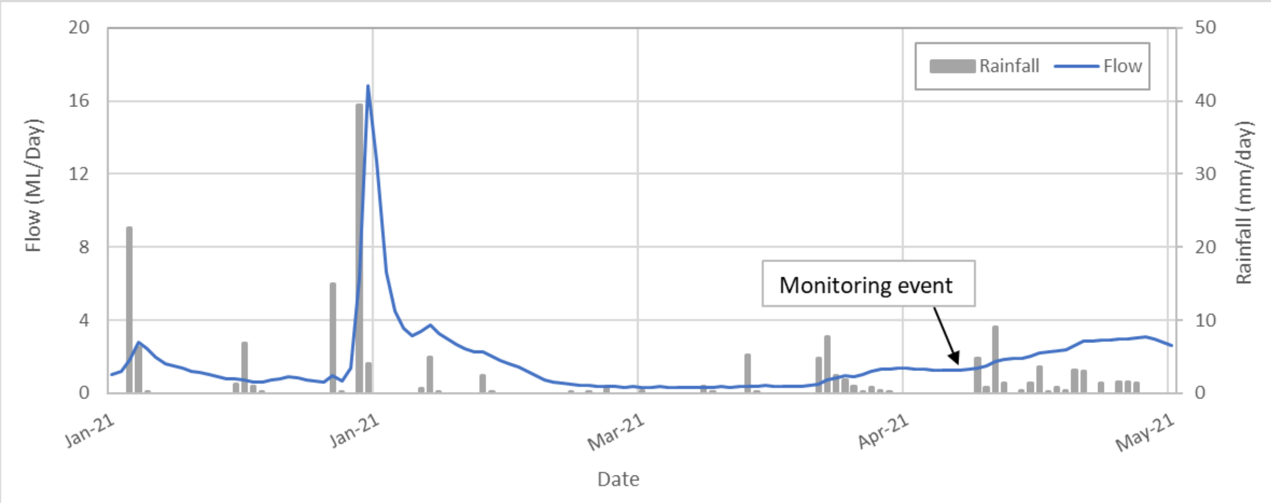

Figure 2-2 Rainfall and surface water flow conditions during surface water monitoring event (surface water monitoring at gauge 233276 and rainfall monitored at gauge 233250).

During the sampling event, flowing surface water was apparent in the interior of the swamp along the entirety of its length (at BH15, BH10, BH07 and BH01). However, flowing surface water was only observed in the northern channel between the gauge upstream of Big Swamp (233275) and the surface water sample point BC02. Surface water monitoring points in the northern channel downstream of this represented discrete pools of surface water that were either remaining from higher flow conditions during January and early February when the pools may have been connected, accumulated rainfall, or the surface expression of groundwater in topographic low points. These observations suggest that the northern channel does not represent the primary flow path through Big Swamp to the east of BC02 and that flows through the interior of the swamp predominate. The representation of flows paths through the swamp should be re-considered during future iterations of groundwater-surface water modelling.

The results of the field monitoring are summarised in Table 2-1 below with detailed laboratory results provided in Appendix A. Trends in the concentration of acidity and pH of surface water in both the northern channel and interior of the swamp have been illustrated in Figure 2-3 and Figure 2-4, respectively. These figures illustrate that under these conditions, concentrations of acidity are significantly less in western half of the swamp compared to the eastern half.

While a decline in pH was also observed along both flow paths, trends did not directly correlate with changes in concentrations of acidity. As indicated by Cook et al. (2020), aqueous pH values in Big Swamp can vary in response to iron reduction and oxidation. Given the dominance of Fe(II) derived acidity during the sampling event (see Appendix A), the increases in pH observed between 600-900 m is likely due to the input of reduced groundwater with elevated Fe(II) concentrations and higher pH values, as indicated by Cook et al. (2020). The subsequent decline in pH values at gauge 233276 is therefore likely to reflect the partial oxidation of dissolved Fe(II). It is also noted that further decline in pH was observed between gauge 233276 and 233278 at Yeodene, from 4.59 to 3.23, indicating further oxidation of Fe(II) through reach 3 of Boundary Creek.

It is also noted that concentrations of acidity and pH values of surface water at BH01 (336 mg/L and 5.44, respectively) have been excluded from the trends illustrated in Figure 2-3 and Figure 2-4 as although surface water was flowing at this location, the sampling location was on the fringes of the main flow paths and is therefore unlikely to characterise the main flow path. It is likely that flow paths around such fringing areas of the swamp will have longer residence times in the swamp and greater opportunity for interaction with soils or inputs from groundwater, resulting in higher concentrations of acidity. Future sampling events should aim to target the centre of the interior flow path in this area of the swamp, perhaps at BH02 or BH03.

Table 2-1 Field monitoring parameters during monitoring event

ID	Time	Easting	Northing	T	DO	EC	pH	ORP
233275	8:30	211227	5742085	12.9	11.83	303.9	7.06	147.5
Mon01	8:52	211253	5742042	12.8	13.47	289.8	7.09	110
Mon02	8:58	211265	5742007	13.1	23.02	289.2	6.98	88.3
Mon03	9:04	211304	5741992	12.9	12.65	290.9	6.76	83
BC01	9:16	211349	5742058	12.9	7.78	292.1	6.81	87
Mon04	9:29	211340	5742109	13.2	11.63	297.7	6.87	73.1
Mon05	9:34	211362	5742163	13	14.18	391.3	6.66	67.6
Mon06	9:42	211399	5742230	13.1	13.88	295.2	6.62	77.9
BC02	10:02	211546	5742352	11.7	3.4	492	5.83	n/a
BC03	10:36	211795	5742345	12.3	4.2	592	6.14	-17.6
Mon07	10:56	211940	5742315	12.6	7.3	562.3	5.99	3.4
BH15	12:50	211526	5742139	13.2	8.75	333.8	5.1	128.1
BH10	13:10	211811	5742255	13.7	7.72	426.5	5.39	86.1
BH07	13:27	211911	5742243	13.9	14.17	485.6	6.13	40.6
BH01	13:50	212056	5742139	15.6	9.77	572.3	5.44	89.1
233276	13:58	212114	5742221	15.1	11.37	638	4.59	141.1
Yeodene	14:47	212858	5742306	14.5	12.14	723	3.23	348.5

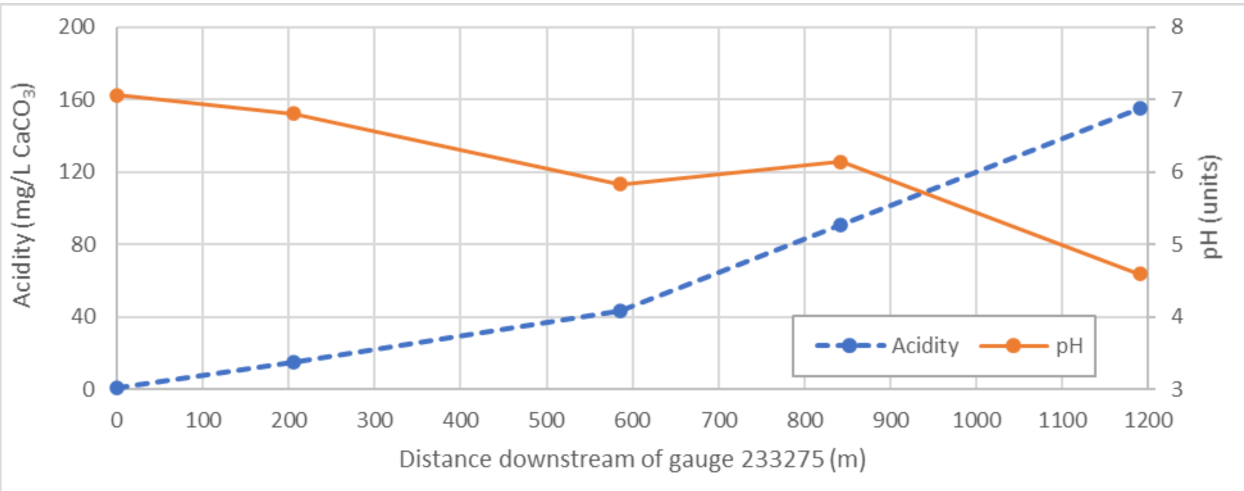

Figure 2-3 Trends in acidity and pH downstream of gauge 233275 in the northern channel

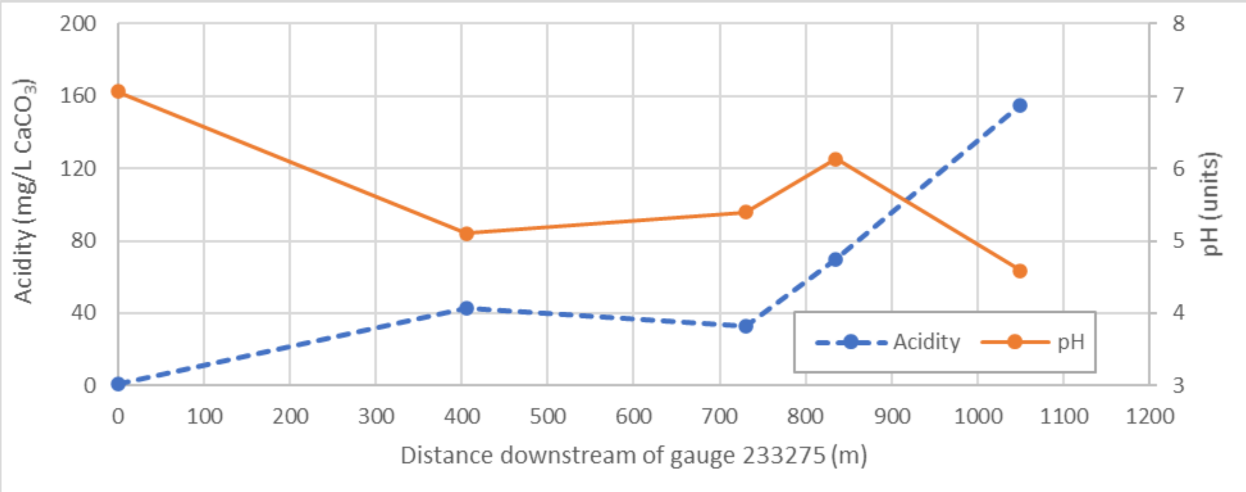

Figure 2-4 Trends in acidity and pH downstream of gauge 233275 in the interior of the swamp

3. Conceptual site model

The formation and oxidation of sulfides in Big Swamp represent natural processes and evidence of acidic discharge from Big Swamp and have been documented as early as 1990 or even earlier (Jacobs, 2018). However, there is benefit in considering the system using a source-pathway-receptor model that is more common of contaminated sites. This is because understanding the potential sources and pathways by which acidic and metalliferous water mobilises to Boundary Creek can aid assessment of potential remediation strategies. As such, the below conceptual site model (CSM) has been developed using a source-pathway-receptor model, which considers the following:

- The potential **sources** of acidity including that stored as solid phase minerals in surface soils; that stored in pore water in the unsaturated zone; and that stored in groundwater in the saturated zone.
- The potential **pathways** by which this can move into Boundary Creek including acidic runoff from surface soils, unsaturated zone flow and groundwater discharge.
- The effects of acidic and metalliferous discharge on water quality at the **receptor,** which in this case is Reach 3 of Boundary Creek.

For the purpose of this CSM, the primary "contaminant" considered is acidity. This is because, while other analytes (such as dissolved metals) may also be considered as contaminants of concern in the system, these are secondary in nature and their concentration is typically related to the concentrations of acidity and the pH of the water in Big Swamp. This is discussed further in section 3.3 below.

It is important to note the difference between "acid" and "acidity". While acid refers to a measure of the free hydrogen ions (H^+) in a solution which is typically expressed as pH (by pH = $-\log_{10}[H^+]$), acidity also considers additional latent H^+ which may be released via the hydrolysis of various metals and precipitation of metal hydroxides from solution. For example, the stepwise release of H^+ from pyrite in acid sulfate soils as summarised by reactions (1) to (3) below illustrates that the oxidation of iron (II) and precipitation of $Fe(OH)_3$ releases an additional net 2 moles of latent H^+ per mole of iron (II) that is oxidised.

$$FeS_2 + 3.5\ O_2 + H_2O \Leftrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + 0.25\ O_2 + H+ \Leftrightarrow Fe^{3+} + 0.5\ H_2O \quad (2)$$

$$Fe^{3+} + 3\ H_2O \Leftrightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

For the purpose of this CSM, acidity has been expressed in units of $CaCO_3$ equivalent (per volume of water or mass of soil). This is a conventional unit used within the ASS and AMD community and is useful in conceptualising the amount of $CaCO_3$ (as a concentration or a mass) required to neutralise the acidity present within a system.

3.1 Source of acidity

The primary source of acidified water in Boundary Creek could be simply described as oxidised sulfides in Big Swamp. However, for the purpose of this CSM this is an overly simplistic conceptualisation, as the oxidation of sulfides over the last 30 years has resulted in the movement of this acidity into different secondary stores. This includes:

- Acidity stored in solid phase as minerals in the soils themselves
- Acidity stored in groundwater resulting from the infiltration of acidic recharge/seepage
- Acidity stored in the pore water of soils in the unsaturated zone

3.1.1 Soil acidity

To characterise acidity in the solid phase, test work undertaken by Cook et al. (2020) on soil cores collected from the swamp have been used. The combined actual and retained acidity from the upper most sample from the soil profile at each of the 17 cores collected has been used to characterise the existing surface soil acidity as the most representative of those above the saturated zone. These soil samples were collected between 0.1 and 0.6 m depth below surface with an average depth of 0.24 m across the 17 samples.

The concentration of existing soil acidity in these samples ranged from 5.1 to 48.9 kg $CaCO_3$/t with an average concentration of 20.8 kg $CaCO_3$/t. The distribution of soil acidity throughout Big Swamp has been illustrated in Figure 3-1 below. This indicates that concentrations of acidity generally range between 10 and 30 kg $CaCO_3$/t throughout the majority of the swamp, with higher concentrations observed along the southern boundary of the swamp (at BH11 and BH14) and in the eastern end of the swamp (at BH01 and BH02).

The total mass of existing acidity in the surface soils of the swamp can be estimated by multiplying the average concentration of acidity measured in samples in each of the zones between contour intervals illustrated in Figure 3-1 by the mass of soil in each of the zones. The mass of soil in each of these zones can be estimated by multiplying the average depth of sampling (0.24 m) with the surface area in each zone and adopting an estimated soil density. Given the soils are clay dominated we have adopted a density of 1,400 kg/m^3 for dry clay (consistent with Cook et al., 2020). It should be noted that there is uncertainty in such an approach related to the heterogeneity of acidity concentrations in each of the zones as well as the density adopted (which commonly range from 1,200-1,600 kg/m^3 for clayey soils: e.g. Hillel, 1980; Linsley, 1993). This uncertainty could be reduced by undertaking additional surface soil sampling and analysis of soil density and acidity.

The mass of acidity in surface soils in Big Swamp can be summarised in each zone according to Table 3-1, which yields an estimated total mass of acidity of approximately 810 tonnes $CaCO_3$ equivalent. To provide an indication of the uncertainty associated with this approach, upper and lower estimates of acidity based on soil densities ranging from 1,200-1,600 kg/m^3 were made. This yields an upper acidity estimate of 920 tonnes $CaCO_3$ equivalent and a lower estimate of 690 tonnes $CaCO_3$ equivalent.

Table 3-1 Estimated mass of acidity in surface soils

Concentrations range	Average acidity (kg/t)	Estimated mass of soil (t)	Estimated mass of acidity (t)
<10	5	11,525	76
10-20	15	5,507	89
20-30	25	9,218	258
30-40	35	5,893	221
40-50	45	3,430	161
Total		35,574	807

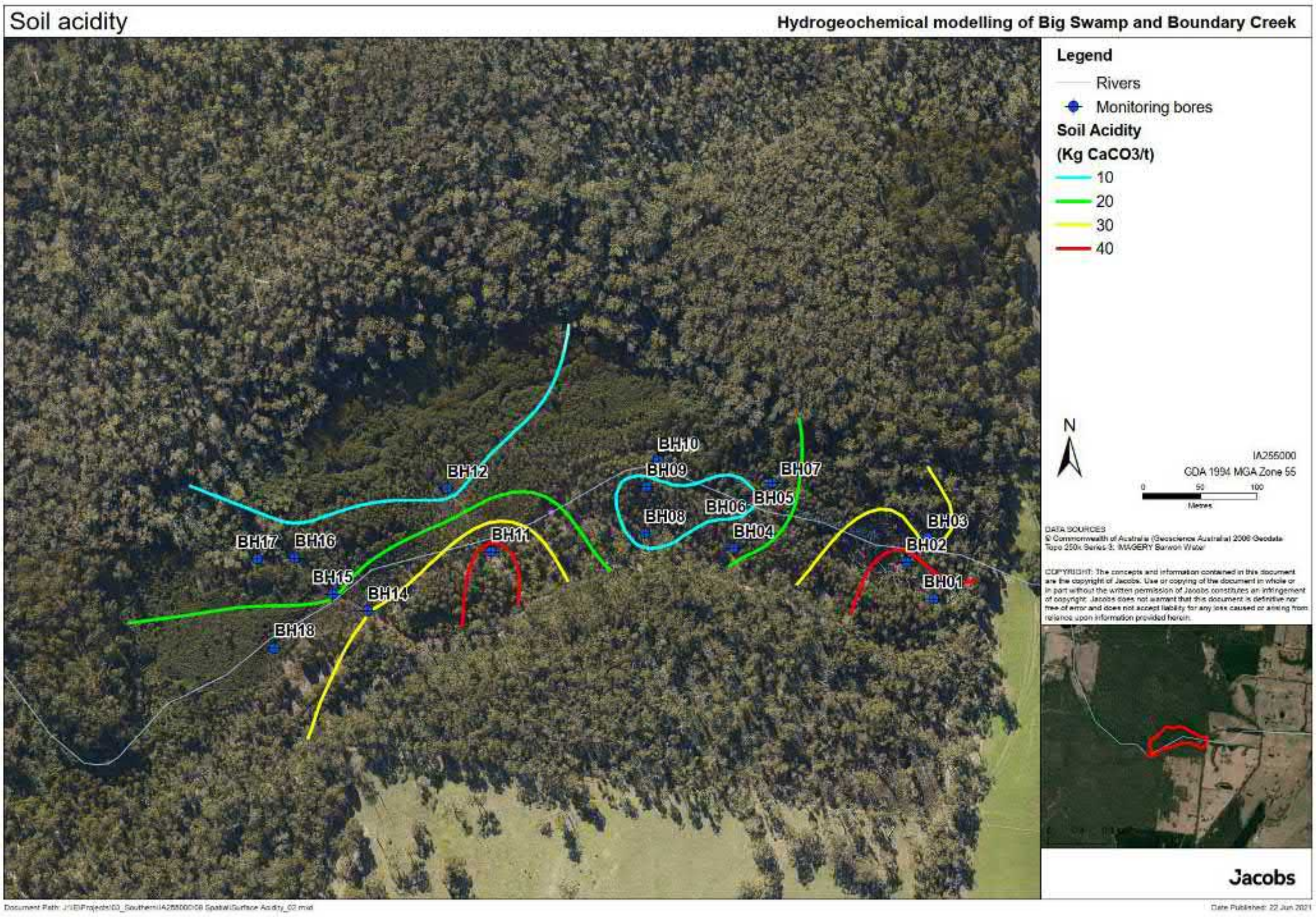

Figure 3-1 Spatial distribution of soil acidity in Big Swamp

3.1.2 Groundwater acidity

Temporal trends in groundwater acidity in each monitoring bore have been presented for the period between November 2019 and February 2021 in Appendix C. While it is recognised that temporal processes may influence the variability of groundwater acidity at each bore, these variations tended to be less significant than spatial variations across the swamp. This is illustrated in Figure 3-2 which shows the average concentration of acidity in groundwater at each bore relative to one standard deviation. On average, the standard deviation represented 40% of the average acidity concentration at any given bore, though this tended to be higher for bores with lower concentrations of acidity and lower for those with higher concentrations of acidity. Regardless, this variability is significantly less than the spatial variability in the average concentration of acidity across bores, which varied by as more than 4,000%. As such, spatial trends in groundwater acidity can be reliably made based on the average concentration of acidity at each monitoring bore.

Spatial trends in the concentrations of groundwater acidity throughout Big Swamp have been illustrated in Figure 3-3 below. This shows that concentrations of acidity are generally higher along the southern boundary of the swamp, as indicated by BH14, BH11, and BH09, BH08 and BH04, though this trend is most heavily influenced by BH14 and BH08 which exhibit average concentrations of >2,000 mg/L $CaCO_3$. BH04 and BH08 exhibit reduced groundwater level fluctuations and are further from surface water flow paths than other bores. As such, groundwater at these bores is unlikely to be diluted or flushed by throughflow or surface water infiltration to the same extent as other bores.

The lowest concentrations of acidity in groundwater in Big Swamp occur at the eastern end of the swamp across BH01, BH02, BH03, BH05, BH06 and BH07, in which the average concentration of acidity is <125 mg/L $CaCO_3$. These bores are located close to surface water flow paths, have groundwater levels close to the ground surface and groundwater is likely to be diluted or flushed by throughflow and surface water infiltration to a greater extent than other bores.

The average concentration of acidity at the remaining bores (BH10, BH12, BH15, BH16, BH17 and BH18) ranges between 200 and 900 mg/L $CaCO_3$. Other than BH12, these bores exhibit significant seasonal groundwater level fluctuations. Unlike BH14 and BH08 which are likely to be less connected to surface water, or bores at the eastern end of the swamp which are often likely to interact with surface wate, groundwater at these bores are likely to be diluted or flushed by throughflow and surface water infiltration predominantly under high rainfall and surface water flow conditions.

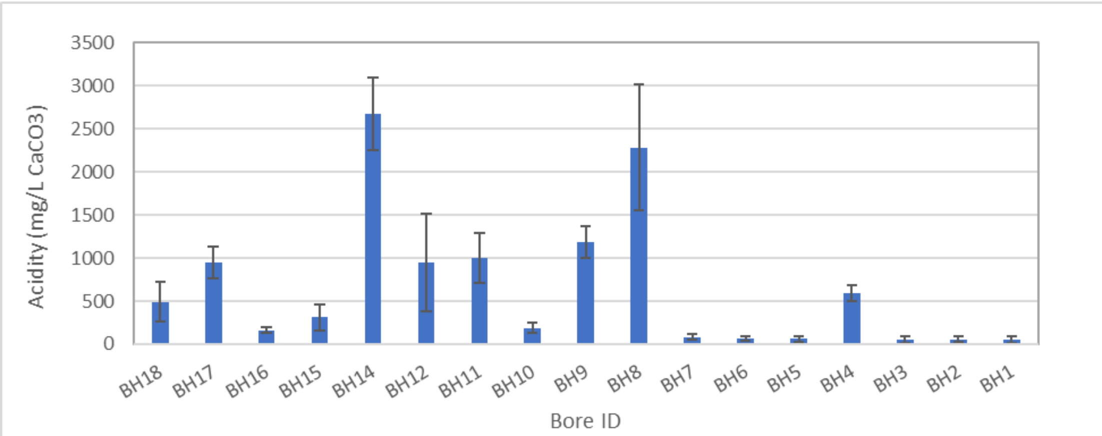

Figure 3-2 Average concentration of acidity in each monitoring bore in Big Swamp by month (+/- 1SD)

[1]Outlier sample May 2020 at BH8 not included in statistical analysis

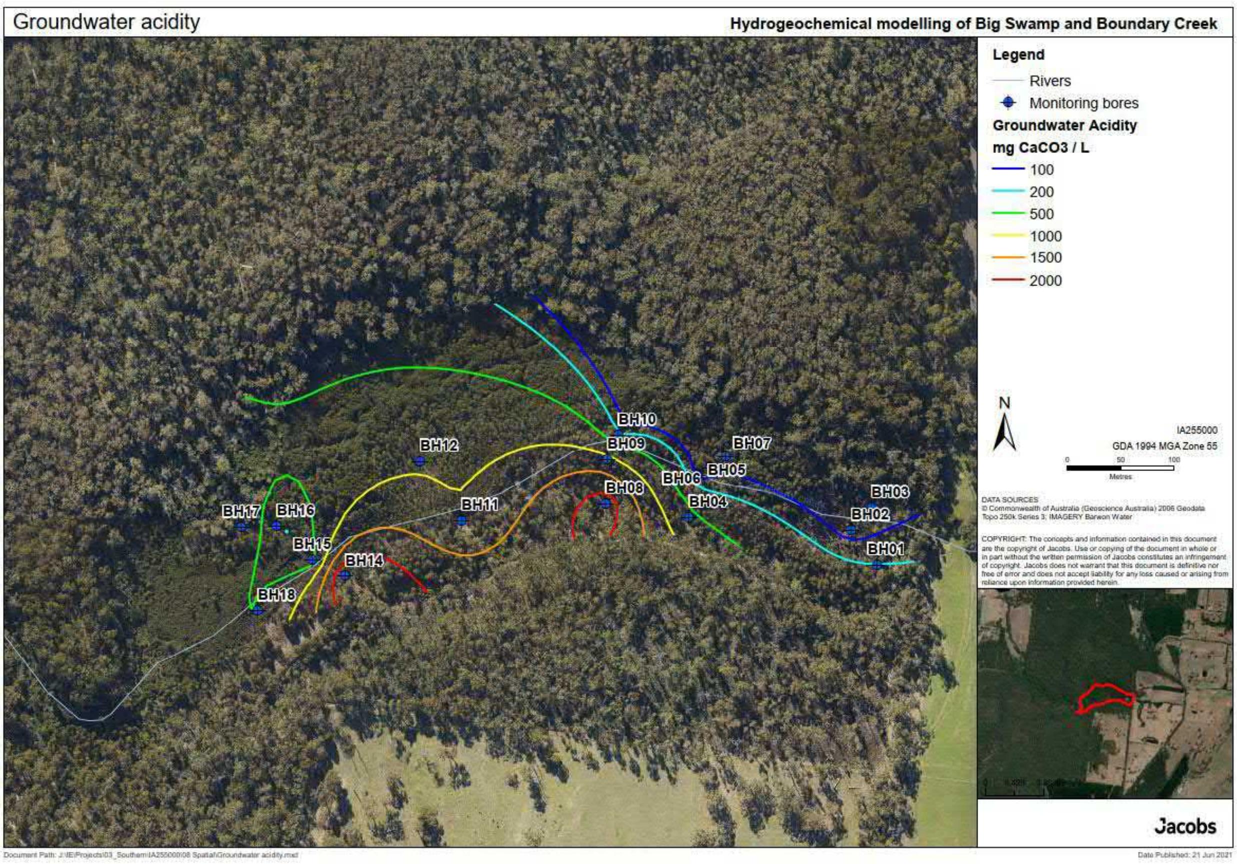

Figure 3-3 Average groundwater acidity concentrations in Big Swamp (based on monitoring data Nov 2019 to August 2020)

The total mass of acidity stored in groundwater in the swamp can be estimated by multiplying the average concentration of acidity measured in the zones between contour intervals illustrated in Figure 3-3 by the volume of groundwater in each of the zones. The volume of water in each of these zones can be estimated by multiplying saturated thickness of the affected aquifer in each zone by the aquifer porosity. The saturated thickness was estimated using the average depth to watertable as represented by monitored in each zone as provided in Appendix B and the bottom of the screened interval of 5 m bgl, and the aquifer porosity was assumed to be 0.4 for silty clays in accordance with Morris and Johnson (1967).

While the porosity of the alluvial aquifer may vary spatially and the range in porosities for a silty clay may range beyond this value (e.g. Morris and Johnson suggest a range of 0.34-0.61 for silts and clays) the value of 0.4 adopted here is reasonable estimate for the purpose of assessing the potential mass of acidity stored in groundwater compared to other sources. It is also recognised that this is higher than the upper estimate of the specific yield of 0.3 set in the groundwater model (GHD, 2021), however the estimate provided here represents the mass of acidity that currently exists in groundwater that could be drained over time via throughflow and discharge and not the current volume available for drainage.

The volume of water stored in the shallow alluvial aquifer in the swamp has been estimated at approximately 190 ML with an estimated acidity mass of 126 tonnes $CaCO_3$ equivalent. To provide an indication of the uncertainty associated with this approach, the range in the mass of acidity stored in groundwater was estimated by considering the range in aquifer porosities for silts and clays (0.34-0.61). This yields a potential range in the mass of acidity in groundwater of 107 to 192 tonnes of acidity as $CaCO_3$ equivalent.

It is noted that the thickness of the shallow aquifer affected by acidic infiltration could extend deeper than 5 m bgl. This uncertainty could be reduced by installing slightly deeper nested monitoring bores next to the existing bores.

Table 3-2 Estimated mass of acidity in groundwater

Concentrations range	Adopted acidity (mg/L)	Estimated volume of water (ML)	Estimated mass of acidity (T $CaCO_3$)
<100	75	49	4
100-200	150	16	2
200-500	450	43	19
500-1000	750	36	27
1000-1500	1250	22	27
1500-2000	1750	17	30
>2000	2250	7	16
Total		190	126

A summary of the temporal trends in the concentration of groundwater acidity in Big Swamp is illustrated in Figure 3-4 below, which presents the time varying average concentration of acidity across all monitoring bores in Big Swamp by month. This indicates that on average, the highest concentrations of acidity occurred during January-February 2020 following reduced rainfall and flow cessation in the swamp. This suggests that the absence of recharge and ongoing sulfide oxidation during this period resulted in the input of acid into the groundwater system. Conversely, the lowest concentrations of acidity occurred in May 2020 after increased rainfall and surface water flows in the catchment returned. While this provides a reasonable representation of general temporal trends across the swamp, it is recognised that such trends vary at each bore as illustrated in Appendix C and already discussed above.

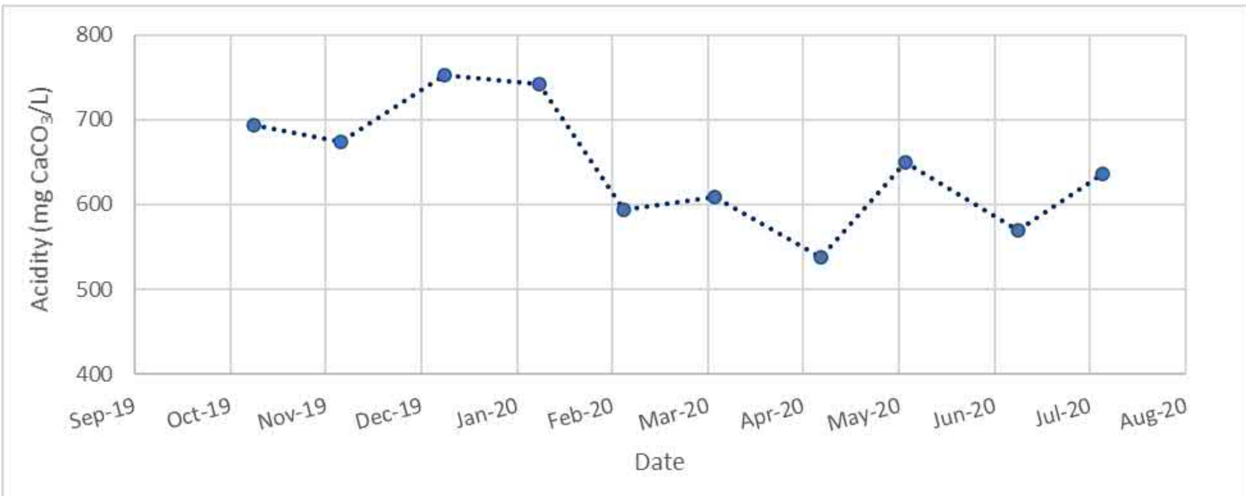

Figure 3-4 Average concentration of acidity across all monitoring bores in Big Swamp by month

3.1.3 Pore water acidity

Acidity stored in pore water in the unsaturated zone of soils in Big Swamp is the most difficult to characterise owing to the absence of leach test data or monitoring of the near surface groundwater (<1 m depth) which would be indicative of the chemistry of soil pore water. In the absence of this data, the best estimate of pore water acidity based on the available data can be made from shallow groundwater in monitoring bores when the watertable is close to the screened section (i.e. when the watertable is low) during periods immediately following rainfall events, when the vertical infiltration of water through the unsaturated zone will have the greatest influence on shallow groundwater chemistry.

To represent this, BH16, BH17 and BH18 have been selected as the groundwater levels in these bores fell to levels to 2.3, 1.9 and 1.3 mbgl over the 2019-2020 summer (see Appendix B), which is close to the top of screen in these bores at this time (2.0, 1.9 and 1.5 mbgl, respectively). Subsequent rainfall and surface water infiltration during February and March 2020 resulted in an increase in groundwater levels in these bores and as such, groundwater chemistry at this time may be more reflective of soil pore water than at other locations at other times. Furthermore, as these bores are located in the western end of the swamp, groundwater in these bores is less likely to be affected by geochemical processes occurring in the groundwater system (i.e. iron reduction) during lateral flow towards the eastern end of the swamp.

The concentration of acidity in groundwater from these bores during February and March ranged from 117 to 145 mg/L $CaCO_3$ in BH16, 723 to 929 mg/L $CaCO_3$ in BH17 and 537 to 897 mg/L $CaCO_3$ in BH18. A more detailed assessment of the relative sources of acidity in groundwater from these bores was evaluated by reviewing the concentration of dissolved metals which typically contribute to acidity of waters. These have been summarised in Table 3-3 below. The potential contribution of acidity from the below metals and existing dissolved H^+ was made by assuming that all metals are fully hydrolysed using the ABATES acidity calculator (Earth Systems, 2012), which provides reasonable estimates of acidity within this system (see further discussion in 3.3).

Based on this assumption, the majority of acidity in water from BH17 and BH18 was derived from Fe(II) (67% on average), followed by Al (19%) and H^+ (9%). Conversely, the majority of acidity in BH16 was derived from Al (43% on average) followed by Fe(II) (30% on average) and H^+ (24% on average). The relative proportion of iron(II) and iron(III) derived acidity in these bores may reflect the stage of the pyrite oxidation reaction chain, with a higher proportion of iron(II) likely to be present during step (1) of the of the chain described above, and a higher proportion of iron(III) likely to be present during step (2) of the chain above. Additionally, as the screened section of these bores includes groundwater from deeper in the groundwater system, it is possible that iron reduction has also affected the groundwater chemistry, yielding higher concentrations of iron(II).

If this is the case, then it is possible that the pore water acidity estimates provided here may be higher than in reality. The mass of acidity stored in pore water in the unsaturated zone can be estimated by multiplying the volume of soil water in the unsaturated zone by the average acidity tabulated in Table 3-3 (560 mg/L $CaCO_3$). The volume of water in the unsaturated zone can be estimated at a high level by assuming the soils are close to saturated because they are close to the watertable and adopting an estimated thickness of the unsaturated zone. For the purpose of this exercise we have assumed 80% saturation to reflect the shallow depth of the watertable in the swamp and a likely high moisture content, while the unsaturated zone thickness was estimated at the average watertable depth less the 0.24 thickness assumed to be exclusively soil acidity as discussed in 3.1.1. This yields a mass of approximately 11 tonnes of acidity as $CaCO_3$ stored in the unsaturated zone and is significantly lower than that estimated in soils or groundwater.

To provide an indication of the potential uncertainty associated with this approach, uncertainty in the porosity of soils (0.34-0.61) has been used to derive a range in the potential mass of acidity stored in pore water (though the real uncertainty may be much greater than this given that leach tests have not been undertaken). This yields a range in the potential mass of acidity stored in pore water of 9 to 16 tonnes $CaCO_3$ equivalent.

Table 3-3 Summary of typical analytes contributing to water acidity

Analyte	Unit	BH16	BH17	BH18	BH16	BH17	BH18
		05-Feb-20	05-Feb-20	05-Feb-20	03-Mar-20	03-Mar-20	03-Mar-20
Aluminium (Al)	mg/L	10	44	30	9.4	30	13
Iron (Fe2+)	mg/L	20	420	280	23	400	180
Iron (Fe3+)	mg/L	-	<0.2	-	1	70	<0.2
Manganese (Mn)	mg/L	0.9	2.1	0.082	0.87	1.7	0.046
Copper (Cu)	mg/L	0.006	0.11	0.031	0.005	0.14	0.026
Lead (Pb)	mg/L	0.001	0.01	0.007	<0.001	0.014	0.003
Zinc (Zn)	mg/L	0.23	0.42	0.4	0.21	0.32	0.21
Arsenic (As)	mg/L	<0.001	0.01	0.036	<0.001	0.007	0.032
Nickel (Ni)	mg/L	0.066	0.14	0.085	0.064	0.11	0.056
Cobalt (Co)	mg/L	0.038	0.06	0.013	0.041	0.046	0.006
Chromium (Cr)	mg/L	<0.001	0.01	<0.001	0.004	0.011	0.006
Cadmium (Cd)	mg/L	0.0002	0.002	<0.0002	0.0002	0.0003	<0.0002
Selenium (Se)	mg/L	0.002	0.04	0.002	0.002	0.027	<0.001
Silver (Ag)	mg/L	<0.001	0.01	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	mg/L	<0.001	0.02	<0.001	<0.001	<0.001	<0.001
Acidity ($CaCO_3$)	mg/L	145	929	897	117	723	537
pH	Units	3.5	3.9	2.5	3	4	2.8

3.2 Pathways for mobilisation

Based on the above described sources, there are three potential pathways by which acidity may move into Boundary Creek. This includes:

- Acidic runoff from surface soils
- Groundwater discharge to surface water
- Flushing of acidity from the unsaturated zone via interflow or hyporheic exchange

These have each been considered in more detail below.

3.2.1 Runoff

To assess the potential for acidic runoff to contribute to acidic discharge from Big Swamp, two analysis were undertaken. The first compares the mass of acidity discharging from Big Swamp to the mass of acidity stored in surface soils to assess whether the mass of acidity in this store could sustain the mass of acidity discharging from the swamp. Based on the source characterisation provided in section 3.1, the total mass of acidity stored in surface soils (upper 0.24 m) in the swamp has been estimated to be 810 tonnes of $CaCO_3$ equivalent. The monthly and cumulative mass of acidity discharging from Big Swamp over a calendar year has been estimated in Figure 3-5 below. This has been estimated by multiplying the average monthly discharge from Big Swamp by the concentration of acidity recorded under similar flow conditions as evidence by the co-variance of acidity concentrations and flow in Figure 3-6.

Accordingly, the annual mass of acidity discharging from Big Swamp has been estimated at approximately 80 tonnes per year. Given this, if runoff from surface soils was the primary pathway by which acidity was discharged in Boundary Creek, the total mass could sustain the current discharge of acidity to Boundary Creek for a period of approximately 10 years. Accordingly, this suggests that it is plausible for acidic runoff from Big Swamp to contribute to the mass of acidity currently being discharged to Boundary Creek.

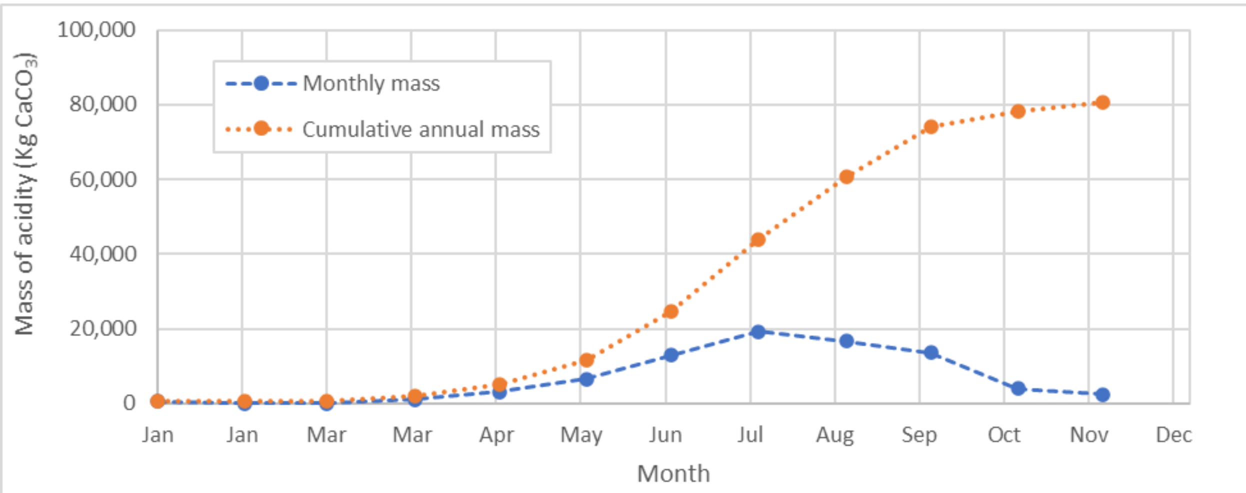

Figure 3-5 Monthly and cumulative mass of acidity discharging from Big Swamp

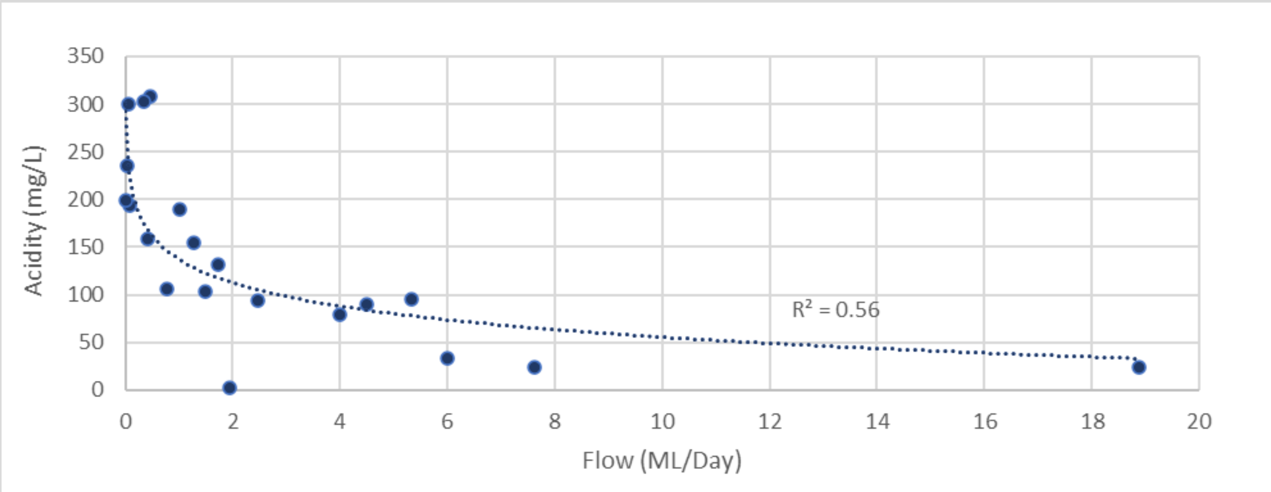

Figure 3-6 Trend in acidity concentrations versus flow in water discharging from Big Swamp 2019-2021 at gauge 233276

Another approach to assessing the potential contribution of acidic runoff from Big Swamp into Boundary Creek is to compare the timing of acidic discharge to Boundary Creek to the modelled surface water runoff in the Big Swamp sub catchment using the GR4J model developed by GHD (2020). This can be done two ways, the first is to review acidic discharge to periods when runoff is negligible and thus, estimate the minimum contribution from other stores (i.e. groundwater or pore water). This has been done for conditions over the 2020-21 summer in Figure 3-7 below. Accordingly, during both the January and February sampling events, there was limited runoff in the Boundary Creek catchment, with runoff representing 18% of streamflow in January and 8% of streamflow in February. Of particular interest, the February sampling even represents the 3rd highest load of acidity discharged from Big Swamp of the sampling rounds undertaken (404 kg $CaCO_3$/day). This suggests that acidic runoff is not the primary pathway by which acidity is discharged from Big Swamp into Boundary Creek.

Conversely, it is possible to assess the relative contribution of acidic runoff from Big Swamp into Boundary Creek by reviewing acidic discharge to periods when groundwater discharge is low and runoff is high and thus, estimate the minimum contribution from stores other than groundwater (i.e. runoff and pore water). The modelled groundwater discharge from Big Swamp into Boundary Creek is discussed in more detail in section 3.2.2 below, however the modelling indicates that the lowest volume of groundwater discharge to Big Swamp occurred during the December 2019 to January 2020 period (see Figure 3-10). The surface water sampling event in January 2020 yielded an acidity load of 5 kg/day discharging from Big Swamp. This suggests that in the absence of significant groundwater discharge when runoff if high, loads of acidity discharging from Big Swamp are negligible and thus, the influence of runoff on the load of acidity discharging from Big Swamp can be assumed to be negligible.

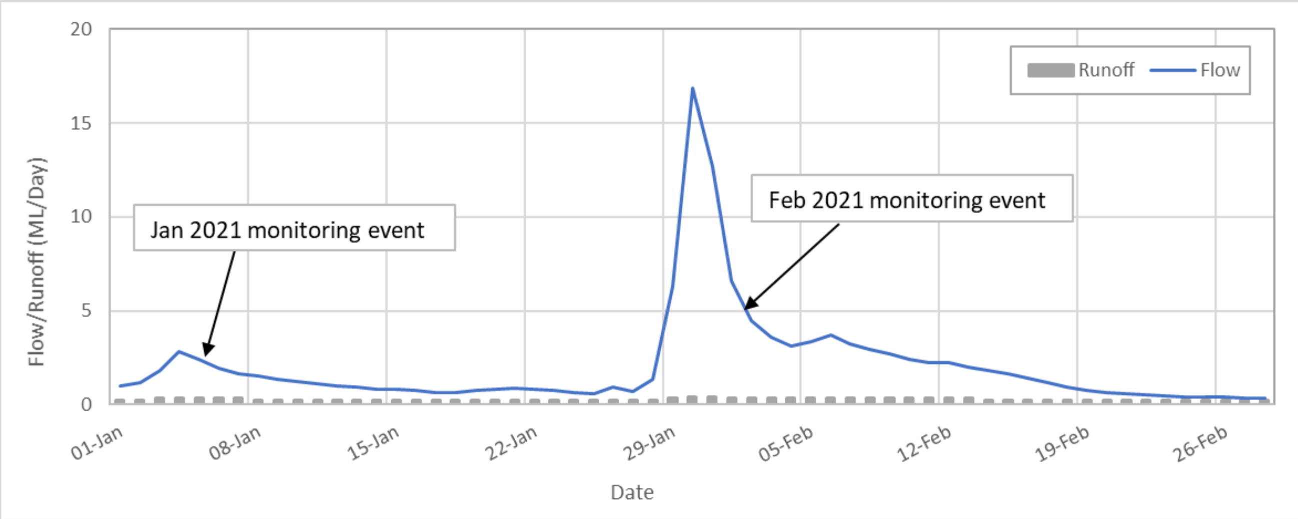

Figure 3-7 Modelled runoff in Big Swamp catchment and recorded flow (surface water monitoring at gauge 233276) during January and February 2021 sampling periods

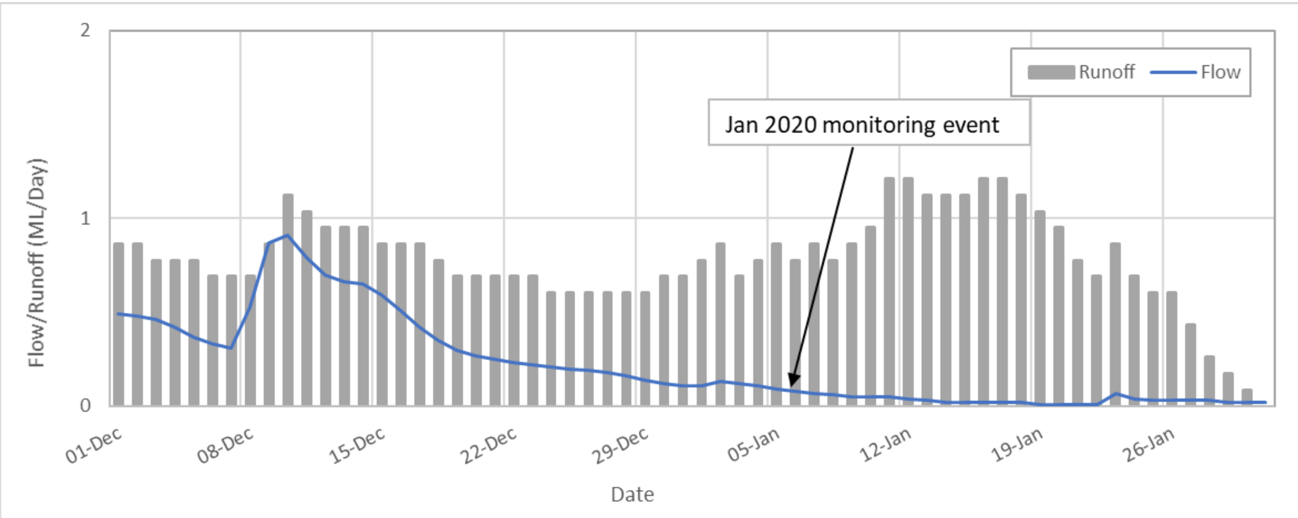

Figure 3-8 Modelled runoff in Big Swamp catchment and recorded flow (surface water monitoring at gauge 233276) during December 2019 - January 2020

3.2.2 Groundwater discharge

The mechanism by which groundwater acidity may move into Boundary Creek is via groundwater discharge. Figure 3-9 illustrates the ground surface elevation along the internal flow path in Boundary Creek and interpolated groundwater level elevations for dry conditions (1st Feb 2020) and wet conditions (1st October 2020) at bores along the flow path. Accordingly, the figure illustrates that groundwater levels in the western end of the swamp are typically below surface elevation (though higher than some of the surrounding topographic low points not on the section presented here) while groundwater elevations in the eastern end of the swamp are often above ground surface elevation. Accordingly, the figure suggests that groundwater discharge in the western end of the swamp will be minor, and dominated by the infiltration of acidic leachate, while the discharge of acidic groundwater to the surface will dominate the eastern end of the swamp.

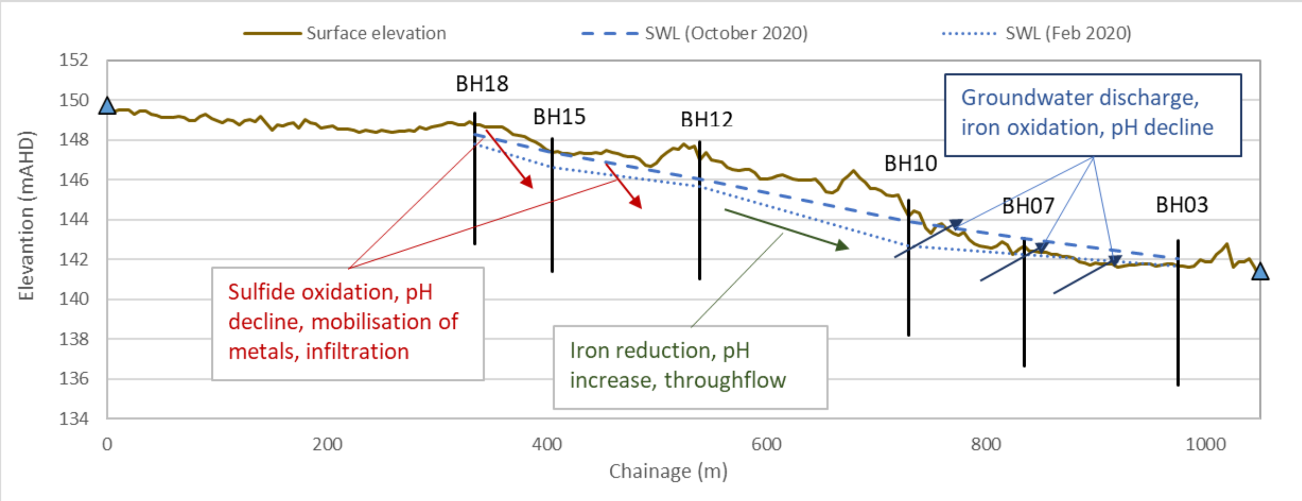

Figure 3-9 Ground surface elevation along internal flow path in Boundary Creek (from the digital terrain model used in the groundwater-surface water model) and interpolated groundwater level elevations for dry conditions (1st Feb 2020) and wet conditions (1st October 2020).

As illustrated in Figure 3-10, this is consistent with the modelling undertaken by GHD (2020). This shows the modelled volumetric discharge of groundwater in the western end of the swamp (represented by zones 1,2,3,8 and 9 in Figure 3-11) compared to those from the eastern end of the swamp (zones 4,5,6,10, 11 and 12). The average rate of groundwater discharge to the eastern end of the swamp represents more than twice that modelled in the western end of the swamp over the model duration, though it is noted that the contribution is more similar (within about 25%) during the January-March 2020 period.

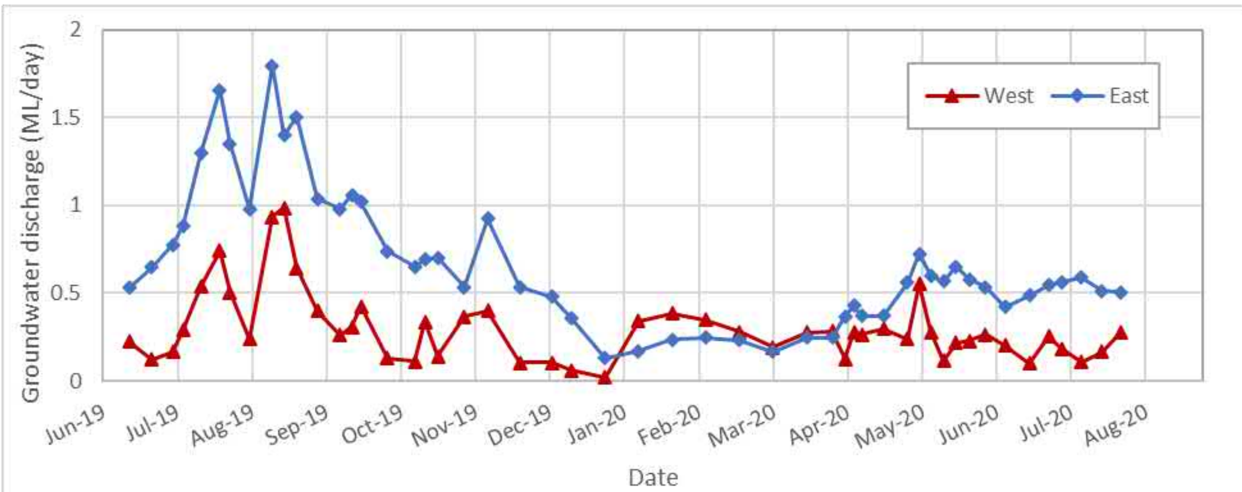

Figure 3-10 Comparison of modelled groundwater discharge to Boundary Creek in the west and east of Big Swamp (GHD, 2020)

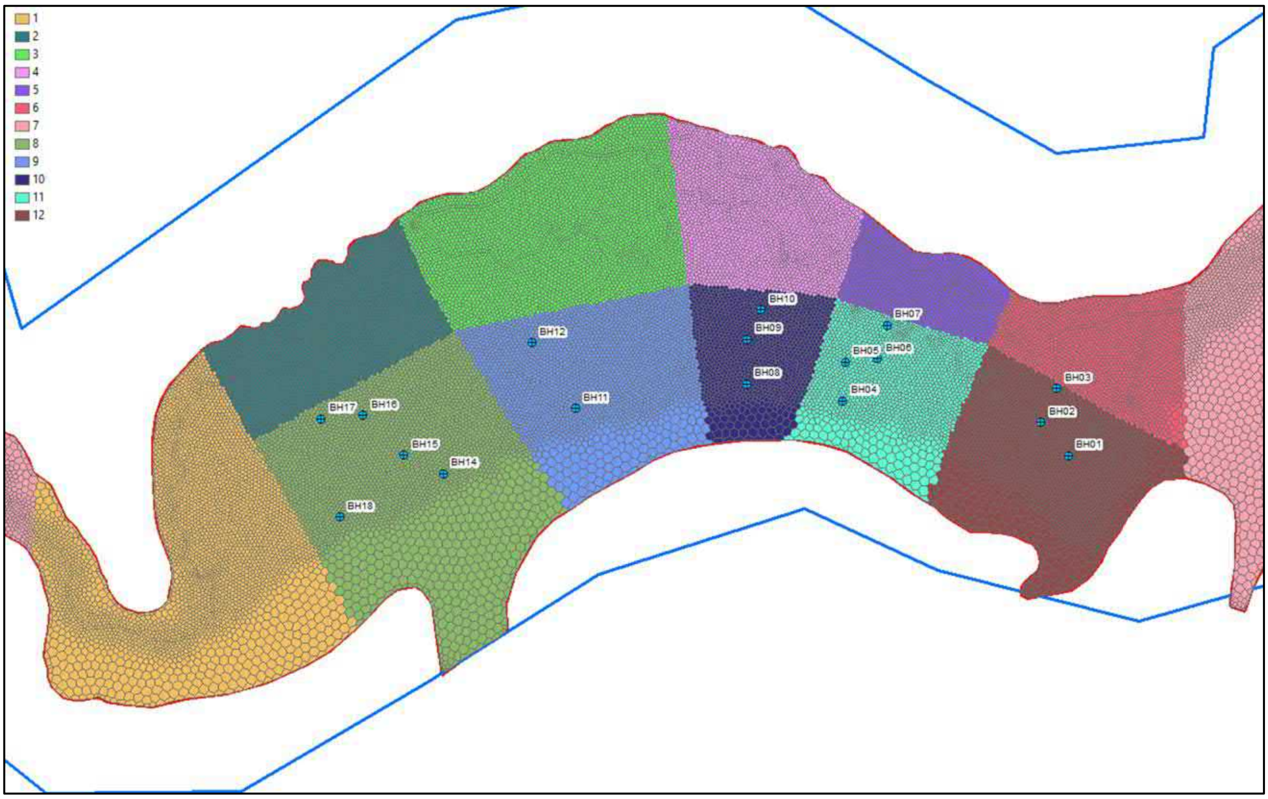

Figure 3-11 Groundwater zones included in groundwater-surface water model in GHD (2020)

Based on the above, the potential load of acidity discharging from Big Swamp into Boundary Creek can be simply estimated by multiplying the volume of groundwater discharging from the western and eastern zones by the relative concentrations of acidity in each zone as discussed in section 3.1.2. At a high level, the concentration of acidity in groundwater can be estimated by averaging the seasonal averages in those bores which appear to interact with groundwater in that area. While this is a crude estimate that would need to be refined as part of the more detailed geochemical modelling discussed in section 6, it is able to provide a useful first pass estimate of the capacity of groundwater discharge to sustain the observed loads of acidity being discharged from Big Swamp. For the purpose of this assessment:

- the average concentration of acidity in BH01, BH02, BH03, BH05, BH06, BH07, BH09 and BH10 has been used to characterise the acidity of groundwater in the eastern end of the swamp (218 mg/L $CaCO_3$)
- the average concentration of acidity in BH11, BH12, BH15, BH16, BH17 and BH18 has been used to characterise the acidity of groundwater in the western end of the swamp (644 mg/L $CaCO_3$)

Figure 3-12 below summarises the mass of acidity discharging from groundwater in the west and east of Big Swamp, and the combined total mass of acidity discharging from groundwater in Big Swamp based on the approach described above. Accordingly, the figure illustrates that the load of acidity derived from groundwater discharge from Big Swamp ranges between 40 and 990 kg $CaCO_3$/day over the groundwater-surface water model period, with the majority derived from groundwater with relatively high concentrations of acidity in the western end of the swamp. The figure suggests that groundwater is capable of accounting for the load of acidity observed in surface water at gauge 233276 which ranged from 2 to 510 kg $CaCO_3$/day over the same period, though it suggests that the method adopted here over accounts for acidity derived from groundwater.

There are number of factors which could account for this, including:

- groundwater discharge volumes are overestimated in the groundwater model
- concentrations of groundwater acidity adopted are too high

- temporal variations in acidity concentrations in groundwater need to be accounted for
- the method adopted here does not account for losses of acidity to the groundwater system (i.e. a portion of the acidity discharged in the western end of the swamp may be lost via seepage to groundwater along the flow path after becoming surface water)

These potential sources of discrepancy will be further interrogated during geochemical model set up and calibration.

Regardless, the estimates provided in Figure 3-12 below suggest that even under winter conditions when rainfall and runoff in the Boundary Creek catchment are high, the loads of acidity being discharge from the system are likely to be primarily sustained by groundwater discharge rather than surface runoff.

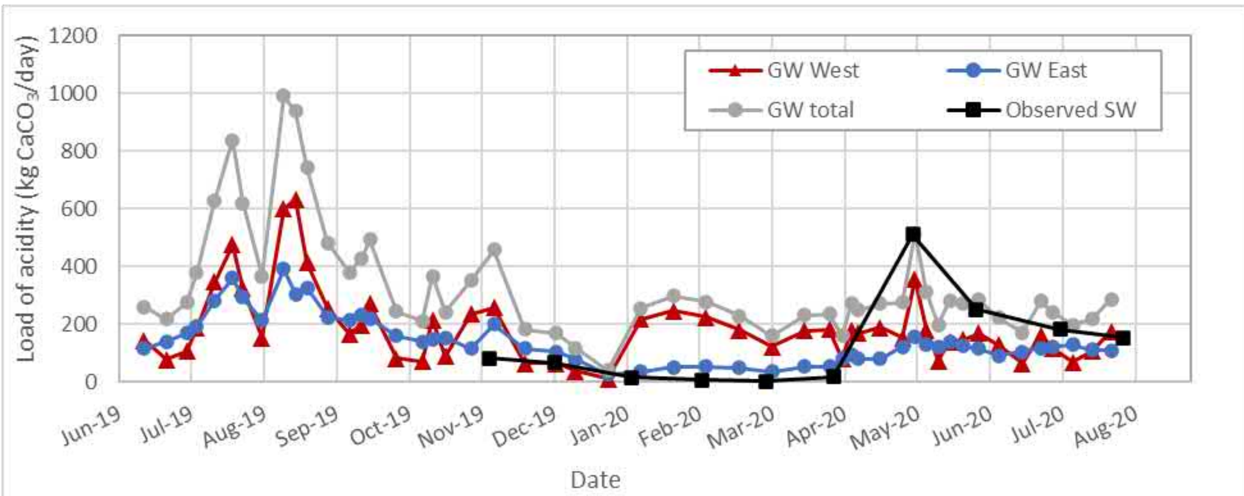

Figure 3-12 Estimated mass of acidity attributed for groundwater discharge from Big Swamp in the west, east and combined (total)

3.2.3 Unsaturated flow

The mass of acidity stored in the unsaturated zone is estimated to be relatively negligible (~13 tonnes $CaCO_3$) compared to other potential sources in the swamp (groundwater = 126 tonnes $CaCO_3$ and soils = 810 tonnes $CaCO_3$). This could be removed from the system in a month based on the estimated annual discharge rate of 80 tonnes per year, suggesting it is not the primary mechanism by which acidity is discharged into Boundary Creek. This is further supported by Figure 3-12 which suggests that loads of acidity being discharge from the system are likely to be primarily sustained by groundwater discharge rather than leaching from the unsaturated zone. Given this, leaching of soil moisture from the unsaturated zone appears to be a negligible process for further consideration as part of hydrogeochemical modelling.

3.3 Influence on the receptor – Reach 3 of Boundary Creek.

This section considers the effect of acidic and metalliferous discharge from Big Swamp on water quality in the receptor (Reach 3 of Boundary Creek) by assessing 3 key surface water quality characteristics:

- Surface water quality entering and exiting the swamp and temporal trends in surface water quality in response to flow;
- Acidity discharging from the swamp, the dominant forms of acidity and the total loads discharging from the swamp to help inform modelling scenarios; and
- Surface water quality compared to water quality objectives to better understand which physical and chemical analytes may have a negative impact on aquatic ecosystems.

The surface water quality of Boundary Creek has been monitored upstream and downstream of Big Swamp through (i) telemetered pH, water temperature and electrical conductivity (EC) measurements reported on a 15-minute timestep and (ii) grab samples collected on a monthly basis between November 2019 and May 2021 which were tested for a more complete set of water quality parameters (acidity, major anions and cations, dissolved metals and nutrients).

There is generally good agreement between the telemetered pH and electrical conductivity data and results from grab samples (Figure 3-13). Over the monitoring period, the pH of water in Boundary Creek rises from slightly acidic to neutral (pH range: 5.3 to 7.8, median: 6.9) upstream of Big Swamp and falls to acidic (pH range: 3.2 to 6.0, median: 3.7) downstream of Big Swamp. The electrical conductivity in Boundary Creek is generally lower upstream of Big Swamp (median EC = 431 µS/cm) than downstream of Big Swamp (median EC = 683 µS/cm). This is consistent with the leaching and mobilisation of metals from acidified soils in the swamp and the input of additional ions (such as sulfate).

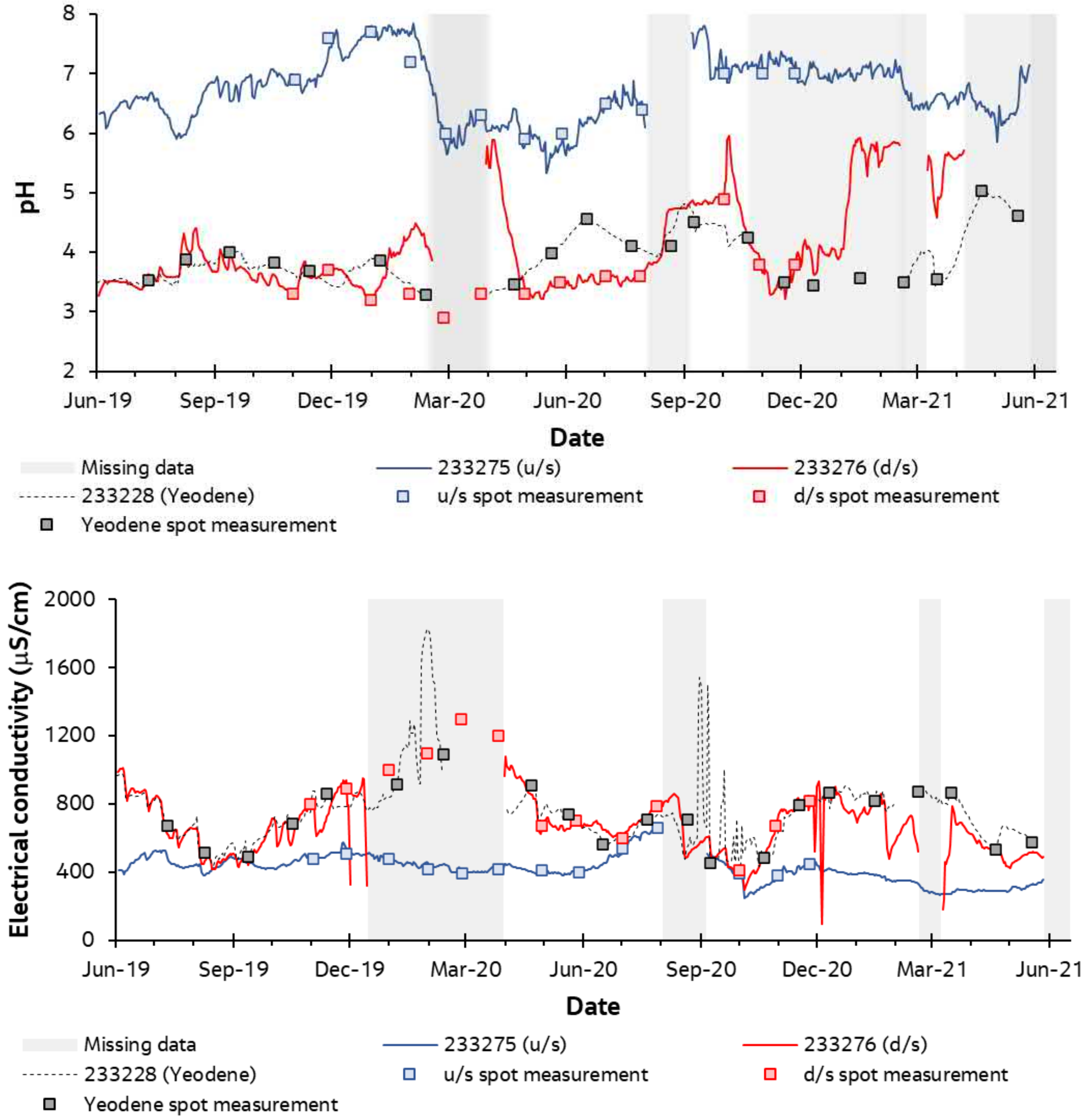

Figure 3-13: Boundary Creek pH (top) and electrical conductivity (bottom) measured upstream (u/s, station 233275) and downstream (d/s, station 233276) of Big Swamp and at Yeodene (station 233228). Lines are telemetered daily mean pH or electrical conductivity from data reported at 15-minute intervals from WMIS (https://data.water.vic.gov.au/). Squares are spot measurements collected during monitoring of surface water in Boundary Creek. Grey shaded areas indicate missing logger data.

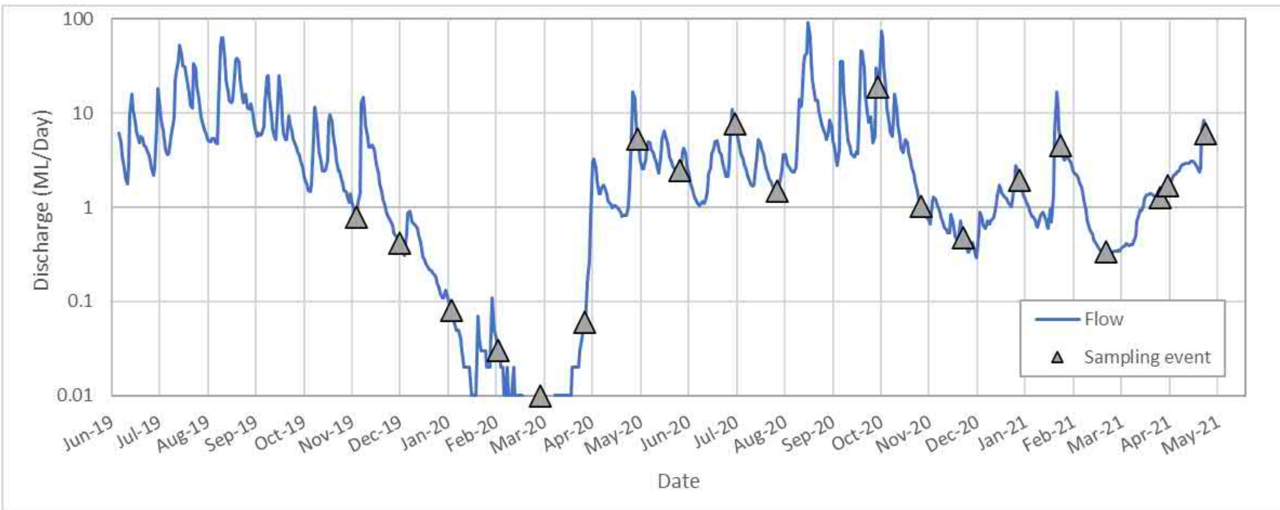

Figure 3-14: Timing of surface water sampling events vs flow in Boundary Creek at gauge 233276 downstream of Big Swamp.

The timing of surface water sampling in Boundary Creek has been illustrated in Figure 3-14 above. Results from sampling of surface water in Boundary Creek upstream and downstream of Big Swamp allow a more detailed assessment of the type of effect that acid sulfate soils in Big Swamp have on surface water chemistry in Boundary Creek. These data are illustrated in Figure 3-15 via statistical analysis that show:

- The pH of Boundary Creek downstream of the swamp is outside the range of water quality guideline values (WQGVs)
  - The pH of Boundary Creek upstream of the swamp is at the lower limit of the quality objective for rivers and streams in the lowlands of the Barwon River catchment in the *Environment Protection Act 2017* Environment Reference Standard (ERS) (pH 6.8 – 8.0). Downstream of the swamp, all pH values were well below the lower limit of the ERS quality objective – this represents an increase in the risk of stress to aquatic ecosystems in Boundary Creek.
  - The pH of Boundary Creek downstream of the swamp is also below WQGVs provided for agriculture and irrigation (pH 6 - 9, ANZECC & ARMCANZ, 2000) and recreation (pH 6.5 – 8.5, NHMRC, 2008).
- Concentrations of metals are higher downstream of the swamp
  - Concentrations of metals such as aluminium, nickel, selenium and zinc are generally below WQGVs for the protection of slightly to moderately modified freshwater ecosystems upstream of the swamp but above Australian and New Zealand guidelines for fresh & marine water quality (ANZG) WQGVs downstream of the swamp (0.055 mg/L for aluminium, 0.011 mg/L for nickel, 0.005 mg/L for selenium and 0.008 mg/L for zinc).[1] This represents an increase in the risk of direct toxicity to aquatic ecosystems as wells as an increase in the potential for secondary poisoning as selenium is known to bioaccumulate within food webs.
  - Although not shown in Figure 3-15, concentrations of boron, cadmium, chromium, cobalt, copper, lead, silver and thallium above WQGVs were also reported downstream of the swamp. Concentration increases associated with these analytes were not as significant as others, however these have been discussed further in section 4 for completeness.
  - Concentrations of iron were above WQGVs upstream and downstream of the swamp (0.3 mg/L; ANZECC & ARMCANZ, 2000) – the increase in concentration downstream of the swamp does however represent an increase in the risk of direct toxicity.

[1] Data are plotted as provided – the high metal concentrations reported for the upstream site were from January 2020 and appear to be more similar to downstream concentrations from surrounding trips. Similarly, the downstream concentrations report for January 2020 are more similar to upstream concentrations from surrounding trips. It appears as though the metals samples for the upstream and downstream locations may have been mixed up for January 2020 however no corrective action has been taken.

- Concentrations of ammonia and total nitrogen are higher downstream of the swamp whilst concentrations of total phosphorus are lower downstream of the swamp.
  - Concentrations of ammonia above the default WQGV for protection of aquatic ecosystems downstream of the swamp (0.90 mg N/L at pH 8; ANZG 2018). This represents an increased risk of direct toxicity to aquatic ecosystems. The toxicity of ammonia is dependent on pH – at a pH of 6, the WQGV for ammonia becomes 2.57 mg N/L which is greater than the reported downstream concentrations.
  - Total nitrogen concentrations downstream of the swamp were above the ERS WQGV (1.1 mg N/L) which could increase the risk of eutrophication in receiving waters.
  - The decrease in Total Phosphorus concentrations observed downstream of the swamp could also affect the risk of eutrophication as the nutrient balance (nitrogen-to-phosphorus ratio) in Boundary Creek is altered (though risks likely to be reduced by phosphorus limitation)..
- Dissolved oxygen saturation was lower downstream of the swamp
  - Dissolved oxygen saturation in Boundary Creek is generally within the ERS range upstream of the swamp (70 - 130%) however downstream of the swamp, dissolved oxygen saturation falls below the lower limit. This represents an increase in the risk of stress to aquatic ecosystems and could potentially lead to toxic effects should dissolved oxygen values be reduced to low levels for prolonged periods of time.
  - Dissolved oxygen saturation downstream of the swamp is also less than the lower limit for recreational water quality (>80%, NHMRC 2008)

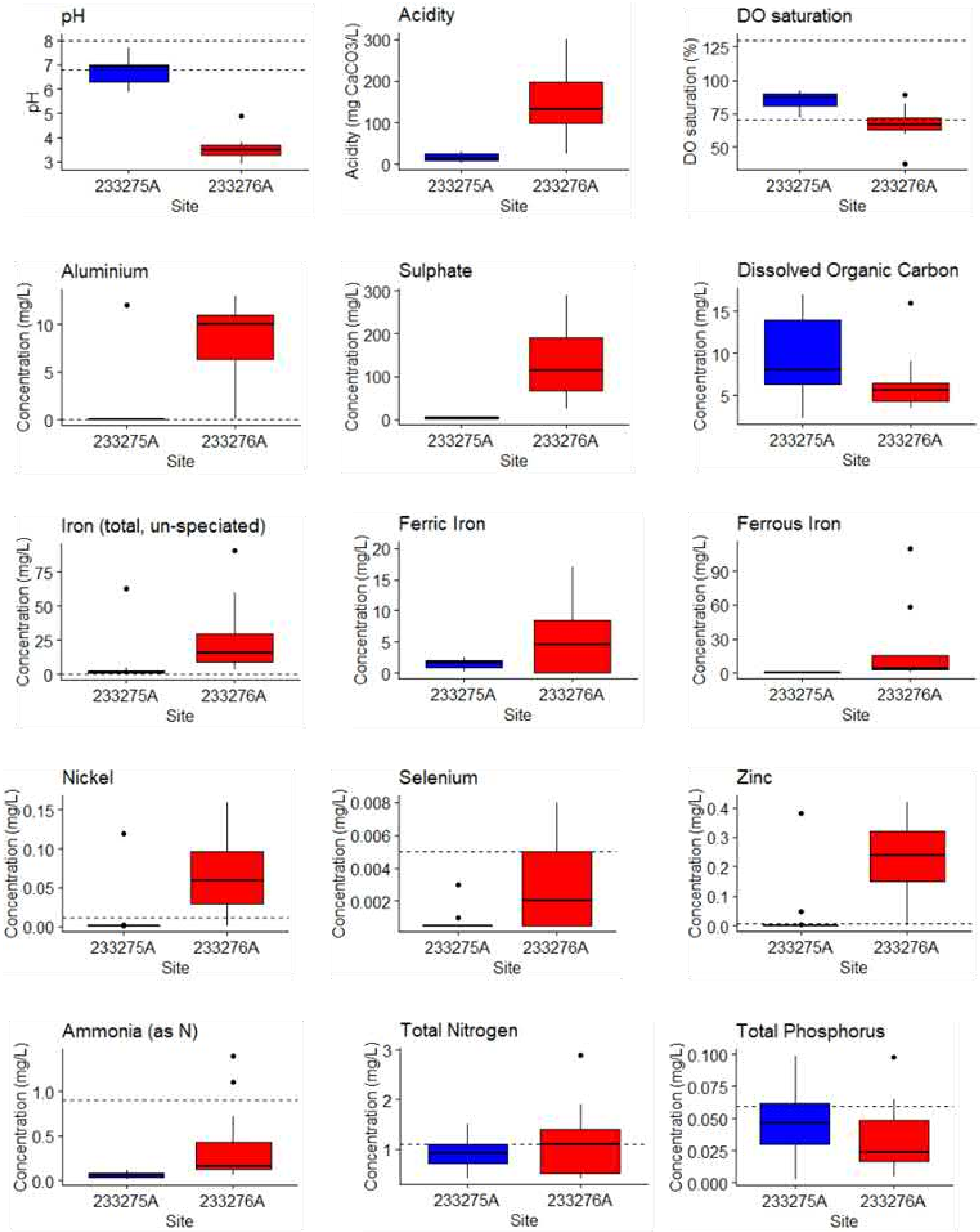

Figure 3-15: Surface water quality in Boundary Creek upstream of Big Swamp (site 233275A, blue box) and downstream of Big Swamp (site 233276A, red box). The box plots show the 1st and 3rd quartiles (lower and upper limits of box), median value (line within box), minimum and maximum values (limits of whiskers) and results R Statistical deems to be outliers (dots). The black dashed line represents water quality guideline values for the protection of ecosystems from the Environment Reference Standard or Australian & New Zealand guidelines for fresh & marine water quality – not all parameters have a guideline value.

A preliminary assessment of the source of acidity in surface water in Boundary Creek was made using the Acid Base Accounting Tool (ABATES) from Earth Systems (Earth Systems, 2012). This tool provides an estimate of the acidity in a given water sample based on the assumption that all dissolved metals within the water are fully hydrolysed, releasing H^+ in addition to the existing free H^+ in the water as indicated by pH. The analysis provides an initial first order estimate of the relative sources of acidity in surface water to inform subsequent modelling and the major mineral precipitates likely to form under remediation scenarios.

A comparison between the concentration of acidity measured in surface water samples at the laboratory and that estimated based on dissolved metal concentrations and pH is provided in Figure 3-16 below. The co-variance exhibits an R^2 value of 0.95 and a good fit between the two data sets, however it is noted that the ABATES tool tends to underestimate the acidity in samples by around 20%. This may be related to other sources of acidity in the water that are not captured in the suite of metals used in the ABATES tool or analytical errors during laboratory analysis. Regardless, the correlation suggests that acidity estimates can be reliably made using the ABATES tool and a correction factor.

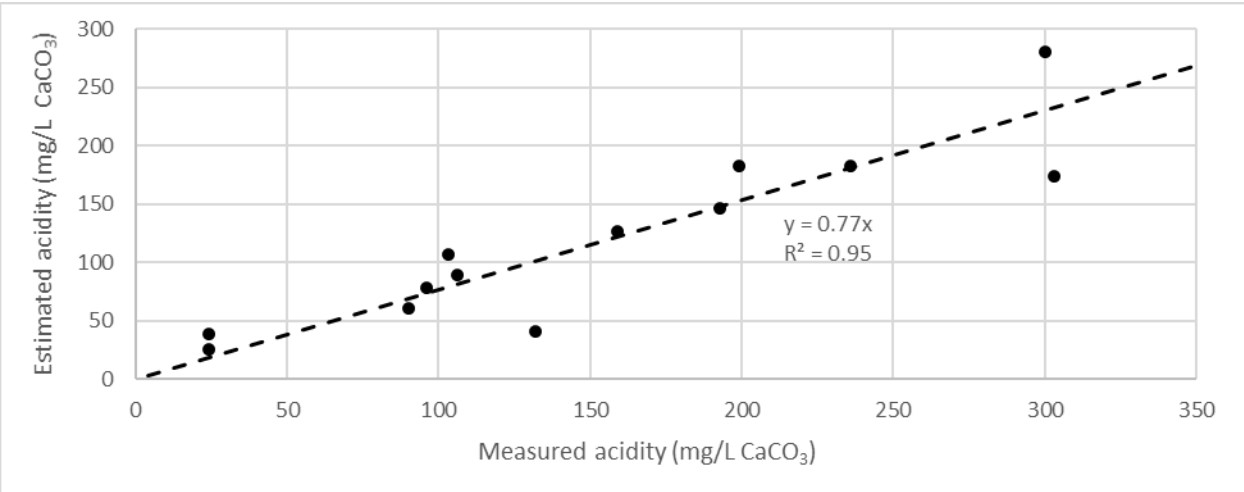

Figure 3-16 Measured and estimated acidity concentrations in surface water

Figure 3-17 illustrates the trends in acidity concentrations and loads downstream of Big Swamp over the monitoring program. The average concentration of acidity discharging from Big Swamp over this period was 130 mg/L $CaCO_3$. Concentrations between November 2019 and March 2020 generally increased, ranging from 109 to 199 mg $CaCO_3$/L as flows in Boundary Creek were low and subject to intermittent flow cessation. This is likely to reflect the absence of dilution effects over the period. This was also observed as flows reduced between October and December 2020.

The load of acidity discharging from Big Swamp over first 12 months of monitoring (Nov 2019 to October 2020), ranged from 2 to 603 kg/day. In the subsequent 5 months from Nov 2020 to May 2021, loads have ranged from 5 to 337 kg/day. During the initial 12-month period, a load of acidity of 511 kg/day was observed in May 2020, approximately 1 month following return to flow conditions in the system subsequent to flow cessation, suggesting such loads may have persisted for over a month in response to the flushing of accumulated acidity over dry conditions and the absence of flow. This was not observed during similar flow conditions in February 2021, suggesting that wetter conditions and the maintenance of flows in Boundary Creek over the 2020-21 summer may have reduced the accumulation of acidity in the system over the 2020-21 summer period to some extent.

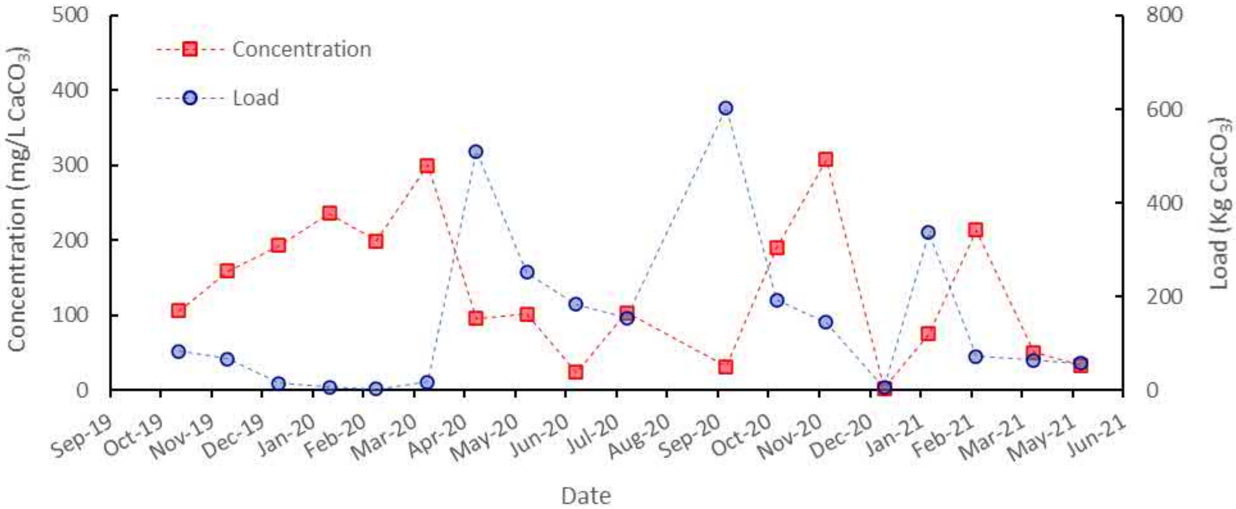

Figure 3-17: Concentrations and load of acidity discharging from Bid Swamp

The ABATES tool indicates that aluminium, iron and pH almost exclusively account for the sources of acidity discharging from Big Swamp during the sampling periods, with only 1-2% of acidity related to other metal species (though this does not include the correction factor applied and does not account for other potential sources of acidity not captured by the tool). The relative proportion of acidity from these sources during each sampling period is illustrated in Figure 3-18 below. As speciated iron analysis data was not available subsequent to September 2020 during this analysis, the analysis has been presented as acidity attributed to total dissolved iron (both iron(II) and iron(III) where speciated data were available and assuming all dissolved iron is iron(II) where speciated data were not available).

Accordingly, the dominant form of acidity discharging from Big Swamp is iron, which accounts for 51% of acidity in discharge water on average. Aluminium accounts for 34% of the acidity discharging from Big Swamp on average, with the remainder (14%) related to H^+. The proportion of acidity related to H^+ has declined from an average of 26% before July to an average of 3% since July 2020, as the pH of water discharging from Big Swamp has increased. Similarly, the proportion of acidity related to Al has decreased since July 2020, most likely due to the reduced solubility of Al at higher pH values. Accordingly, the proportion of acidity related to Fe has increased since July 2020.

As indicated by Cook et al. (2020), iron reduction can occur in Big Swamp sediments over weeks to months under reducing conditions, increasing water pH and reducing the solubility of aluminium. This suggests the drainage of subsurface water with residence times long enough to drive iron reduction in the absence of oxygen inputs has predominated since July 2020 under wetter conditions and the maintenance of flows in Boundary Creek.

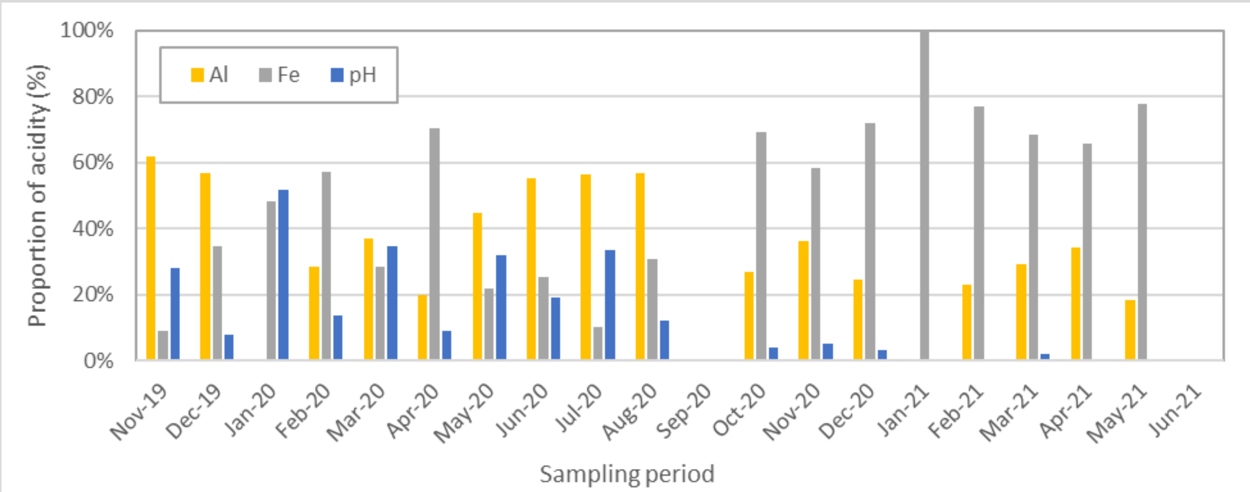

Figure 3-18 Relative proportion of acidity during each sampling period attributable to Al, Fe and H^+ (pH).

3.4 Summary of the conceptual site model

The above described conceptual site model indicates the following:

- The greatest store of acidity in Big Swamp appears to be soil acidity, and the upper 0.24 m of the soil profile has been estimated to contain 810 tonnes of $CaCO_3$ equivalent. However, the timing of acidic discharge with respect to periods of high and low runoff suggest this is not the primary mechanism by which acidity is discharged to Boundary Creek.

- Groundwater acidity stored in the shallow alluvial aquifer represents the second largest store of acidity in Big Swamp (126 tonnes of acidity as $CaCO_3$ equivalent) and modelling suggests that this is the primary mechanism by which acidity is discharged into Boundary Creek (though this would be sustained by the infiltration of acidity stored in the upper soils). As such, the recharge of acidity to groundwater via overlying soils and subsequent movement of groundwater into Boundary Creek should represent the focus of subsequent hydrogeochemical modelling.

- Pore water acidity in the unsaturated zone represents a minor store of acidity in Big Swamp (estimated to represent 11 tonnes of $CaCO_3$ equivalent) and leaching of soil moisture from the unsaturated zone appears to be a negligible process for further consideration as part of hydrogeochemical modelling (though movement of recharge through this zone into groundwater would occur).

- By combining the groundwater surface water model (GHD, 2020) with the monitored groundwater acidity, it is possible to characterise the discharge of acidity from Big Swamp into Boundary Creek under current conditions and assess how this may change in response to barrier installation.

- Uncertainty in the groundwater model, adopting appropriate groundwater acidity concentrations, temporal variations in groundwater acidity concentrations and losses of acidity to the groundwater system are processes which should be interrogated as part of designing and calibrating the hydrogeochemical model.

4. Potential impacts on the Barwon River from Boundary Creek

Historically, Boundary Creek was a perennial system with flows sustained during summer low flow period by groundwater discharge, primarily via discharge from the Lower tertiary Aquifer (LTA). Subsequent to borefield operation and the millennium drought, which lowered groundwater levels in the LTA, groundwater discharge to the creek has been reduced, resulting in flow cessation in the creek during summer low flow periods as early as 1984. A supplementary flow release of water to the creek has been in place since 2003, however the limited delivery and effectiveness of this release has resulted in ongoing flow cessation during low flow periods. As a result, acid sulfate soils in Big Swamp have dried out, oxidised and become acidic, resulting in the discharge of acidic waters to the lower reaches of Boundary Creek when it does flow.

The discharge of acidic waters from the swamp have been documented to cause a fish kill event in the Barwon River downstream of its confluence with Boundary Creek in 2016 (Barwon Water, 2019). In 2016, fish deaths in the Barwon River upstream of Winchelsea were attributed to undiluted acidic discharge from Boundary Creek (Ryan, 2016, Neal, 2018). The first report of fish kills at this time was made on Friday the 17th of June.

Similar low pH conditions in the Barwon River in 2018 were highlighted by the Corangamite Catchment Management Authority (Vogt, 2018). This low pH event was again attributed to discharge from Boundary Creek after heavy rainfall generated increased acidic discharge from Big Swamp. The first recorded pH decline associated with this event was made on Friday the 8th of June and while a fish kill event was not confirmed at this time, a pH value of 5.7 was recorded in the Barwon River downstream of its confluence with Boundary Creek.

While the discharge of acidic water from Boundary Creek into the Barwon River is relatively well documented, to date there has been little investigation into how this translates into a risk of a fish kill event occurring in the Barwon River. This section aims to do this by:

1- Reviewing the available surface water quality data available for Boundary Creek and the Barwon River upstream of its confluence with Boundary Creek.

2- Identifying key analytes of concern which pose the greatest risk of toxicity to fish.

3- Estimating the conditions under which the contribution of key analytes of concern from Boundary Creek are likely to result in a high risk of fish mortality in the Barwon River

4- Assessing the flow conditions under which this is likely to occur

The scope of this assessment was limited to understanding how acidic discharge from Boundary Creek could impact fish in the Barwon River due to community concern following the fish kill event in 2016 and low pH event in 2018, described above. Risks from acidic water discharge from Boundary Creek on other beneficial uses such as agricultural water use (stock water and irrigation), other industrial and commercial uses, recreation or Traditional Owner cultural values in the Barwon River were not assessed as part of the current scope of works.

4.1 Parameters of concern

Detailed surface water quality data for Boundary Creek was not available during the 2016 and 2018 events. As such, the screening level risk assessment described below includes surface water quality monitoring in Boundary Creek upstream and downstream of Big Swamp completed monthly since November 2019. Due to the timing constraints of this project, the screening level risk assessment has been based on data for Boundary Creek up to December 2020 (see section 3.3). Monitoring data continues to be collected and is available to inform future assessments.

The assessment also uses surface water monitoring in the Barwon River upstream of its confluence with Boundary Creek which includes:

- Barwon River at Forrest - monthly samples between June 2018 and April 2021 which measured conductivity, pH, dissolved oxygen, temperature, aluminium (acid soluble), iron and manganese, and a single sample for a broader metals suite from July 2018,

- Barwon River at Seven Bridges Road - two samples from July 2016 for major ions, pH, temperature, hardness, aluminium (acid soluble), iron, manganese and zinc.

For completeness, a comparison of these water quality data with that collected during macroinvertebrate studies between 2019 and 2021 (Austral, 2020) at similar locations to those above indicated that both data sets were relatively similar, with the majority of analytes below detection in the Barwon River upstream of Boundary Creek except aluminium, iron, manganese and zinc. Increases in Iron, aluminium and zinc were also observed in the Barwon River downstream of its confluence with Boundary Creek during sampling by Austral (2020).

4.1.1 Screening level assessment

There are a number of potential parameters associated with the acidic discharge from Big Swamp that could lead to ecological impacts such as fish kills in the Barwon River. To assess these, an initial screening level risk assessment has been completed as follows:

1- Comparison of water quality in Boundary Creek downstream of Big Swamp to water quality objectives for the protection of water dependent ecosystems and species from the ERS or ANZG (section 3.3), which are assumed to be WQGVS that would ensure the protection of fish. This step reviews water quality indicators in Boundary Creek downstream of Big Swamp and if a water quality indicator meets the ERS/ANZG WQGVs, then it poses a low risk to fish and no further assessment of a given parameter is required. The WQGVs used in the assessment are described in full in Table 10-1 in Appendix D, as are the test metrics used in the assessment.

2- Comparison of water quality in Boundary Creek upstream and downstream of Big Swamp. This step evaluates if water quality in Boundary Creek downstream of Big Swamp is the same or better than water quality in Boundary Creek upstream of Big Swamp. If so, then the residual risk posed by a parameter is low, and no further assessment of a given parameters is required. As above, metrics used in the assessment are described in Appendix D.

3- Comparison of water quality in Boundary Creek downstream of Big Swamp to water quality in the Barwon River upstream of its confluence with Boundary Creek. This step evaluates if water quality in Boundary Creek downstream of Big Swamp is the same or better than water quality in the Barwon River upstream of its confluence with Boundary Creek. If so, then the residual risk posed by a given parameters is low, and no further assessment is required. As above, metrics used in the assessment are described in Appendix D.

Subsequent to the above screening, theoretical dilution requirements for water quality in Boundary Creek to meet ERS/ ANZG WQGVs after mixing with passing flows in the Barwon River were calculated. Following this process, parameters with higher dilution requirements are likely to pose a higher level of risk to water dependent ecosystems and species than indicators with lower dilution requirements.

Theoretical dilution requirements can be compared to available dilution in the Barwon River (section 4.2) to identify when passing flows in the river are high enough to dilute Boundary Creek inflows so WQGVs are met downstream of the Boundary Creek – Barwon River confluence.

Dilution requirements (Sreq) were calculated using Equation 1 – further information for the calculation is provided in Appendix D. The Sreq is a ratio X:1 where X is flow in the Barwon River upstream of the Boundary Creek confluence.

Equation 1

where, S_{req} = required dilution factor to meet WQGV

$C_{Boundary\ Creek}$ = concentration in Boundary Creek downstream of Big Swamp.

C_{wqgv} = water quality guideline value

$C_{Barwon\ River}$ = ambient concentration in Barwon River, i.e. upstream of Boundary Creek confluence.

If the concentration in the Barwon River was higher than the WQGV or no data were available for the Barwon River, then Sreq was calculated by simple dilution, $C_{Boundary\ Creek}/C_{wqgv}$. As simple dilution does not consider the reduced dilution capacity of the receiving water (the Barwon River) caused by the presence of the indicator it is a lower limit of Sreq.

For aluminium and iron, the ambient concentration in the Barwon River did not meet WQGVs and (interim) site-specific WQGVs were also used to estimate Sreq. The (interim) site-specific WQGVs were 80th percentile values from the Barwon River upstream of the Boundary Creek confluence (n=70). Further information about setting of these site-specific WQGVs is provided in Appendix D.

The following parameters in Boundary Creek downstream of Big Swamp did not meet WQGVs for the Barwon River (Table 4-1):

1- Metals – aluminium, cadmium, chromium, cobalt, copper, iron, nickel, selenium, silver, thallium and zinc
2- Nutrients – ammonia and total nitrogen
3- Physicochemical parameters – dissolved oxygen saturation (lower limit) and pH (lower limit).

None of these indicators were of equal or better quality than Boundary Creek upstream of Big Swamp or the Barwon River upstream of its confluence with Boundary Creek.

For ammonia and nitrate, the WQGVs adopted were for protection of water dependent ecosystems and species from toxic effects rather than stress caused nutrient enrichment leading to eutrophication. Although there are WQGVs for the action of ammonia and nitrate as ecosystem stressors provided in ANZECC & ARMCANZ (2000), the ERS does not refer to these objectives. Instead, the ERS provides WQGVs for total nitrogen and total phosphorus for the geographic region of the Barwon river basin. As the WQGVs provided for ammonia and nitrate as ecosystem stressors in ANZECC & ARMCANZ (2000) are regional WQGVs for south-east Australia, adoption of the local WQGVs for total nitrogen and total phosphorus as indicators for eutrophication is in line with guidance provided in the ANZG (2018).[2]

Table 4-1: Screening level risk assessment summary. Green cell shading indicates that the condition for 'low risk' is met and no further assessment is required.

Parameter	Unit	WQGV [1]	Boundary Creek downstream of swamp [2]	Boundary Creek upstream of swamp [2]	Barwon River upstream of Boundary Creek [3]	Dilution requirement (Sreq, X;1)
Aluminium	mg/L	0.055	12.4	0.02	0.22	230 [4]
		0.15 [1]a			0.06	136
Ammonia (as N)	mg/L	0.9	1.2	0.06	No data	1 [4]
Antimony	mg/L	0.009	0.001	WQGV met - No further assessment required		
Arsenic	mg/L	0.013	0.001	WQGV met - No further assessment required		
Boron	mg/L	0.94	0.21	WQGV met - No further assessment required		
Cadmium	mg/L	0.0002	0.0004	<0.0002	<0.0002 [3]a	2

[2] https://www.waterquality.gov.au/anz-guidelines/monitoring/data-analysis/derivation-assessment

Parameter	Unit	WQGV [1]	Boundary Creek downstream of swamp [2]	Boundary Creek upstream of swamp [2]	Barwon River upstream of Boundary Creek [3]	Dilution requirement (Sreq, X;1)
Chromium	mg/L	0.001	0.054	<0.001	<0.001 [3]a	54 [4]
Cobalt	mg/L	0.0014	0.036	<0.001	<0.001 [3]a	86
Copper	mg/L	0.0014	0.003	<0.001	<0.001 [3]a	4
Dissolved Oxygen	% saturation	70-130	62.7 – 89.1	81.1 – 92.1	75.3	N/A [5]
Electrical Conductivity	µS/cm	2,000	1000	WQGV met - No further assessment required		
Iron	mg/L	0.3	72.4	2	2.9	241 [4]
		1.4			0.8	118
Iron (total dissolved)	mg/L	0.3	53.2	0.46	2.9	177 [4]
		1.4 [1]a			0.8	86
Lead	mg/L	0.0034	0.002	WQGV met - No further assessment required		
Manganese	mg/L	1.9	0.087	WQGV met - No further assessment required		
Mercury	mg/L	0.00006	<0.0001	WQGV met - No further assessment required		
Molybdenum	mg/L	0.034	0.001	WQGV met - No further assessment required		
Nickel	mg/L	0.011	0.13	<0.001	<0.001 [3]a	12
Nitrate (as N)	mg/L	2.4	0.01	WQGV met - No further assessment required		
pH	pH units	6.8-8.0	3.3 – 3.7	6.3 – 7.0	6.7 – 6.9	3,162 [6]
Selenium	mg/L	0.005	0.007	<0.001	<0.001 [3]a	1
Silver	mg/L	0.00005	0.004	<0.001	No data	84 [4]
Thallium	mg/L	0.00003	0.006	<0.001	<0.001 [3]a	200 [4]
Total Nitrogen	mg/L	1.1	1.4	0.9	No data	1 [4]
Total Phosphorus	mg/L	0.06	0.05	WQGV met - No further assessment required		
Turbidity	NTU	25	7	WQGV met - No further assessment required		
Vanadium	mg/L	0.006	0.002	WQGV met - No further assessment required		
Zinc	mg/L	0.008	0.414	0.001	0.006 [3]b	203 [4]

Notes:

1. WQGV sources are described in Table 10-1 in Appendix D. WQGVs are default guideline values (those specified in guidance documents) except for parameters marked (a) which are (interim) site specific guideline values.
2. The metric used in the assessment is specified in guidance documents, see Table 10-1 in Appendix D for more information. In general toxicants (metals, ammonia, nitrate) are 95th percentile values and stressors (total nitrogen and phosphorus, turbidity and electrical conductivity) are 75th percentile values. The pH range is 25th – 75th percentile values and the dissolved oxygen range is 25th percentile to maximum values.
3. Data are generally 95th percentile values for toxicants and 50th percentile values for stressors, except for comparison of aluminium and iron to (interim) site-specific WQGVs (WQGV is the 80th percentile value for the Barwon River so the 50th percentile value is used to calculate Sreq). See Appendix D for further information. The pH range is the 25th and 75th percentile values. Metals marked (a) are single values and (b) is the maximum of two values.
4. Simple dilution only – either no data for Barwon River or Barwon River concentrations is > WQGV. Simple dilution is explained below Equation 1.
5. Dilution requirement for dissolved oxygen saturation cannot be calculated as dissolved oxygen saturation in freshwater is a function of both concentration and temperature in freshwaters. In turn, dissolved oxygen concentration is strongly controlled by processes such as re-aeration, photosynthesis and respiration rather than mixing or dilution.
6. pH dilution requirement is for pH (as concentration of H^+=, i.e. re-arrangement of pH = $-\log_{10}[H^+]$) to meet the lower limit of the WQGV range through mixing. Buffering capacity of water and residual acidity associated with metal load is not considered.

Indicators with highest theoretical dilution requirements to meet WQGVs are summarised in (Table 4-1) as:

1. For pH (lower limit), Sreq is approximately 3,000:1
2. For Iron, Sreq is approximately 240:1 to meet the ANZECC & ARMCANZ (2000) WQGV and approximately 120:1 to meet the interim site specific WQGV.
3. For Aluminium, Sreq is approximately 230:1 to meet the WQGV applicable to waters of pH 6.5 or greater (Barwon River) and 136:1 to meet the interim site specific WQGV. For waters of pH<6.5, Sreq would be 15,500:1.
4. For Zinc and Thallium, Sreq is approximately 200:1 to meet ANZG (2018) WQGVs.

As described above, the magnitude of dilution required for these indicators to meet WQGVs in the Barwon River after inflow of water from Boundary Creek suggests that of the 27 indicators assessed, pH, iron, aluminium and zinc pose the highest risk to fish. As such, it is prudent to consider the pathways by which these can have ecological impacts in freshwaters – these are described in Table 4-2.

Zinc is not included in this list of higher risk water quality parameters (or Table 4-2) because further monitoring data provided by Austral (2021) has shown that zinc concentrations up to 0.017 mg/L have been reported in the Barwon River immediately upstream of the Boundary Creek confluence. This elevated concentration was reported for Spring 2019 where concentrations at three additional upstream sites were also at or above the WQGV (concentrations ranged from 0.008 mg/L to 0.051 mg/L). Zinc concentrations reported for the Barwon River site immediately upstream of the Boundary Creek confluence and three additional upstream sites were <0.005 mg/L for trips completed in Autumn 2020 and Spring 2020 (Austral 2021). It is possible that the dilution requirement estimated from the maximum of two available zinc concentrations for the screening level analysis (0.006 mg/L) overestimates the dilution requirement for zinc.

Further data for zinc in the Barwon River would be required to calculate a 95th percentile value or a site-specific WQGV to refine the theoretical dilution requirement. However, all zinc concentrations in the Barwon River both upstream and downstream of the Boundary Creek confluence reported by Austral (2020) are below 0.14 mg/L - the lower limit of acute toxicity value for Australian freshwater species compiled by USEPA (1978) and reported by ANZECC & ARMCANZ (2000). Bioaccumulation is not generally considered to be a problem for zinc in freshwaters (ANZECC & ARMCANZ 2000). As such, zinc has not been considered further in this assessment.

Thallium is also not included in the list of indicators that pose the highest level of risk to fish (or Table 4-2). Although the calculated dilution requirement for thallium is similar to aluminium, the dilution requirement is heavily influenced by two elevated concentrations (0.006 mg/L in May and November 2020). The other 11 thallium measurements were below the limit of reporting (<0.001 mg/L).

As the dilution requirement for total nitrogen concentrations in Boundary Creek downstream of the swamp to meet the ERS WQGV is low (1:1), and total phosphorus concentrations are below the ERS WQGV (Table 4-1), the risk of acidic discharge from Boundary Creek causing eutrophication in the Barwon River is likely to be low. However, there was no nutrient data available for the Barwon River and the Sreq value estimated for total nitrogen is likely to be an underestimate of the true dilution requirement (any total nitrogen present in the Barwon River reduces its dilution capacity). To further investigate the potential for acidic discharge from Big Swamp to cause eutrophication in Boundary Creek or the Barwon River, nutrient concentrations for the Barwon River upstream of the Boundary Creek confluence would be required. If monitoring is completed to inform such an assessment it would be advantageous to also collect samples for chlorophyll analysis and measure dissolved oxygen saturation on a sub-daily basis in the Barwon River upstream and downstream of the Boundary Creek confluence.

Table 4-2: Ecological impacts of low pH and elevated concentrations of aluminium, iron and zinc in freshwaters

Indicator	Ecological impacts
pH	The ERS water quality objective for pH of waters in the Central Foothills and Coastal Plains segment (lowlands of the Barwon River) consists of lower and upper WQGVs (pH 6.7 – 7.7). This range was set using data from reference sites and is intended to protect ‘water dependent ecosystems and species’ that are ‘slightly to moderately modified’. Low pH (acidic conditions) can cause ecological impacts such as dissolution of exoskeletons, damage to gill epithelium, mucus formation on gills, decreased growth or reduced reproductive success, respiratory inhibition, impaired ionoregulatory function and mortality (USEPA, 2017). The main pathway through which low pH can lead to fish kills is the alteration of gill membranes and/or coagulation of gill mucus that in turn leads to hypoxia and death (Fromm, 1980).
Iron	The WQGV for iron (0.3 mg/L) is an indicative interim working level based upon the current Canadian guideline level (ANZECC & ARMCANZ, 2000). It is of unknown reliability and an unknown level of species protection. There is currently no WQGV for iron endorsed in the ANZG (2018). Iron is an essential trace element for plants and animals, but high concentrations can have toxic effects. Acute toxicity from iron has been reported for aquatic insects at concentrations ranging from 0.32 to 16 mg/L (ANZECC & ARMCANZ 2000 and references therein). Ecological impacts such as reduced hatching success for fish and smothering of both benthic habitats and organisms due to flocs of ferric hydroxides have also been reports (ANZECC & ARMCANZ 2000). Suspension of ferric hydroxides within the water column can also increase turbidity/ reduce light penetration that in turn can reduce primary production.
Aluminium	There are two WQGVs for aluminium in freshwater endorsed by ANZG (2018) – 0.055 mg/L for waters of pH >6.5 and 0.0008 mg/L for waters of pH<6.5. The range of pH values reported for ambient conditions in the Barwon River (i.e. upstream of the Boundary Creek confluence) was 6.3 to 7.2 and only 2 of the 71 results were <pH 6.5. The WQGV of 0.055 mg/L is appropriate for the Barwon River – this is a low reliability value intended to provide a 95% level of species protection from chronic toxicity. It is the recommended WQGV for ‘slightly to moderately disturbed freshwater ecosystems’. Toxicity of aluminium is increased at low and high pH, e.g. pH<5.5 and pH>9. Under very acidic conditions the toxicity effects of elevated H^+ concentrations appear to be more important than the generally low concentrations of aluminium found in the environment. In other systems, acidic conditions are thought to have altered food supply that in turn has affected numbers and densities of aquatic macroinvertebrates (ANZECC & ARMCANZ 2000 and references therein). In general, single-celled aquatic plants are the most sensitive aquatic species to aluminium toxicity. Fish are more susceptible to aluminium toxicity than aquatic invertebrates. Aluminium toxicity impacts fish through the gills by effecting both ionoregulatory and respiratory function (ANZECC &ARMCANZ 200 and references therein). For fish, acute toxicity (which yields adverse effects from short term exposure, usually less than 24 hrs) has been reported at concentrations of aluminium between 600 and 106,000 mg/L whilst chronic toxicity (which yields adverse effects as the result of long term exposure, usually over 10% of an organisms lifespan) has been reported at concentrations between 0.034 to 7.1 mg/L.

4.1.2 PHREEQC simulations

While section 4.1.1 provides a useful estimate of the potential parameters of concern to the Barwon River and indicative dilution requirements for flows discharging from Boundary Creek to meet relevant WQGV’s, it does not account for geochemical reactions that may be occurring in the lower reaches of Boundary Creek following discharge from the swamp, mixing with water from the Barwon River or exchange with the atmosphere. To account for this, representative waters from the Barwon River and Boundary Creek were mixed using the hydrogeochemical modelling software package PHREEQC in varying ratios with the inclusion of equilibrium phases to account for atmospheric exchange (to maintain equilibrium with CO_2 and O_2) and the precipitation of minerals found to be saturated upon atmospheric exchange and mixing (namely iron hydroxides and aluminium hydroxides).

To account for sensitivity in the model and the range of precipitates that may form, two species of iron and aluminium hydroxides were considered during model runs. This includes amorphous aluminium hydroxide as $Al(OH)_3$(am) which as a relatively high solubility and thus, will more readily yield higher pH values and high aluminium concentrations and Gibbsite, which has a lower solubility and thus more readily yield lower aluminium concentrations and lower pH values. Similarly, the runs adopted $Fe(OH)_3$(a)_pqe which has a high solubility and thus, more readily yield higher pH values and high iron concentrations and $Fe(OH)_3$_Maj , which has a lower solubility and thus more readily yield lower iron concentrations and lower pH values. These have been used to present a range in the concentrations and pH values of mixed waters.

The representative water qualities adopted for the PHREEQC simulations are summarised in Table 4-3 below. Chemistries were adopted from specific monitoring rounds instead of those based on statistical analysis of analyte concentrations as discussed above. While statistical analysis provides a useful indication and screening of analytes of concern, amalgamation of chemistries for different sampling periods can result in solutions with poor ionic balances that would not occur in reality, resulting in the saturation of minerals that may not form. Where analytes were reported below the detection limit, the detection limit of a given analyte was adopted for PHREEQC simulations.

For the simulations, water quality from Boundary Creek during three periods were adopted to represent the seasonal variability of water quality discharging from Big Swamp under different flow conditions, including:

- April 2020, which represents the chemistry of water discharging from Boundary Creek during autumn flushing events when fish kills appear to be at the highest risk of occurring. This has the highest concentration of acidity monitored and thus, provides an upper estimate of mixing/dilution requirements when the concentration of key parameters of concern (aluminium, iron, H^+) are high.

- July 2020, which represents the chemistry of water discharging from Boundary Creek during winter-spring high flow conditions. Flows during this sampling event were 7.6 ML/day in Boundary Creek, similar to average discharge rates over July-October and represents more dilute concentrations of key parameters of concern (aluminium, iron, H^+).

- November 2020, which represents the chemistry of water discharging from Boundary Creek during low flow conditions in which concentration of key parameters of concern (aluminium, iron, H^+) increase as less flows are available for dilution.

It is noted that water discharging from Big Swamp can exhibit a higher pH than that monitored at Yeodene, a likely result of iron(II) oxidation in Reach 3 of boundary Creek. This has been accounted for in the mixing model via inclusion of the atmospheric exchange terms described above which yields oxidation of iron(II) to iron (III).

For the Barwon River, the sample collected during the 4th of July 2018 was used as the primary solution as it represents the most complete analysis suite undertaken on samples collected from the Barwon River upstream of Boundary Creek. However, some data gaps were infilled based on samples collected during monitoring on July 23rd 2018. In the case of sulfate and alkalinity, these analytes were infilled using data from Boundary Creek upstream of Big Swamp as these analytes were not monitored in the Barwon River. With respect to the parameters of concern, this represents a good representation of water chemistry in this section of the Barwon River with a pH of 6.8 (compared to a median pH of 6.9) an aluminium concentration of 0.09 mg/L (compared to a median of 0.06 mg/L) and an iron concentration of 0.83 mg/L (compared to a median of 0.84 mg/L) (median values based on 71 samples across Forrest and Seven Bridges road).

Table 4-3 Surface water chemistries adopted for mixing simulations in PHREEQC (all units mg/L unless specified)

Analyte	Barwon River upstream of Boundary Creek	Boundary Creek Low flow (November 2020)	Boundary Creek First Flush (April 2020)	Boundary Creek High flow (July 2020)
temp (°C)	8.5	14.5	14.3	7.8
pH (units)	6.9	3.7	3.3	3.7
Na	53	59	71	60
K	2.9[1]	3.1	4.2	3.0
Ca	6.3[1]	4.4	7.5	4.0
Mg	9.1[1]	7.3	9.5	7.0
Cl	99	100	140	120
Fe	0.83[3]	24	110	2.1
Mn	0.17	0.043	0.085	0.02
SO_4	18[2]	130	290	46
Alkalinity ($CaCO_3$ equiv.)	17[2]	0	0.13	0
Al	0.09[3]	10.0	10	3.9
Sb	0.001	0.0005	0.0005	0.0005
As	0.001	0.001	0.001	0.0005
Ba	0.019	0.025	0.029	0.025
Be	0.001	0.002	0.002	0.0005
B	0.02	0.01	0.49	0.01
Cd	0.0002	0.0001	0.0004	0.0001
Cr	0.001	0.0005	0.13	0.0005
Co	0.001	0.023	0.034	0.006
Cu	0.001	0.0005	0.001	0.003
Pb	0.001	0.0005	0.004	0.0001
Hg	0.0001	0.00005	0.00005	0.00005
Mo	0.001	0.0005	0.002	0.0005
Ni	0.001	0.059	0.16	0.017
Se	0.001	0.002	0.004	0.0005
Ag	0.001	0.002	0.003	0.0005
Sr	0.062	0.049	0.088	0.048
Tl	0.001	0.0005	0.0005	0.0005
Sn	0.001	0.006	0.0005	0.0005
Ti	0.005	0.0005	0.0005	0.0005
V	0.001	0.0005	0.0005	0.0005
Zn	0.003	0.24	0.42	0.072

[1] Data infilled to achieve ion balance using Boundary Creek upstream gauge April 2020 as data unavailable for Barwon River.

[2] Data infilled using July 5th 2018 data from Seven Bridges Rd as not available for July 4th 2018 at Forrest.

[3] Data infilled from July 23rd 2018 from Forrest to reflect conditions more consistent with median conditions.

[4] Detection limit adopted for samples reported below detection limit for PHREEQC simulations shaded in green

Outputs from the PHREEQC mixing simulations with respect to pH, aluminium and iron are presented in Figure 4-1, Figure 4-2 and Figure 4-3 below, respectively. These figures illustrate that under low flow conditions similar to the November 2020 sampling period, surface water at the confluence of Boundary Creek and the Barwon River could:

- reach the WQGV of pH ≥ 6.8 provided that discharge from Boundary Creek represents ≤5% of flows in the Barwon River
- reach the WQGV of aluminium ≤ 0.15 mg/L provided that discharge from Boundary Creek represents ≤0.5-10% of flows in the Barwon River
- reach the WQGV of iron ≤ 1.4 mg/L provided that discharge from Boundary Creek represents ≤10-30% of flows in the Barwon River

Under first flush conditions similar to the April 2020 sampling period, surface water at the confluence of Boundary Creek and the Barwon River could:

- reach the WQGV of pH ≥ 6.8 provided that discharge from Boundary Creek represents ≤3% of flows in the Barwon River
- reach the WQGV of aluminium ≤ 0.15 mg/L provided that discharge from Boundary Creek represents ≤0.5-4% of flows in the Barwon River
- reach the WQGV of iron ≤ 1.4 mg/L provided that discharge from Boundary Creek represents ≤5-10% of flows in the Barwon River

Under higher flow conditions similar to those in the July sampling period, surface water at the confluence of Boundary Creek and the Barwon River could:

- reach the WQGV of pH ≥ 6.8 provided that discharge from Boundary Creek represents ≤20% of flows in the Barwon River
- reach the WQGV of aluminium ≤0.15 mg/L provided that discharge from Boundary Creek represents ≤1-20% of flows in the Barwon River
- reach the WQGV of iron ≤1.4 mg/L provided that discharge from Boundary Creek represents ≤40% of flows in the Barwon River

The modelling is most sensitive with respect to aluminium owing to the large difference in solubilities in the mineral phases adopted. While the modelling suggests that a 99.5% contribution of flow from the Barwon River is required to meet the required WQGV for aluminium under some conditions, it is recognised that water samples collected from Boundary Creek were filtered using a 0.45 µm filter prior to analysis. Previous studies have shown that smaller filters (0.2-0.025µm) can significantly reduce the concentration of aluminium and iron measured in samples due to further removal of fine-grained particulate aluminium and iron suspended in solution, even at low concentrations (e.g. Wagemann and Brunskil, 1975). As such, the dilution requirement for aluminium and iron estimated here may be overly conservative.

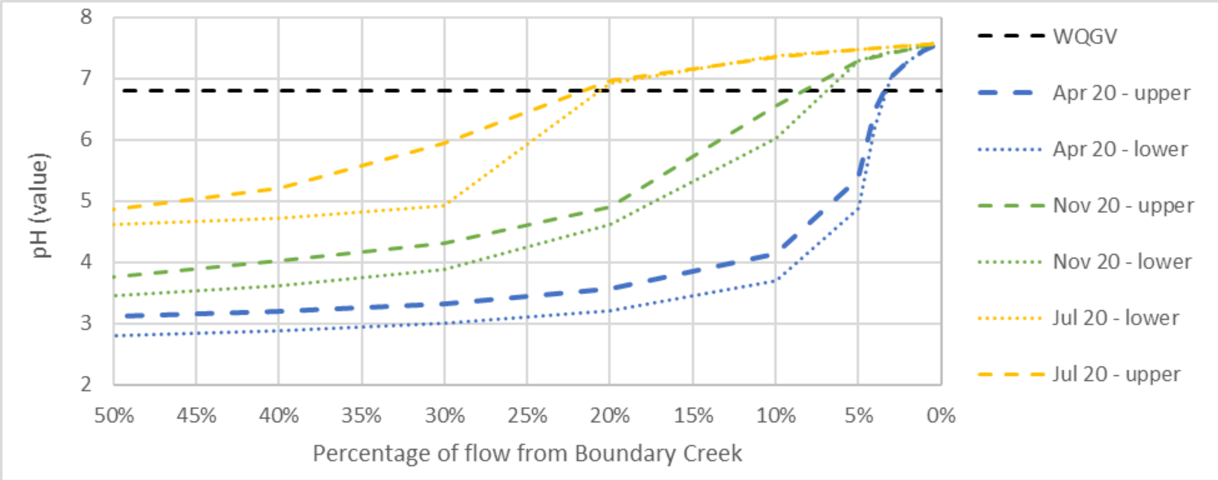

Figure 4-1 Modelled pH values in "mixed" Boundary Creek and Barwon River water

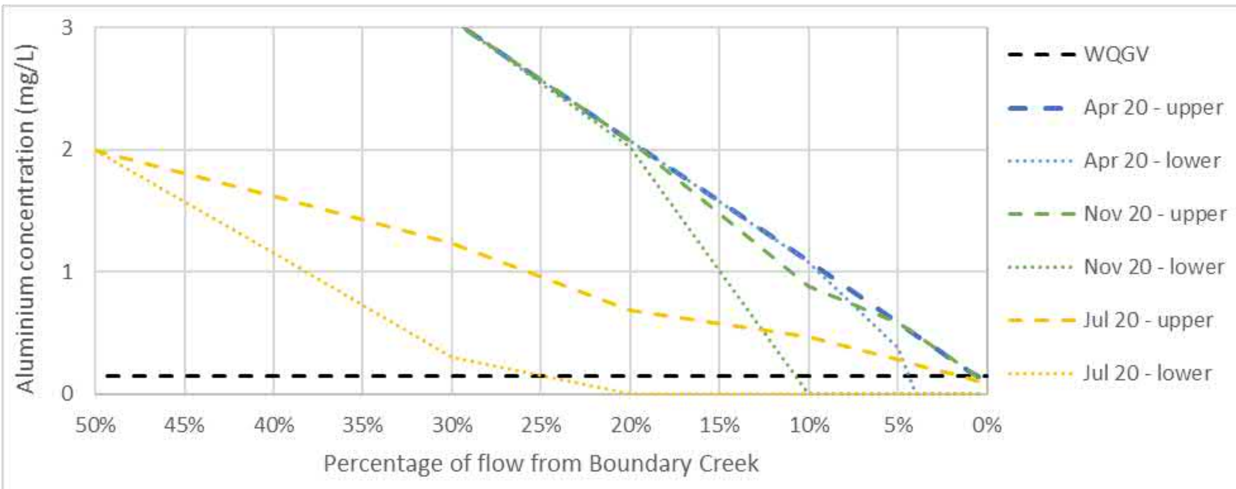

Figure 4-2 Modelled Aluminium concentrations in "mixed" Boundary Creek and Barwon River water

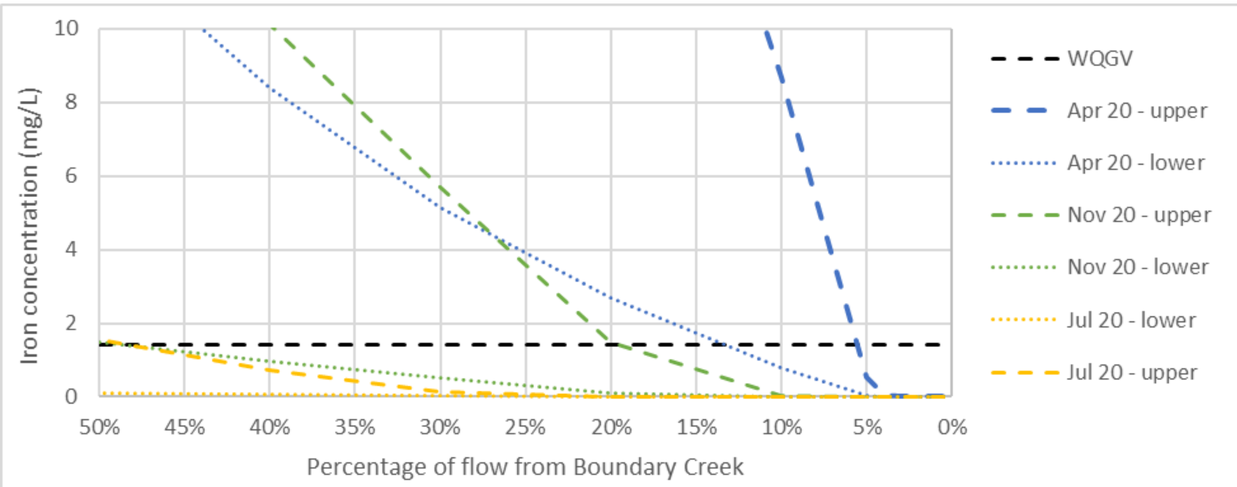

Figure 4-3 Modelled iron concentrations in "mixed" Boundary Creek and Barwon River water

4.2 Flows

This section provides a comparison of the relative contribution of flows from the Barwon River catchment upstream of Boundary Creek to those derived from the Boundary Creek catchment to subsequently evaluate the timing and conditions under which the water quality outcomes discussed above may occur.

While streamflow data for the Boundary Creek catchment has been collected at Yeodene (gauge 233228) since 1985, gauging in the upper catchment has been more sporadic with data available at the West Barwon River (gauge 233255) since February 2021, the Barwon River West branch (gauge 233203) from 1926 to 1965, the West Barwon River (gauge 233245) since 2000, the Barwon River east branch at Forrest (gauge 233204) from 1926 to 1959 and the east Barwon River (gauge 233254) from July 2021.

A complete catchment rainfall runoff model was not feasible within the time limitations associated with the undertaking of this project to simulate flows at the Barwon River at its confluence with Boundary Creek. As such, to provide an estimate of flows in the Barwon River at the Boundary Creek confluence, flow data from the Barwon River at Rickets Marsh (gauge 233224, which has flow data from 1971 to 2021) was scaled to the catchment area upstream of the confluence of Boundary Creek. The Barwon River catchment area upstream of the Boundary Creek confluence was estimated via a spatial topographic analysis at an area of 265.5 km^2, which represents approximately 45% of the river catchment upstream of the Rickets Marsh gauge (Figure 4-4). In addition, comparison of contemporaneous flow data at the Rickets Marsh gauge with that from the east Barwon River (gauge 233254) and west Barwon River (gauge 233255) suggests an average lag of 1.5 days between flows at the Boundary Creek confluence and the Rickets Marsh gauge. As such, the Rickets Marsh flow data was also time shifted to account for flow lag.

A comparison of the median daily flows in Boundary Creek and those in the Barwon River upstream of Boundary Creek by month is presented in Figure 4-5 below. These have been provided for data including and subsequent to the year 2000 to represent current conditions in the catchment (i.e. following groundwater extraction and the millennium drought). This shows that typically, the relative contribution of flow from Boundary Creek falls during the summer months, from 5% in December to 2% in January and 0% in February and March. The contribution remains low in April (1%) before steadily increasing from 7% in May to 16% in August (when the contribution of Boundary Creek to the Barwon River is the highest) and remains at 15% between September and November.

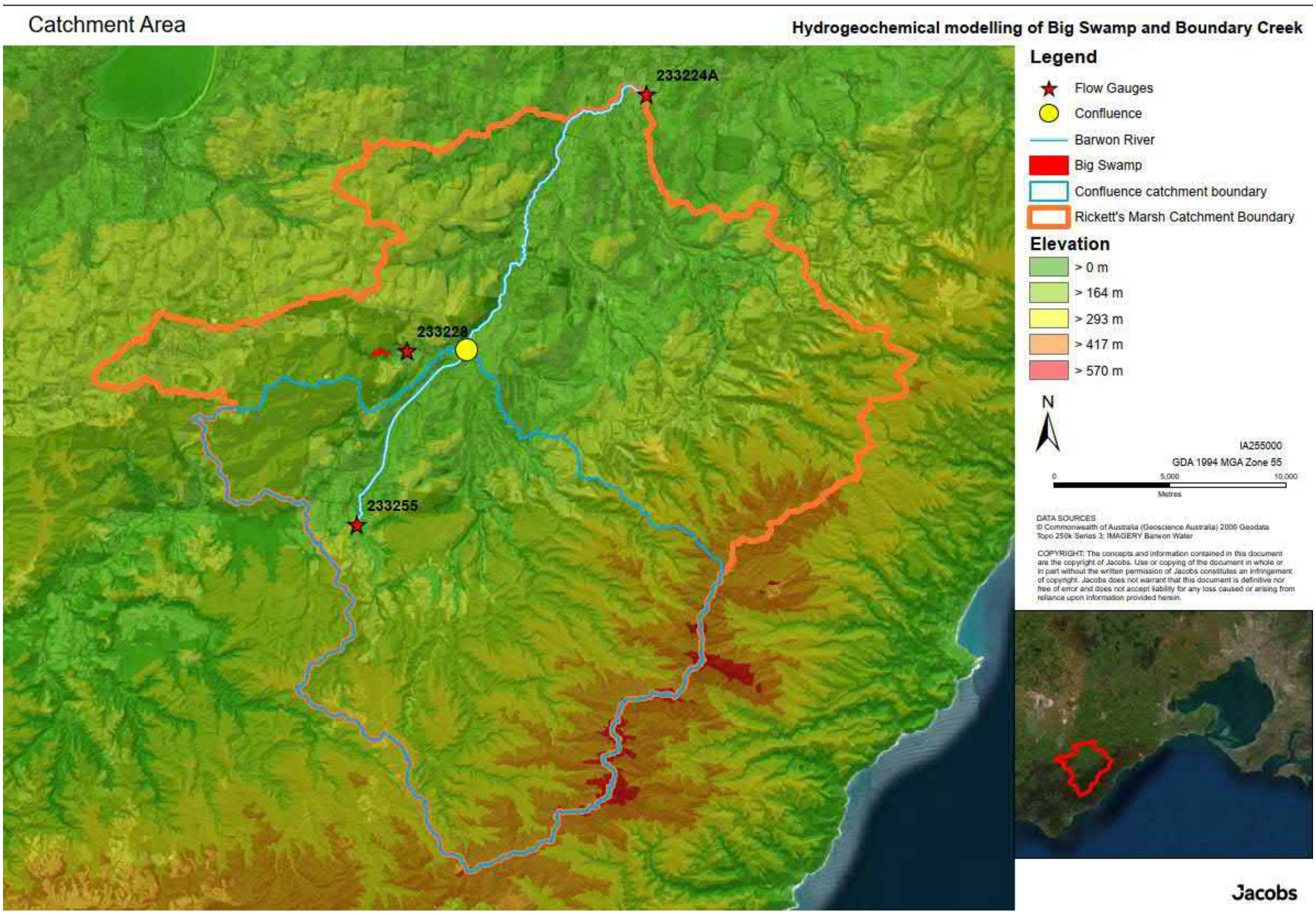

Figure 4-4 Topographic analysis undertaken to derive catchment area for the Barwon River upstream of Boundary Creek

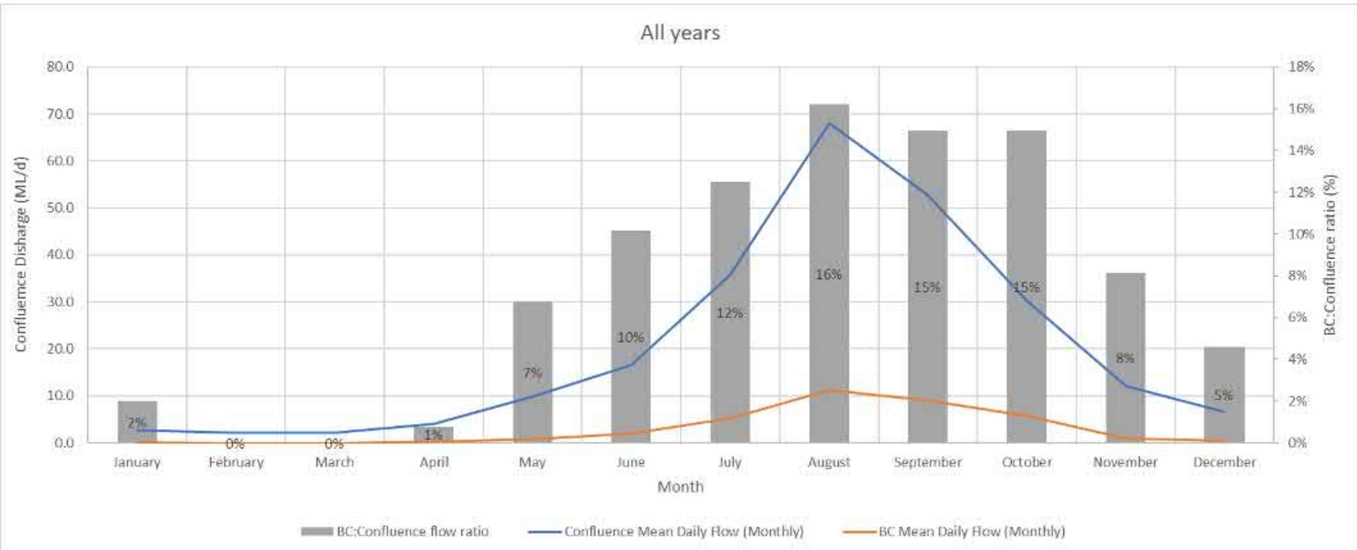

Figure 4-5 Summary of average daily flows in Boundary Creek and the Barwon River upstream of Boundary Creek by month

In addition to the above, which provides an assessment of typical flow contributions from Boundary Creek to the Barwon River, Figure 4-6 and Figure 4-7 below show the relative contribution of Boundary Creek to the Barwon River based on average daily flow rates for June 2016 and June 2018 in which fish kill and low pH events were recorded in the Barwon River, respectively. For both months in question, the contribution of flow from Boundary Creek to the Barwon River was significantly higher than typical conditions, with approximately 24% of average daily flows derived from Boundary Creek over the month of June 2016 and approximately 22% of average daily flows derived from Boundary Creek over the month of June 2018. Further, during both periods, the week leading up to the reported fish kill and low pH events was characterised by significantly higher than typical contributions from Boundary Creek, with contributions in June 2016 exceeding 40% of flows in the Barwon River and contributions in June 2018 exceeding 30% of flows in the Barwon River.

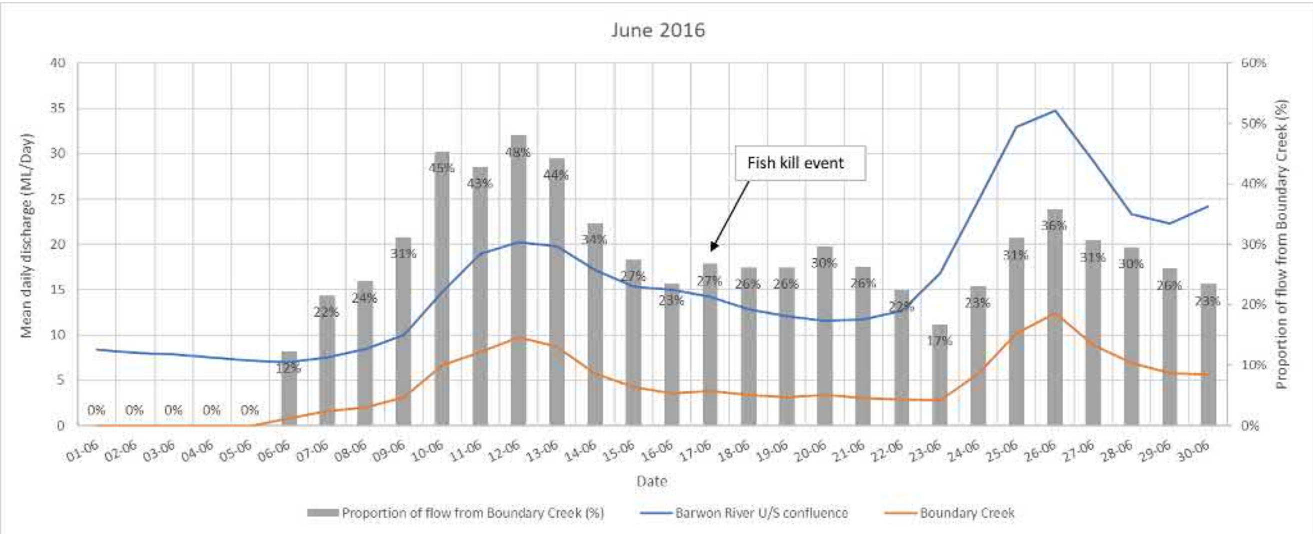

Figure 4-6 Summary of average daily flows in Boundary Creek and the Barwon River upstream of Boundary Creek June 2018

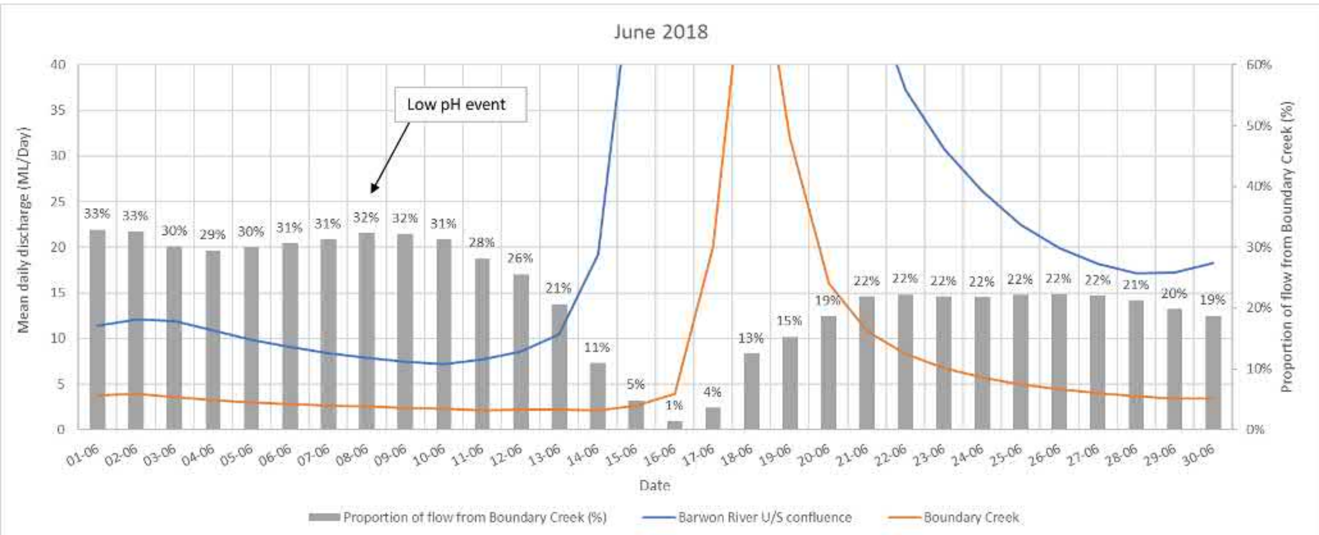

Figure 4-7 Summary of average daily flows in Boundary Creek and the Barwon River upstream of Boundary Creek June 2018

4.3 Risks to the Barwon River

This section combines the outputs of the PHREEQC simulations provided in section 4.1.2 with the flows assessment provided in section 4.2 above to provide an assessment of the typical conditions in which aquatic ecology (primarily fish) in the Barwon River may be at a risk of impact from poor water quality discharging from Boundary Creek. It does so by comparing the predicted water quality outcomes under different mixing ratios with the typical mixing ratios between Boundary Creek and the Barwon River on a monthly basis.

The proportion of flow from Boundary Creek contributing to flows in the Barwon River at their confluence based on section 4.2 is summarised in Table 4-4 below. The maximum proportion of flow derived from Boundary Creek at its confluence with the Barwon River which still achieves WQGV's as modelled in section 4.1.2 is summarised in Table 4-5 below (this presents a lower value for the lower bound simulation and an upper value for the upper bound simulation as discussed in section 4.1.2). These have been shaded to represent different flow conditions in Boundary Creek including low flow (yellow shading) flushing flows (green shading) and high flow (blue shading) conditions.

Table 4-4 Typical (median) proportion of flows at the Barwon River confluence derived from Boundary Creek

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median flow in Boundary Creek (ML/Day)	0.1	0.0	0.0	0.2	0.7	2.0	5.3	11.3	9.0	5.7	1.0	0.5
Median flow in Barwon River U/S BC (ML/Day)	2.6	2.2	2.2	4.1	9.9	16.9	35.7	68.0	52.7	30.3	12.2	6.6
Proportion of flow from Boundary Creek (%)[1]	2%	0%	0%	1%	7%	10%	12%	16%	15%	15%	8%	5%

[1] Proportions only calculated for periods with synchronous data available at Ricketts marsh and Yeodene gauges

Table 4-5 Maximum contribution to the Barwon River derived from Boundary Creek to achieve WQGV

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH	5%	5%	5%	3%	3%	3%	20%	20%	20%	20%	5%	5%
Iron	10-40%	10-40%	10-40%	5-10%	5-10%	5-10%	40%	40%	40%	40%	10-40%	10-40%
Aluminium	0.5-10%	0.5-10%	0.5-10%	0.5-4%	0.5-4%	0.5-4%	1-20%	1-20%	1-20%	1-20%	0.5-10%	0.5-10%

Accordingly, under typical flow conditions, ecological risks to the Barwon River could be realised when the proportion of flow from Boundary Creek presented in Table 4-4 exceeds the proportion of flow presented in Table 4-5. This has been summarised in Table 4-6 below. A risk rating has been assigned as low if WQGV's were met for all simulations, moderate if they were met for the lower bound simulation but not the upper bound simulation and high if they were not met under any simulation. Accordingly, the table illustrates that:

- Ecological risks associated with pH are high in June, moderate in May and November and Low for the remainder of the year.
- Ecological risks associated with iron are moderate in May and June and low for the remainder of the year.
- Ecological risks associated with aluminium are high in May and June, low in February and March and moderate for the remainder of the year. As discussed above, this may over-represent the risk associated with aluminium due to the presence of particulate aluminium in samples and uncertainties in the PHREEQC model.

This suggests that the greatest periods of potential ecological risk to the Barwon River associated with the discharge of water from Boundary Creek occurs in May and June, when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase. Higher flow periods (July-August) tend to represent lower risks to the Barwon River due to the reduced concentration of parameters of concern while lower flow periods (December-March) tend to represent lower risks to the Barwon River due to the reduced contribution of flows from Boundary Creek.

Table 4-6 Timing of ecological risks to the Barwon River based on typical flow conditions

Analyte	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH	Low	Low	Low	Low	Mod	High	Low	Low	Low	Low	Mod	Low
Iron	Low	Low	Low	Low	Mod	Mod	Low	Low	Low	Low	Low	Low
Aluminium	Mod	Low	Low	Mod	High	High	Mod	Mod	Mod	Mod	Mod	Mod

These results are consistent with results from Austral (2020) in which inflows to the Barwon River from Boundary Creek in October 2019 yielded a low ecological risk related to pH (with a fall from 7.40 upstream of Boundary Creek to 7.34 downstream of Boundary Creek) a low ecological risk related to iron (with a fall from 0.33 mg/L upstream of Boundary Creek to 0.13 mg/L downstream of Boundary Creek) and a moderate risk related to aluminium (which increased from <0.05 mg/L upstream of Boundary Creek to 0.09 mg/L downstream of Boundary Creek – above the ANZG DGV but below the interim site specific value). Similarly, ecological risks in the Barwon River related to Boundary Creek in March 2020 were low due to the absence of flows in Boundary Creek at this time.

While the above provides an indication of when the Barwon River may be subject to ecological risks related to water quality, historical observations indicate that such risks do not directly translate into fish kill events, as such events are not documented as occurring in May and/or June of every year.

Based on the limited reports of such events, it can be asserted that "low pH events" in the Barwon River may be realised when flows from Boundary Creek represent ≥30% of flows in the Barwon River, while fish kill events may be realised when flows from Boundary Creek represent ≥40% of flows in the Barwon River (as discussed in section 4.2). Based on the flow comparison undertaken in section 4.2, the probability of flows in Boundary Creek exceeding a given proportion of flow in the Barwon River at their confluence has been illustrated in Figure 4-8. This shows that between 2000 and 2021, flows from Boundary Creek have represented ≥30% of flows in the Barwon River 8% of the time, while flows from Boundary Creek have represented ≥40% of flows in the Barwon River 4% of the time. Though this would suggest that such conditions are infrequent, Figure 4-9 indicates that such conditions have been met almost annually since 2000.

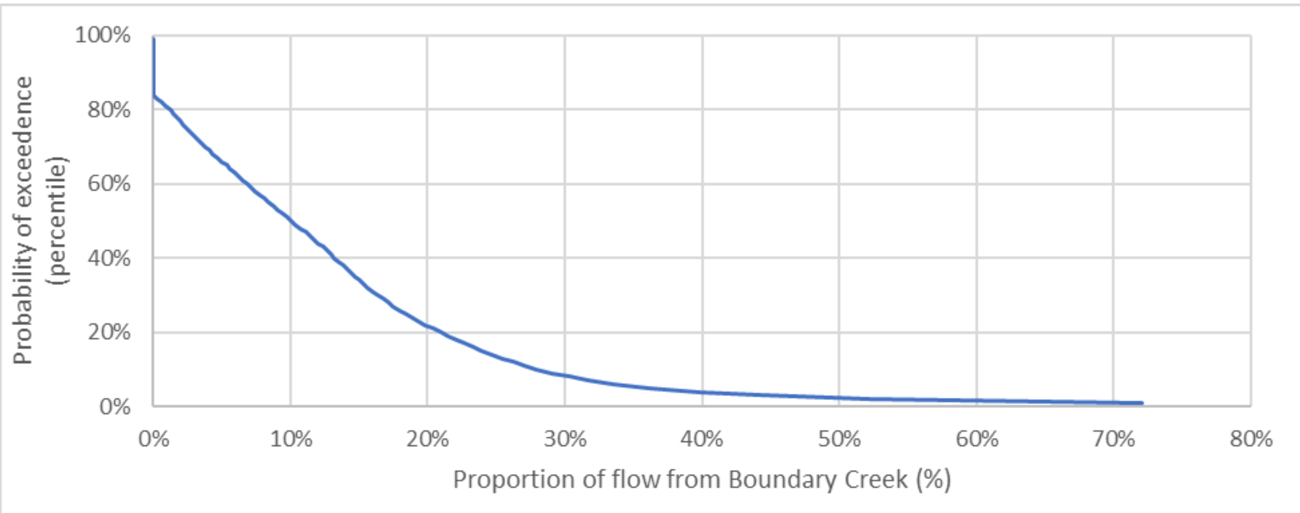

Figure 4-8 Probability of flows from Boundary Creek exceeding a given proportion of flow in the Barwon River at its confluence.

A total of 21 time periods were identified in which flows from Boundary Creek represented ≥40% of flows in the Barwon River at their confluence. Each of these periods has been summarised in Table 4-7 below according to their month, season and flow condition. The flow condition has been assigned according to the following descriptors:

- Summer low flow if during summer months and flows <2.5 ML/day.
- Winter and spring high flow during winter or spring months which exceeded flows of 15 ML/day.
- Recession, which represents events which were preceded by higher flows before reaching ≥40% of flows in the Barwon River at their confluence.
- Wet season and end of wet season, which represent events which occurred at the end of or during the wet season and were preceded by multiple flow events.
- First flush, which represents the first flow event at the end of a period of flow cessation.

For the three identified summer low flow periods, these were not preceded by significant flow cessation in Boundary Creek and therefore, the accumulation of stressors (acidity, iron and aluminium) in the swamp available for subsequent mobilisation into Boundary Creek are likely to have been reduced. The same is true of recession events and wet season or end of wet season conditions, which have been preceded by flows through Big Swamp which are likely to have removed a portion of any stressors built up in the swamp prior to flows in Boundary Creek representing ≥40% of those in the Barwon River. Conversely, during winter and spring high flow events, the high volume of water flowing through Boundary Creek is likely to dilute the concentrations of potential stressors and reduce the risk of fish kill events.

Given this, the four first flush periods similar in nature to the June 2016 fish kill event include periods in February-March 2006, March-April 2010, April 2014, and April 2019. Of interest, the period of flow cessation preceding these four events varied between approximately 1 and 4 months, while the June 2016 fish kill event was preceded by over 8 months of flow cessation in Boundary Creek.

These results suggests that the greatest risks of fish kill events in the Barwon River occurs when flows in Boundary Creek represent a relatively high portion (≥40%) of flows in the Barwon River during first flush events that have been preceded by extended (>4 months) periods of flow cessation in Boundary Creek, which have allowed for the accumulation of stressors in Big Swamp prior to flushing.

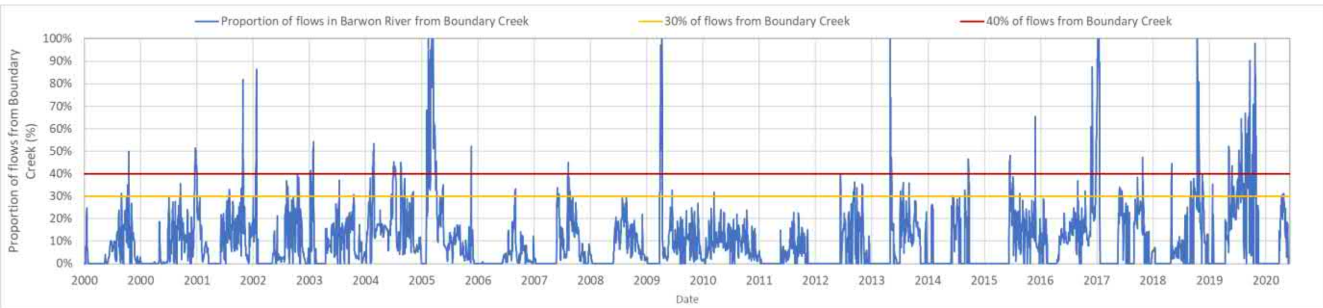

Figure 4-9 Proportion of flows in the Barwon River derived from Boundary Creek at their confluence

Table 4-7 Timing and conditions in which Boundary Creek represents ≥40% of flows in the Barwon River

Year	Month	Season	Condition
2000	October	Spring	High flow
2001	December	Summer	Recession event
2002	October	Spring	High flow
2003	January	Summer	Low flow
2004	January	Summer	Low flow
2005	February	Summer	Recession event
2005	July-August	Winter	Wet season flows
2006	February-March	Summer-Autumn	First flush
2006	November	Spring	End of wet season
2008	August	Winter	High flow
2010	March-April	Autumn	First flush
2014	April	Autumn	First flush
2015	September	Spring	End of wet season
2016	June	Winter	First flush
2016	November	Spring	High flow
2017	November	Spring	End of wet season
2018	January	Summer	Low flow
2018	October	Spring	Wet season flows
2019	April	Autumn	First flush
2019	October	Spring	High flow
2020	July-October	Winter-Spring	High flow

4.4 Summary of potential impacts on the Barwon River

The below summarises the risk posed to aquatic ecology (principally fish kills) in the Barwon River related to the discharge of acidic water from Boundary Creek:

- pH, iron and aluminium pose the greatest ecological risk to the Barwon River, including the greatest risk of fish kills related to acute toxicity associated with respiratory failure due to low pH conditions and high aluminium concentrations.
- Simulations via the modelling package PHREEQC and comparison of flows in Boundary Creek to those in the Barwon River suggest that under typical conditions, ecological risks to the Barwon River are highest during May and June, when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase. Higher flow periods (July-August) tend to represent lower risks to the Barwon River due to the reduced concentration of parameters of concern under these conditions while lower flow periods (December-March) tend to represent lower risks to the Barwon River due to the reduced contribution of flows from Boundary Creek. This is consistent with sampling undertaken to date by Austral (2020).
- The only recorded fish kill event in the Barwon River occurred in June 2016 when flows from Boundary Creek represented ≥40% of those in the Barwon River. This period represents a flow event following flow cessation in Boundary Creek (known as a first flush). While other first flush events have yielded a similar contribution of flows to the Barwon River, these were preceded by 4 months or less of flow cessation in Boundary Creek, whereas the June 2016 event was preceded by more than 8 months of flow cessation in Boundary Creek. This suggests that the Barwon River is at the greatest risk of a fish kill event following an extended period of flow cessation in Boundary Creek (>4 months) when flows from Boundary Creek represent ≥40% of those in the Barwon River.

5. Downstream Contingency Measure

The contingency measures that have been considered for implementation have been selected from several remedial actions that were considered as potential remediation options in the Remediation and Environmental Protection Plan (REPP) to improve water quality in Boundary Creek. CDM Smith (2019) completed an options assessment as part of development of the REPP and recommended aerial liming and an active treatment system be investigated as contingency measures.

The objective of the contingency measure is to improve water quality in Reach 3 of Boundary Creek and reduce the risk to ecology in the Barwon River. If required, the contingency measure could be implemented whilst the ultimate long term remediation option is constructed and proven to be effective in controlling the release of acidity from the Swamp.

Jacobs (2021b) further refined the options assessment for the contingency measures, focusing on the implementation, constructability and operation and maintenance. Jacobs investigated the range of potential locations, application methods and chemicals that could be adopted as a contingency measure. A chemical dosing system located on the downstream (Eastern) end of the Big Swamp using sodium hydroxide (NaOH) as a pH correction chemical was recommended as the preferred option for the contingency measure.

This section aims to inform the design of the downstream contingency measure recommended by Jacobs (2021b) by providing estimates on the volume/mass of treatment material that may need to be stored on site and the required rates of treatment. A series of treatment simulations were undertaken using the hydrogeochemical modelling software PHREEQC to achieve different water quality outcomes.

5.1 Approach to estimate sodium hydroxide treatment rates

Simulations using PHREEQC were undertaken to achieve a variety of different pH outcomes for the downstream contingency measure involving a chemical dosing system using sodium hydroxide. Atmospheric, aluminium hydroxide and iron hydroxide equilibrium terms were accounted for in the model simulations. The NaOH volumes provided below assume a 40% by weight concentration of sodium hydroxide in solution.

A range of different flow rates and acidity concentrations were selected for simulations to reflect the range in conditions which may occur in a given year. This includes:

- **Initial flush**: selected to represent higher concentrations of acidity discharging from Big Swamp as flows return following summer low flow conditions or flow cessation.
- **Ongoing flush**: selected to represent higher loads of acidity discharging from Big Swamp as flows continue to increase while concentrations remain moderately high.
- **Winter-Spring high flow**: selected to represent higher flow rates in which concentrations of acidity decline through flushing and or dilution, though loads remain relatively high due to high flow rates.
- **Summer low flow**: selected to represent lower flow rates during summer when concentrations of acidity tend to increase while flow rates decline.

The sampling periods selected to represent the above described range in conditions were April 2020, May 2020, October 2020 and December 2019, respectively, as illustrated in below in Figure 5-1.

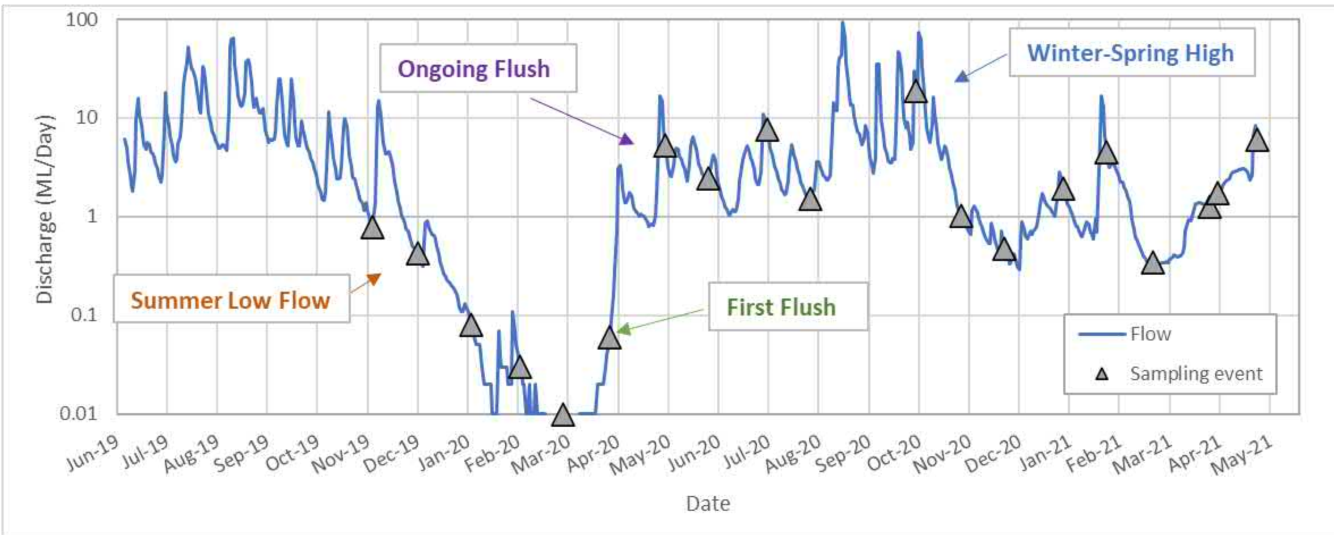

Figure 5-1 Sampling periods used to inform treatment rates

To assess the annual treatment loads, similar modelling simulations were undertaken to estimate the total volume of sodium hydroxide that may be required to offset potentially negative water quality impacts on Boundary Creek and the Barwon River. The pH endpoints adopted for these simulations included a pH of 5 and a pH of 6. A pH of 5 or 6 would improve water quality outcomes downstream of Big Swamp beyond current pH ranges and offset potentially negative water quality outcomes in Boundary Creek or the Barwon River.

To estimate the volume of sodium hydroxide which may be utilised annually, daily dosing rates for individual sampling periods were multiplied by the number of days in a given month to estimate the monthly and subsequently, the annual total volume and mass of utilised material. This was done for the December 2019 to November 2020 period. Sampling events generally provided a reasonable representation of typical monthly conditions and therefore, were able to provide reasonable monthly dosing estimates. However, this was not the case for the May and August 2020 sampling periods:

- For the May period, flows were 5.3 ML/day during sampling compared to the median monthly flow of 0.7 ML/day and yielded unsuitably high dosing rates.
- For the August period, flows were 1.5 ML/day compared to the median monthly flow of 11.3 ML/day, yielding unsuitably low dosing rates.

For these periods, dosing rates for more representative flow conditions were adopted.

An additional consideration for the downstream sodium hydroxide dosing plant was the potential build up of aluminium hydroxide and iron hydroxide precipitates which may form a sludge in response to treatment and hence, may require management. As such, sludge build up in response to dosing was estimated from the same sodium hydroxide dosing model runs by multiplying the moles of aluminium and iron removed from solution by the relative molar masses of aluminium hydroxide $Al(OH)_3$ and iron hydroxide $Fe(OH)_3$.

5.2 Predicted sodium hydroxide treatment rates

5.2.1 Seasonal variability in treatment rates

The rates of sodium hydroxide treatment required to achieve different end points during initial flush, ongoing flush, winter-spring high flows and summer low flows is summarised in Table 5-1 and Figure 5-2 below. This shows that under summer low flow and initial flushing conditions, dosing rates of less than 80 L/day are required to achieve pH of 6.

Under winter-spring high flow conditions, dosing is not required to achieve pH values of 4 to 5 as discharge pH is already at a pH of 4.9, however rates increase up to 200 L/day to achieve a pH of 6 under these conditions. The highest dosing rates are required during ongoing flushing conditions, with rates increasing from around 400L/day to achieve a pH of 5 to 700 L/day to achieve a pH of 6.

Table 5-1 Simulated NaOH dosing rates to achieve different pH outcomes downstream of Big Swamp

Summer Low 0.42 ML/day		Initial Flush 0.06 ML/day		Ongoing Flush 5.3 ML/day		Winter-Spring High 18.87 ML/day	
pH	L/day	pH	L/day	pH	L/day	pH	L/day
3.7	0	3.3	0	3.3	0	3.5	0
4	7	4	15	4	284	4	0
4.5	11	4.5	19	4.5	332	4.5	0
5	17	5	24	5	382	5	0
5.5	62	5.5	29	5.5	502	5.5	138
6	80	6	33	6	709	6	197
6.5	84	6.5	34	6.5	771	6.5	276
7	87	7	35	7	814	7	390

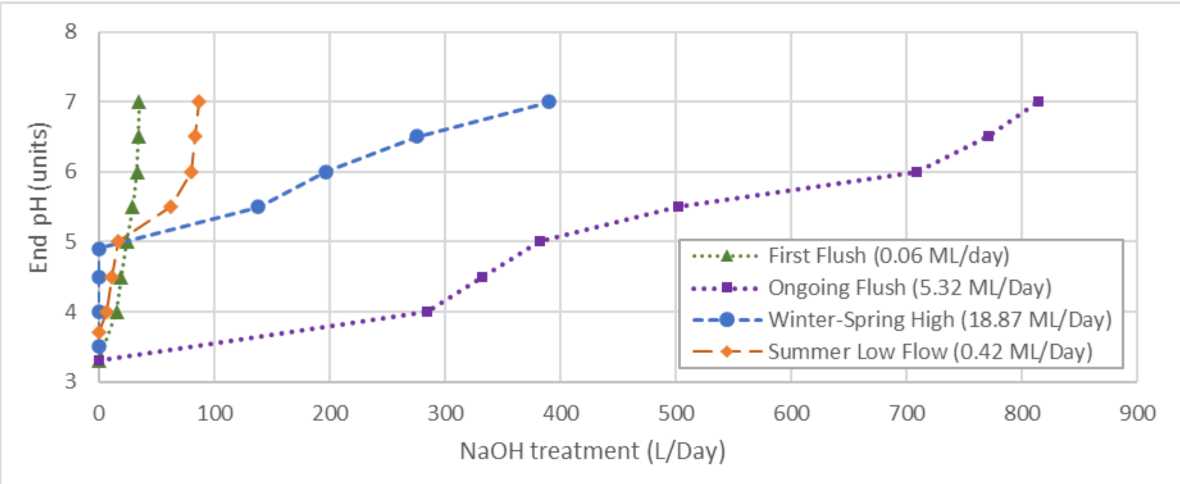

Figure 5-2 Simulated NaOH dosing rates to achieve different pH outcomes downstream of Big Swamp

5.2.2 Total annual treatment load

The estimated monthly and annual volumes of sodium hydroxide required to yield a pH of 5 and 6 downstream of Big Swamp are illustrated in Figure 5-3 and Figure 5-4 respectively. These indicate that based on the typical flow conditions and the concentrations of analytes observed during 2019-2020, monthly treatment rates to achieve a pH of 5 downstream of Big Swamp range from as little as 22 L in March to as much as 6,600 L in July. The total annual volume required to achieve a pH of 5 is approximately 28,000 L, with the majority (21,000 L) required between the months of May and September.

To achieve a pH of 6 downstream of Big Swamp, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. The total annual volume required to achieve a pH of 6 is approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.

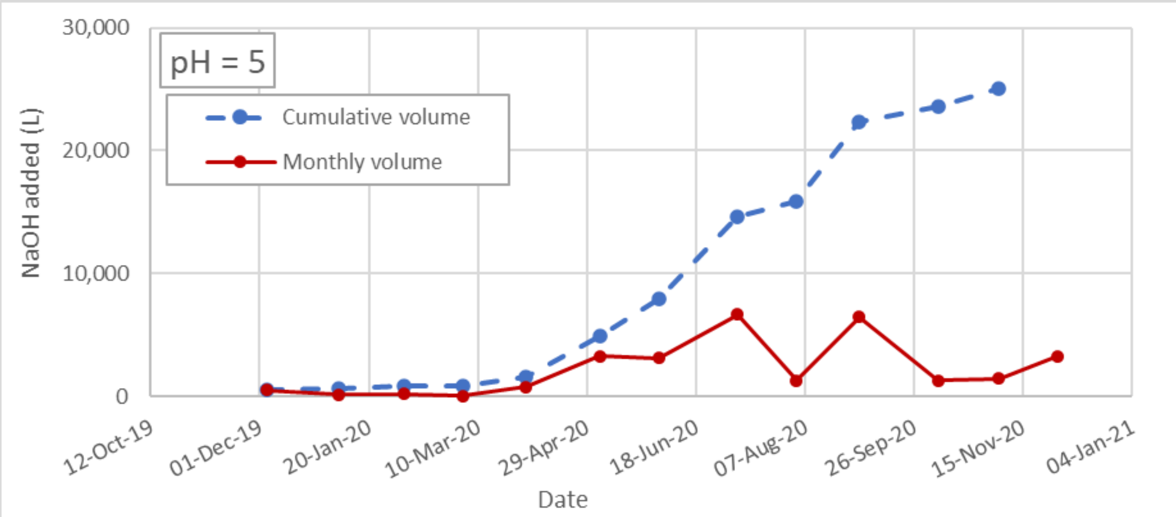

Figure 5-3 Estimated monthly and annual NaOH treatment volumes to yield a pH of 5 downstream of Big Swamp

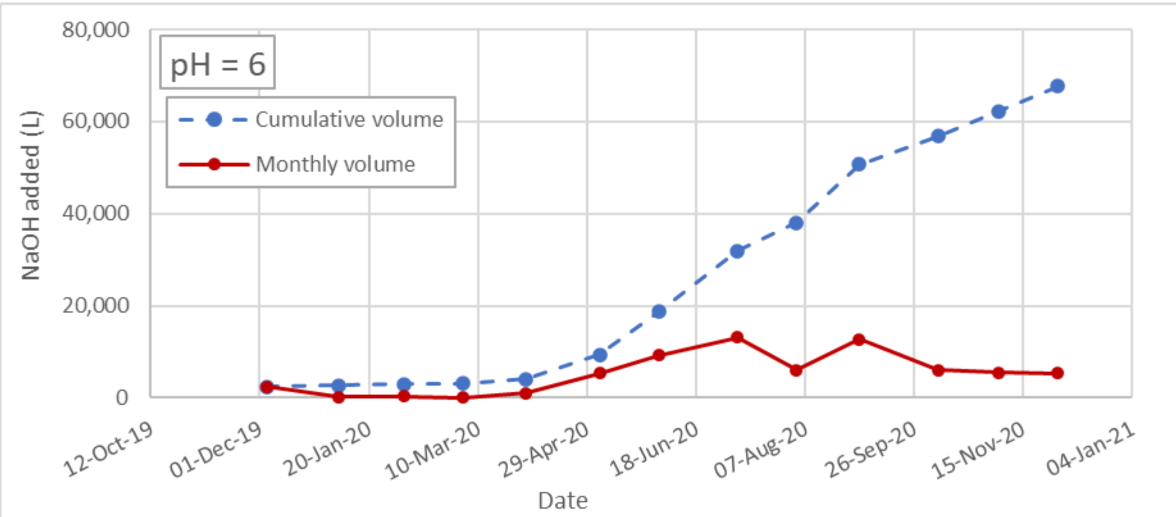

Figure 5-4 Estimated monthly and annual NaOH treatment volumes to yield a pH of 6 downstream of Big Swamp

5.3 Predicted build-up of aluminium and iron hydroxide sludge

The estimated monthly and annual build-up of aluminium and iron hydroxide sludge in response to sodium hydroxide dosing has been illustrated in Figure 5-5 and Figure 5-6 to achieve a pH of 5 and 6, respectively. Following treatment to a pH of 5, sludge build up was almost exclusively limited to April and May in which approximately 9,400 kg of sludge is estimated to build up over the 2 months, compared to the annual build-up of 10,000 kg.

Treatment to a pH of 6 yielded more frequent precipitation of aluminium and iron hydroxides, though April to July still represented the greatest period of build up with approximately 24,000 kg occurring over that period compared to an annual mass of approximately 28,000 kg.

Assuming a density of 1,200 kg/m^3 for treatment sludges (Ramirez et al., 2018), these results suggest annual sludge volumes of approximately 8 to 24 m^3 per year assuming treatment to pH values of 5 and 6, respectively.

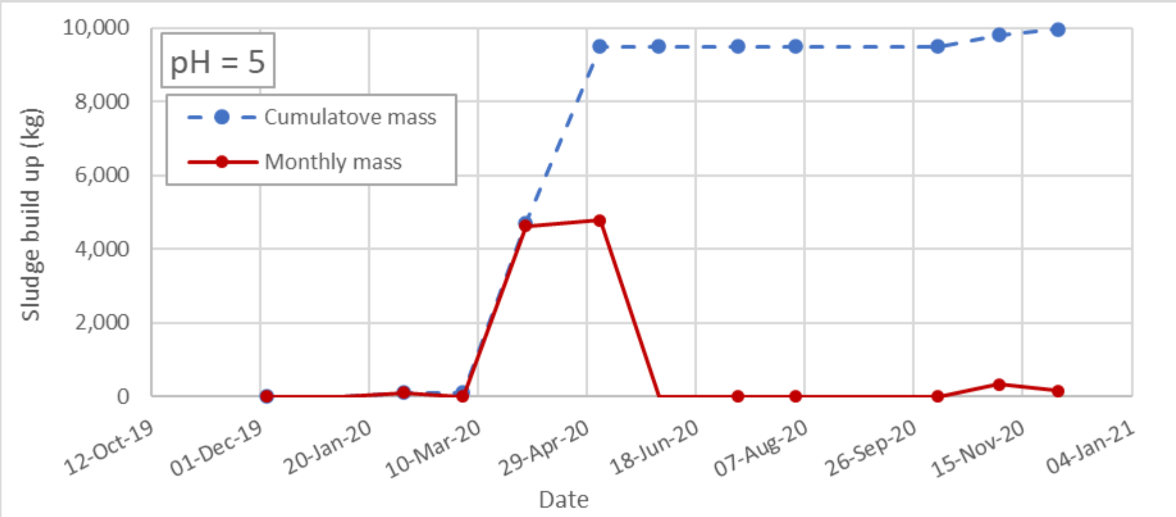

Figure 5-5 Estimated monthly and annual sludge build up following treatment of discharge water to a pH of 5

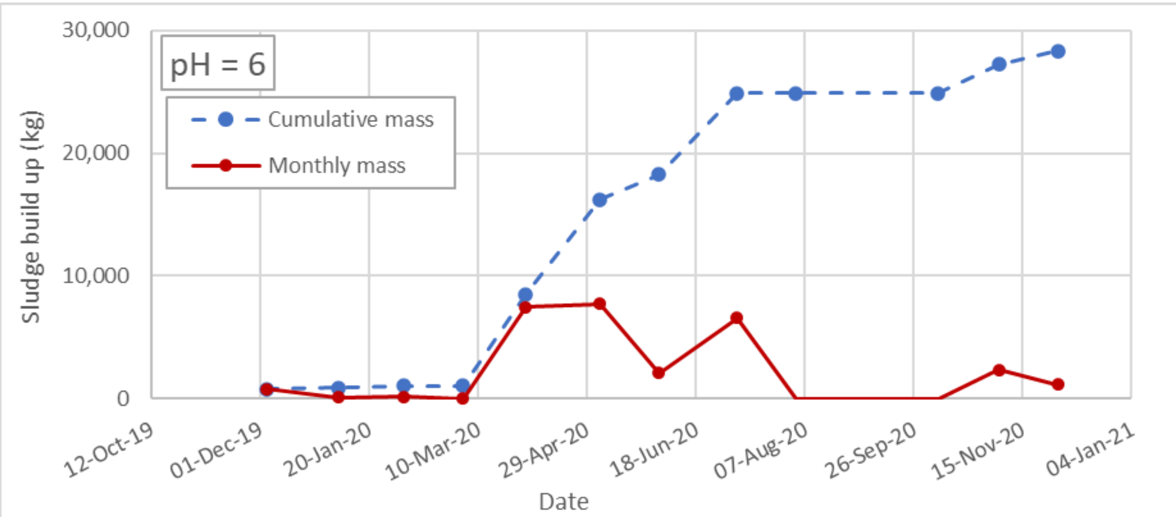

Figure 5-6 Estimated monthly and annual sludge build up following treatment of discharge water to a pH of 6

5.4 Summary

A summary of the dosing requirements for the downstream contingency measure using sodium hydroxide is outlined below:

- To achieve a pH of 6, dosing rates range between less 80 L/day under summer low flow and initial flushing conditions, to 200 L/day during winter-spring high flows conditions and 700 L/day during ongoing flushing conditions.
- To achieve a pH of 6, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. The total annual volume required to achieve a pH of 6 is approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.
- The annual build-up of aluminium and iron hydroxide sludge in response to sodium hydroxide dosing is estimated to be 24 m^3 assuming treatment to pH of 6.

6. Predicted water quality outcomes of inundation

The installation of hydraulic barriers through Big Swamp is one of several remedial actions recommended in the Remediation and Environmental Protection Plan (REPP) to improve the flows and water quality, as well as the vegetation and ecology in Boundary Creek and Big Swamp. The predicted water quality outcomes of the hydraulic barriers were informed by the conceptual site model (Section 3), the groundwater-surface water model (GDH, 2020) and the hydrogeochemical modelling software PHREEQC. The hydrogeochemical modelling also aims to validate the CSM and groundwater-surface water model.

The outcomes of the CSM, GW-SW model and hydrogeochemical model are combined to estimate the potential water quality outcomes in Boundary Creek downstream of Big Swamp in the presence and absence of the proposed barriers and comment on the potential implications for treatment options.

It is recognised that this approach will not generate a fully parameterised reactive solute transport model but instead, represents the first step in understanding the implications of barrier installation versus doing nothing. In this respect, the aim of the model is to provide a first order estimate of how long it may take (months, years, decades) for water quality in Boundary Creek to improve in the presence or absence of the proposed hydraulic barriers. By doing so, the modelling helps to (1) determine whether there is sufficient benefit to water quality outcomes associated with the proposed barriers to warrant installation, and (2) whether there is sufficient confidence to directly proceed with remediation or whether further investigations and detailed modelling are required to inform further decision making.

6.1 Hydrogeochemical model calibration

6.1.1 Method

As discussed in section 3, the main pathway by which acidity is discharged into Boundary Creek appears to be via groundwater discharge. As such, it is possible to model the surface water chemistry downstream of Big Swamp using a mixing model that accounts for the input of groundwater from different areas in Big Swamp, with different respective chemistries. The mix function in the modelling package PHREEQC was used, with the relative input of groundwater from different areas of the swamp represented by different mixing fractions. This has been done at monthly time steps over a 12-month monitoring period (November 2019-October 2020) to reflect the different groundwater and surface water chemistries observed over that period.

Section 3 also indicates that temporal variations in groundwater chemistry may have significant implications on water chemistry discharging from Big Swamp. To account for this, the groundwater chemistries adopted for each modelled time step reflects those analysed in samples collected during each month of the monitoring period.

Six monitoring bores were selected to reflect the spatial variability of groundwater chemistry throughout the swamp that may contribute to surface water quality downstream of Big Swamp. This included BH18, BH15, BH12, BH10, BH07 and BH03. These bores were selected for two reasons. Firstly, they represent a good longitudinal section of bores along Big Swamp, including three from the western half of the swamp (BH18, BH15 and BH12) and three from the eastern end of the swamp (BH10, BH07 and BH03). Secondly, these bores are located closer to the interior flow path of Big Swamp than other bores which appears to be the primary surface water flow path through the swamp. Groundwater from these bores therefore represents the chemistry of groundwater most likely to interact with surface water. It should be noted that this conceptual model contrasts with the groundwater-surface water model, which represents the primary surface water flow path as the northern channel.

Following the input of groundwater fractions from each bore into the PHREEQC mixing model, equilibrium phases were included to account for atmospheric exchange (changing equilibrium with CO_2 and O_2) and mineral precipitation (mineral phases were included for amorphous $Al(OH)_3$, amorphous $Fe(OH)_3$, (ferrihydrite), gypsum and barite). The mass of O_2 and CO_2 available for equilibrium was set in excess (10.0), while the saturation index (SI) for CO_2 was set at -3.23 (calculated from surface water upstream of Big Swamp). The saturation index for O_2 was allowed to vary between -10 and -40 to represent more oxidising and more reducing water (respectively) as indicated by the relative proportion of iron (II) and iron (III) in a sample. That is, if a sample had no iron (II) it was considered more oxidising and the SI for O_2 was set at -10 while if the iron in a sample was dominantly iron (II) it was allowed to be more reducing and the SI for O_2 was set as low as -40. If alkalinity was not present in a sample due to low pH, the total inorganic carbon of the sample was calculated by applying a CO_2 SI of -1.8, estimated from neutral groundwater in the swamp area.

Models were initially set up with an equal contribution of groundwater from each bore and the relative proportions were subsequently iterated until the resulting chemistry provided calibration to the water chemistry observed downstream of Big Swamp at gauge 233276. The relative contribution of groundwater from the eastern and western halves of the swamp were subsequently compared to those represented in the groundwater-surface water to provide an additional point of calibration. The model was calibrated using the groundwater discharge from groundwater-surface water model and 5 key analytes which were deemed to represent those of most concern based on discussions in Sections 3 and 4 and included acidity, pH, sulfate, iron and aluminium (note, acidity was estimated based on dissolved metal concentrations in the mixed water using the ABATES tool discussed in section 3).

6.1.2 Results

The modelled and measured concentrations of acidity, sulfate, iron, aluminium and pH, are illustrated in Figure 6-1 to Figure 6-5 below, as well as the relative groundwater contribution given by the groundwater-surface water model and PHREEQC model in Figure 6-6. These results are also presented in co-variance plots in Appendix D.

Accordingly, the mixing model provides good calibration to observed data for acidity, pH, sulfate and iron with R^2 values (where an R^2 value of 1 means that all data can be explained by the model) of 0.97, 0.89, 0.95, and 0.98, respectively. The model provided the worst fit for aluminium with an R^2 value of approximately 0.60. The model tends to underpredict the concentration of dissolved aluminium in surface water discharging from Big Swamp. As discussed in section 4, this may be the result of particulate aluminium passing through the field filter, resulting in aluminium concentrations in measured samples above the model results. Further investigation into this may be warranted.

Figure 6-6 shows that the contribution of groundwater discharging from Big Swamp tended to be greater in the eastern portion of the swamp relative to the western end, particularly outside of summer low flow conditions, and is consistent with the groundwater-surface water model (GHD, 2020). While this may be the case volumetrically, the greatest input of acidity to the swamp tended to come from the western end of the swamp, due to the comparatively high concentration of acidity in groundwater in the western end of the swamp.

For example, during the November 2019 time step, the volumetric contribution of groundwater in the eastern end of the swamp was twice that of groundwater from the western end. However, groundwater from the western end of the swamp accounted for approximately 85% of the sulfate and iron input into the model and 96% of the aluminium. While this trend was observed in general, it was not always the case. For example, the input of iron during the June 2020 time step was approximately equal in both the eastern and western portions of the swamp. This suggests that the results of the transect sampling event on the 7th of April 2021 which indicated the majority of acidity inputs occurred in the eastern end of the swamp may remain valid. Although temporal variations in both groundwater chemistry and volumetric inputs to surface water may yield highly variable contributions of acidity spatially along the swamp.

These results support the notion that the introduction of alkalinity and subsequent neutralisation of acidity in the upstream end of the swamp is likely to yield improved water quality outcomes in surface water discharging from Big Swamp. This may not have been the case if the majority of acidity was being discharged via groundwater in the eastern end of the swamp, as the loss of alkalinity via the infiltration of alkaline water in the western end of swamp may have limited its effectiveness in the eastern end of the swamp. A potential upstream treatment option is discussed in Section 7.

The results presented below suggest that the time varying input of acidity from different groundwaters is a valid model for representing the discharge of acidity (and other parameters of concern) from Big Swamp and thus, presents a suitable method for predicting potential water quality outcomes in Boundary Creek in the presence or absence of barrier installation.

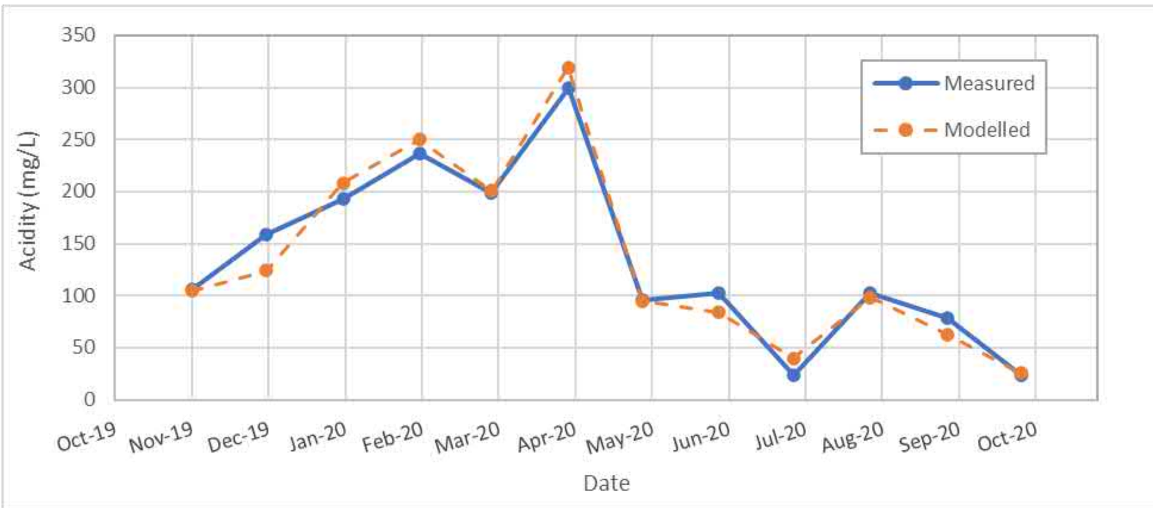

Figure 6-1: Modelled versus measured acidity concentrations downstream of Big Swamp

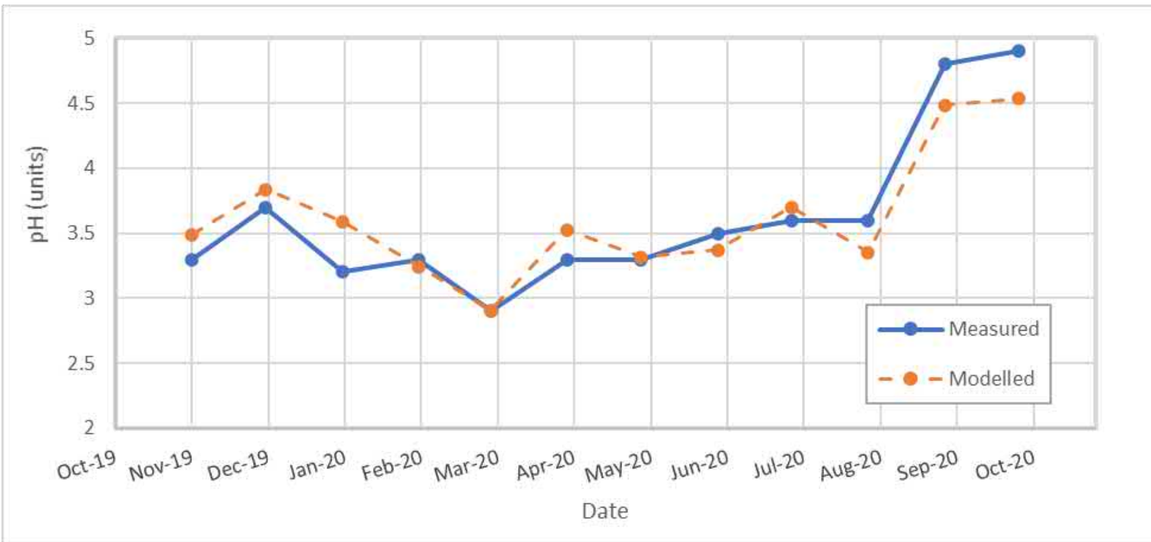

Figure 6-2: Modelled versus measured pH downstream of Big Swamp

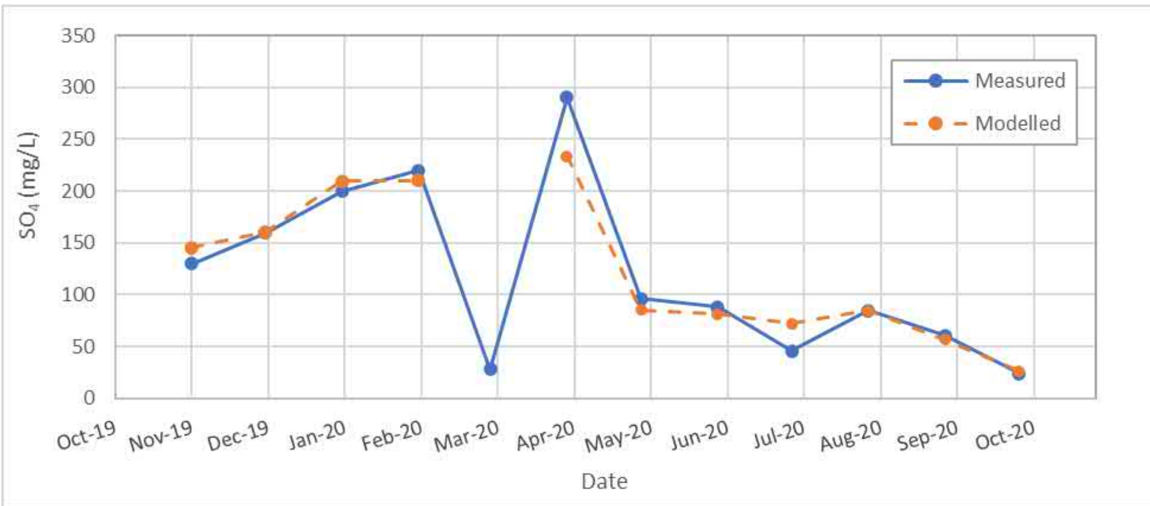

Figure 6-3: Modelled versus measured sulfate concentrations downstream of Big Swamp

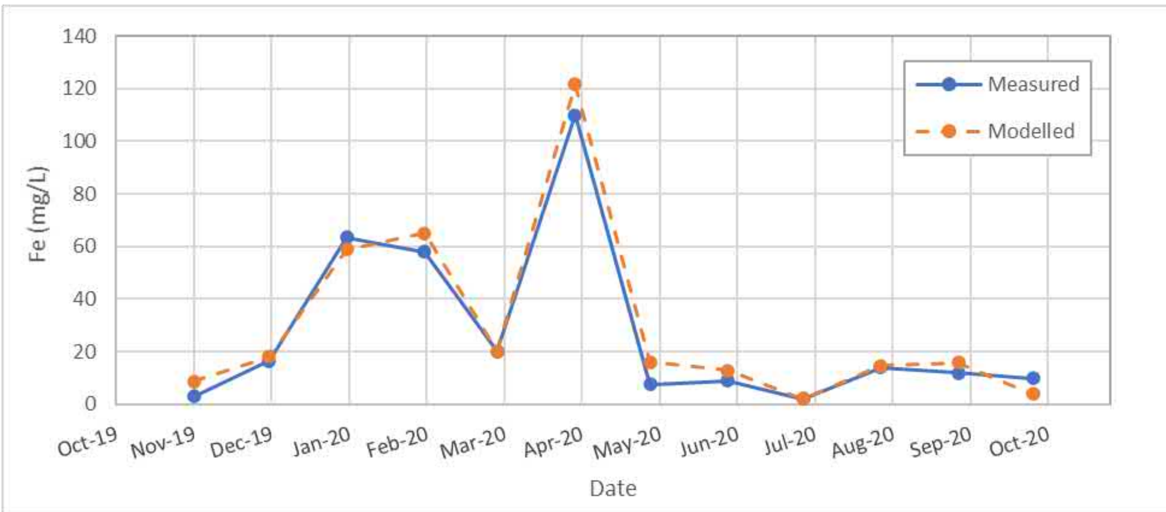

Figure 6-4: Modelled versus measured iron concentrations downstream of Big Swamp

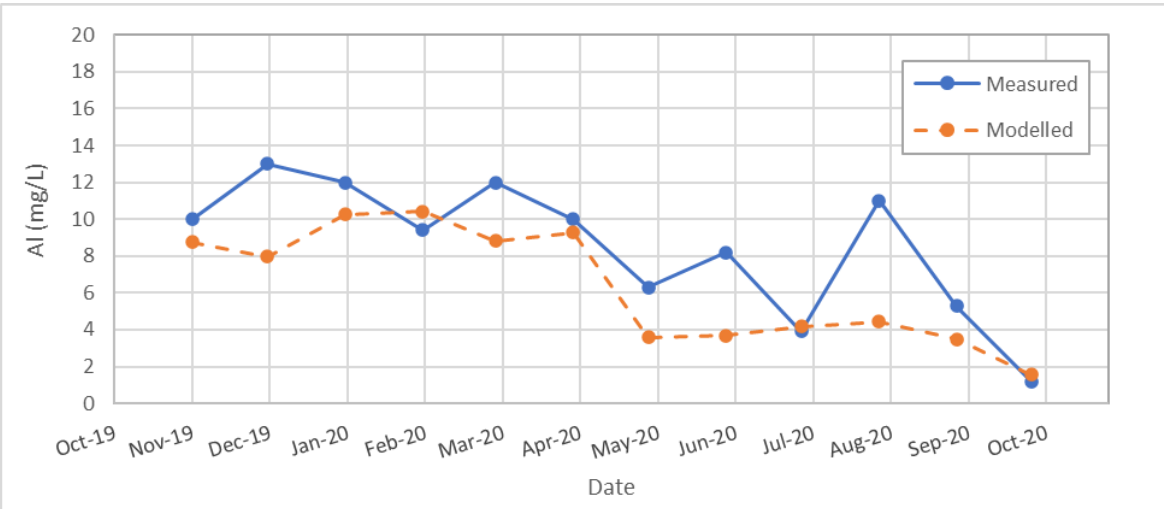

Figure 6-5: Modelled versus measured aluminium concentrations downstream of Big Swamp

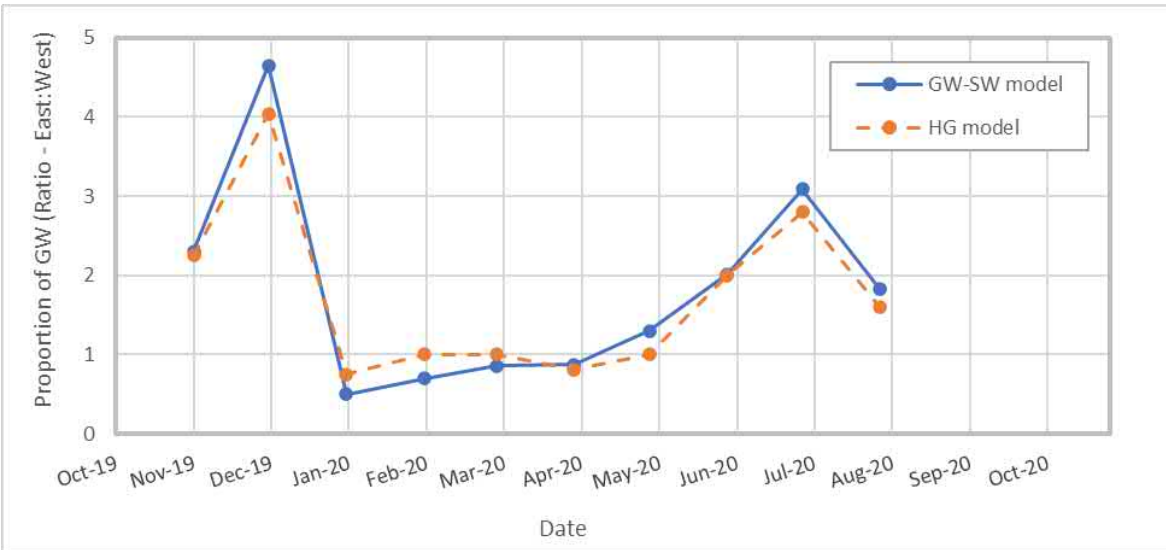

Figure 6-6: Modelled proportion of groundwater (Ratio of East:West) in groundwater-surface water model and PHREEQC model

6.2 Predictive modelling

6.2.1 Method

To estimate the potential water quality outcomes in Boundary Creek downstream of Big Swamp in the presence and absence of the proposed barriers, this section incorporates the outcomes of the above PHREEQC modelling and the groundwater surface water modelling (GHD, 2020) in an acidity mass balance model. The model incorporates a series of mass storage and flux terms including:

- the mass of acidity currently stored in groundwater in the swamp,
- the mass of existing acidity stored in the soil profile above the existing watertable which may be mobilised into the groundwater system via groundwater recharge and watertable rise,
- the mass of potential acidity stored in the soil profile above the predicted watertable which may be mobilised into the groundwater system via oxidation and subsequent groundwater recharge and watertable rise,
- the rate at which acidity may be mobilised into the groundwater system via recharge,
- the rate at which acidity may be mobilised from the groundwater system to Boundary Creek via groundwater discharge.

The mass of acidity currently stored in groundwater in Big Swamp was estimated in section 3.1.2 based on the range of groundwater acidity concentrations measured in Big Swamp, an assumed saturated aquifer thickness and porosity.

The mass of acidity stored in the soil profile above the watertable which may be mobilised into the groundwater system via groundwater recharge and rise in watertable can be estimated by multiplying the concentration of existing soil acidity above the watertable in different areas of the swamp and adopting an assumed soil density, similar to the estimates provided in section 3.1.1. The key difference to these estimates and those made in section 3.1.1 are the thickness of the soil profile assessed. Estimates in section 3.1.1 considered only the upper 0.24 m of the soil profile available for runoff, while the total mass is much greater in some areas of the swamp where the watertable is greater than 2 meters below ground surface.

The existing depth to watertable across the swamp adopted for this assessment is based on that achieved during model calibration by GHD (2020) for a typical climatic scenario (Figure 6-7, left). For this assessment, areas where the watertable is close to the surface (i.e. approach 0 m bgl) have been ignored as these will have limited acidity available to for addition to the system via recharge or watertable rise. Further, areas to the north of the northern channel and in the south at the fire trench have been ignored as these areas are elevated and soil samples have not been collected in these areas and as such, it is unclear whether these areas contain acid sulfate soils.

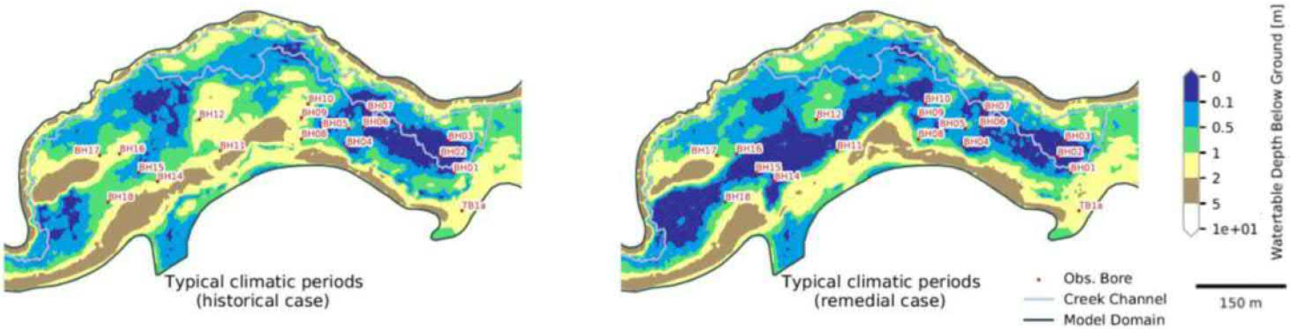

Figure 6-7: Modelled depth to watertable across Big Swamp under typical climatic conditions for historical (no barriers) and remedial (with barriers) scenarios

The mass of potential acidity stored above the watertable can be estimated following a similar method, using the potential acidity results given by Cook et al., (2020) and the modelled depth to watertable under typical climatic conditions for current/historical conditions (Figure 6-7, left) and that modelled under barrier installation/remediation (see Figure 6-7, right). The resulting difference in the mass of acidity available for addition to the groundwater system via sulfide oxidation and subsequent recharge represents the effect of remediation on the mass of potential acidity available to the system. It is noted that if recovery if the LTA occurs in the western portion of the swamp and yields groundwater level increases in this area, it may have a similar effect to the installation of barriers. However, as this data is not yet available and modelling has not considered this to date, we have not accounted for it in the estimated remediation duration and this potential effect is not discussed further in this report.

The rate at which acidity may be mobilised into the groundwater system via recharge has been estimated using an adopted range in potential recharge chemistries based on the assumed pore water chemistry as discussed in section 3.1.3. and the calibrated recharge rate in the groundwater-surface water model which equates to 40% of the average annual rainfall for the area (GHD, 2020). For the purpose of this assessment, it has been assumed that all sulfides above the watertable will oxidise and become available for addition into the system via recharge prior to the complete removal of existing acidity above the watertable. While there is uncertainty in this approach, it is reasonable for the purpose of this assessment given the mass of existing acidity estimated, its rate of mobilisation and duration over which it is likely to take prior to its full removal (this is discussed further in section 6.2.2 below).

The rate at which acidity is discharged from Big Swamp under current conditions has been estimated using the observed loads at the downstream gauge. The rate at which acidity is discharged from Big Swamp under the remedial case has been estimated by revising the PHREEQC model outputs in 6.1.2 to account for changes in groundwater discharge rates associated with barrier installation as predicted by the groundwater-surface water model (GHD, 2020).

6.2.2 Results

As discussed in section 3, the mass of acidity currently stored in groundwater in Big Swamp can be estimated at 126 tonnes of acidity as $CaCO_3$ equivalent

The mass of acidity stored above the watertable which may be made available to the groundwater system via recharge or watertable rise has been estimated in Table 6-1 below. This estimate is based on the current depth to watertable across the swamp under typical climatic conditions for historical conditions as illustrated in Figure 6-7 and the spatial distribution of existing soil acidity above the watertable throughout the swamp illustrated in Figure 6-8 below. Accordingly, assuming a soil density of 1,400 kg/m^3, the mass of existing acidity in Big Swamp available for addition to the groundwater system has been estimated at approximately 3,900 tonnes of $CaCO_3$ equivalent, though this could range from approximately 3,300 to 4,400 tonnes of $CaCO_3$ equivalent based on a range in potential soils densities (1,200-1,600 kg/m^3) alone. The key difference in this estimate to that made for surface soils in section 3.1.1 is that this estimate takes into account thicker sections of the soil profile above the watertable which exceeds 2 m in some areas, while section 3.1.1 only considered the upper 0.24 m of the soil profile available for surface runoff estimates.

The mass of potential acidity which may be made available via sulfide oxidation in the absence of remediation has been estimated in Table 6-1 below. This estimate is based on the current depth to watertable across the swamp under typical/historical climatic conditions as illustrated in Figure 6-7 and the spatial distribution of potential acidity above the modelled watertable throughout the swamp illustrated in Figure 6-9 below. Accordingly, assuming a soil density of 1,400 kg/m^3, the mass of potential acidity in Big Swamp available for addition to the groundwater system has been estimated at approximately 4,000 tonnes of $CaCO_3$ equivalent, though this could range from approximately 3,400 to 4,500 tonnes of $CaCO_3$ equivalent based on a range in potential soils densities (1,200-1,600 kg/m^3) alone.

The mass of potential acidity which may be made available via sulfide oxidation following remediation using the method discussed in section 6.2.1 has been estimated in Table 6-1 below. This estimate is based on the predicted depth to watertable across the swamp under typical climatic conditions for the remedial scenario as illustrated in Figure 6-7 and the spatial distribution of potential acidity above the modelled watertable throughout the swamp illustrated in Figure 6-10. Note the distribution of potential acidity in Figure 6-10 varies slightly to Figure 6-9 due to additional potential acidity becoming submerged below the predicted watertable. Accordingly, assuming a soil density of 1,400 kg/m^3, the mass of potential acidity in Big Swamp available for addition to the groundwater system has been estimated at approximately 1,600 tonnes of $CaCO_3$ equivalent, though this could range from approximately 1,400 to 1,800 tonnes of $CaCO_3$ equivalent based on a range in potential soils densities (1,200-1,600 kg/m^3) alone.

This shows that following remediation with the installation of hydraulic barriers, the predicted increase in watertable may reduce the mass of acidity from approximately 4,000 tonnes of $CaCO_3$ equivalent to approximately 1,600 tonnes of $CaCO_3$ equivalent.

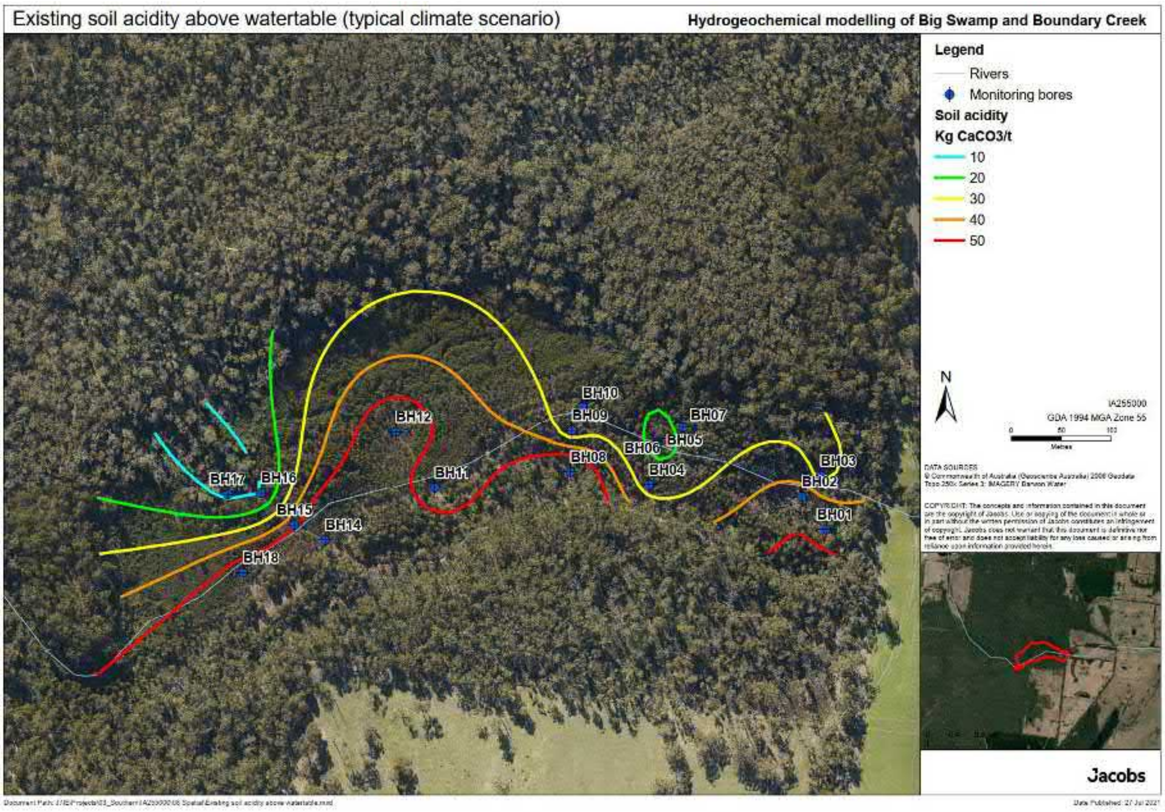

Figure 6-8: Spatial distribution of existing soil acidity in Big Swamp above the watertable under typical historical climatic conditions

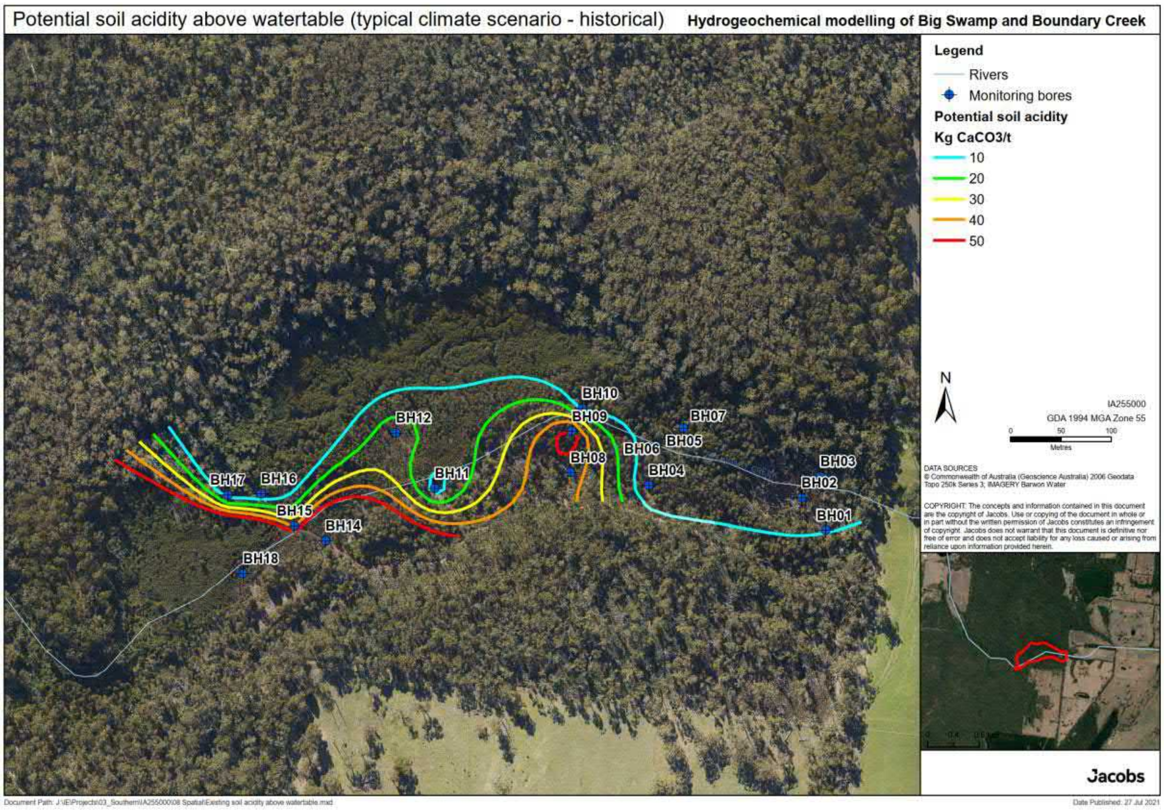

Figure 6-9: Spatial distribution of potential soil acidity in Big Swamp above the watertable under typical historical climatic conditions

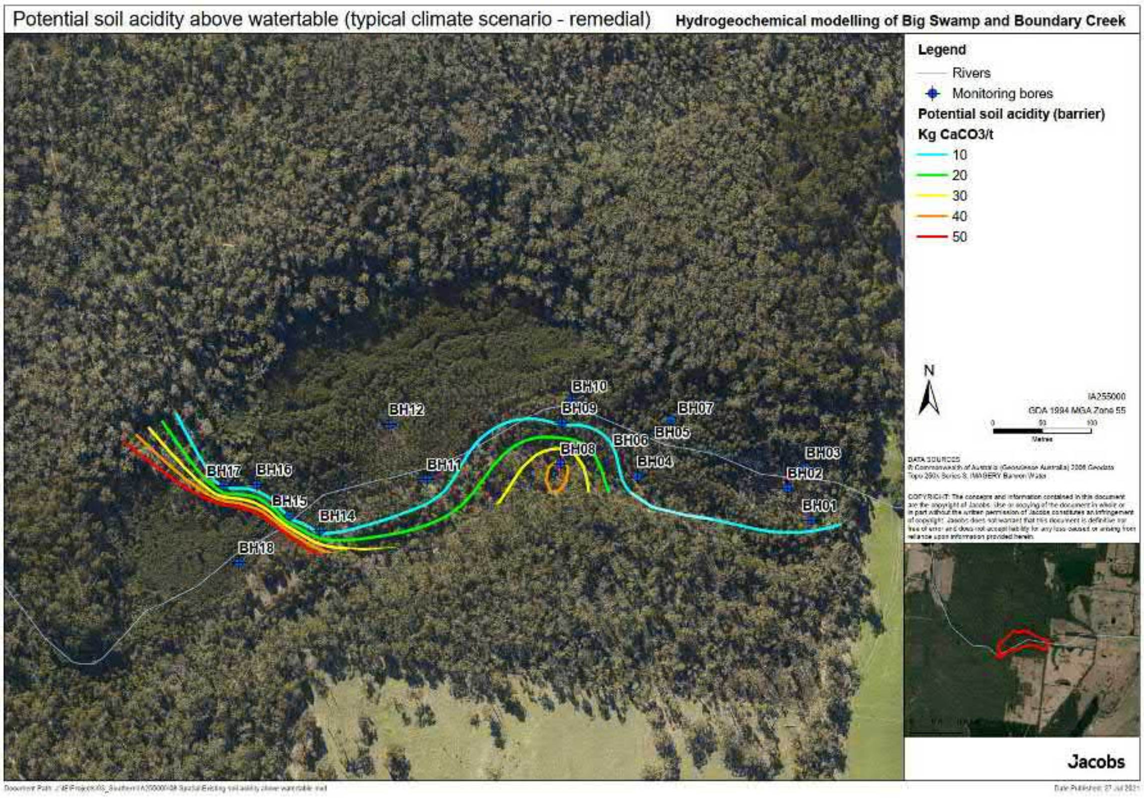

Figure 6-10: Spatial distribution of potential soil acidity in Big Swamp above the predicted watertable under typical climatic conditions under remediation scenario

The rate at which acidity may be added to the groundwater system via recharge has been estimated using the long-term average rainfall from the closest rainfall gauge (agroforestry site, station 233250) which has data from 1994 to 2021, yielding an average long term rainfall value of 609 mm/yr. As indicated by GHD (2020), the groundwater-surface water model was calibrated by adopting a recharge value of 40% of annual recharge. This yields a recharge volume of approximately 100 ML/yr across the surface area of the swamp.

The mass of acidity recharged to the system was estimated by multiplying recharge by the concentration of acidity estimated in recharge water. As discussed in section 3.1.3, leachate tests have not been undertaken and as such, the nearest approximation of these concentrations are given by shallow groundwater responding to recharge, which gives a range of acidities across BH16, BH17 and BH18 of 145 to 929 mg $CaCO_3$/L and an average concentration of 560 mg/L $CaCO_3$ equivalent. Accordingly, the addition of acidity to the groundwater system via rainfall recharge can be estimated at 56 tonnes per year $CaCO_3$ equivalent (though this could range from 15 to 93 tonnes per year $CaCO_3$ equivalent based on the adopted range in acidity concentrations in recharge water).

The mass of acidity discharged from Big Swamp under current conditions has been estimated based on the observed concentration and volumes as discussed in Section 3 at approximately 80 tonnes per year, and is primarily attributable to groundwater discharge. This is similar to the rate of acidity added to the groundwater system via recharge and suggests that the Swamp may have established a dynamic equilibrium over the last 30 years since acidification processes began. Further, this suggests that significant changes in water quality would not be expected until the mass of acidity stored in soils in the swamp has been mobilised from the soil profile via recharge and subsequently discharged via groundwater discharge.

The mass of acidity discharged from Big Swamp under remedial conditions has been estimated by revising the relative contribution of groundwater from different areas of the swamp based on the outputs from the groundwater-surface water model. Accordingly, while the model predicts a relatively high contribution of groundwater from the eastern end of the swamp under current conditions, the proportion becomes more even under remedial conditions, as illustrated in Figure 6-11. The predicted change in acidity concentrations over the model period associated with this effect is illustrated in Figure 6-12 below. The modelling shows that in general, concentrations of acidity discharging from Big Swamp are likely to increase following remediation in response to enhanced groundwater discharge from the western portion of the swamp, where concentrations of groundwater acidity are higher than those in the east.

The change in acidity concentrations over this period has been used to estimate the mass of acidity discharged from the swamp (note this also takes into account a minimum flow rate of 0.5 ML/day over low flow periods associated with remediation). Accordingly, the annual mass of acidity discharging from Big Swamp following remediation is estimated to be approximately 160 tonnes of acidity as $CaCO_3$ and is approximately double that the absence of remediation.

Based on the above, it is estimated that in the absence of remediation, the combined mass of existing acidity in groundwater, existing acidity in soils, and potential acidity in soils would take approximately 100 years before they are removed from Big Swamp. Conversely, following remediation, it is estimated that the combined mass of existing acidity in groundwater, existing acidity in soils, and potential acidity in soils would take approximately 35 years to be removed from Big Swamp. The reduction in time associated with remediation is related to a combination (1) reducing the mass of potential acidity available for oxidation via watertable rise and (2) an increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation. This process could be accelerated by the treatment of acidic soils in the swamp by the introduction of alkalinity, which is discussed in the following Chapter.

The results indicate that while the proposed remediation may reduce the duration required to improve water quality in Boundary Creek, it also highlights that water quality is likely to decline in the interim. This risk could be mitigated by the installation of a downstream contingency measure or introduction of a treatment system upstream of Big Swamp.

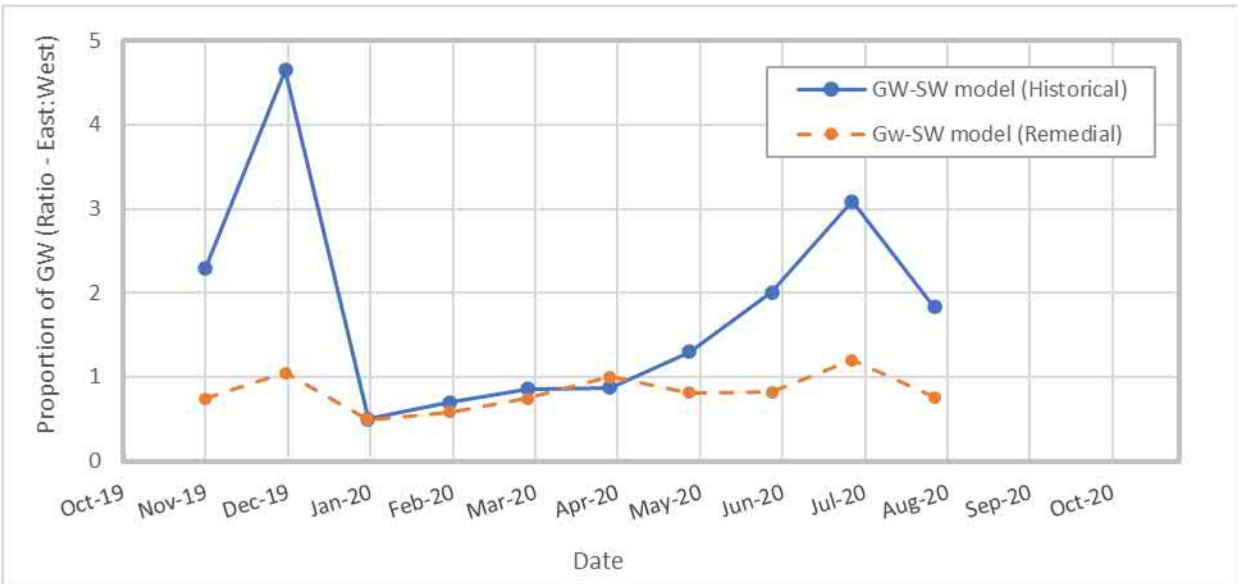

Figure 6-11 Modelled proportion of groundwater from the eastern end of the swamp vs the western end of the swamp for current and remedial conditions (based on GHD, 2020)

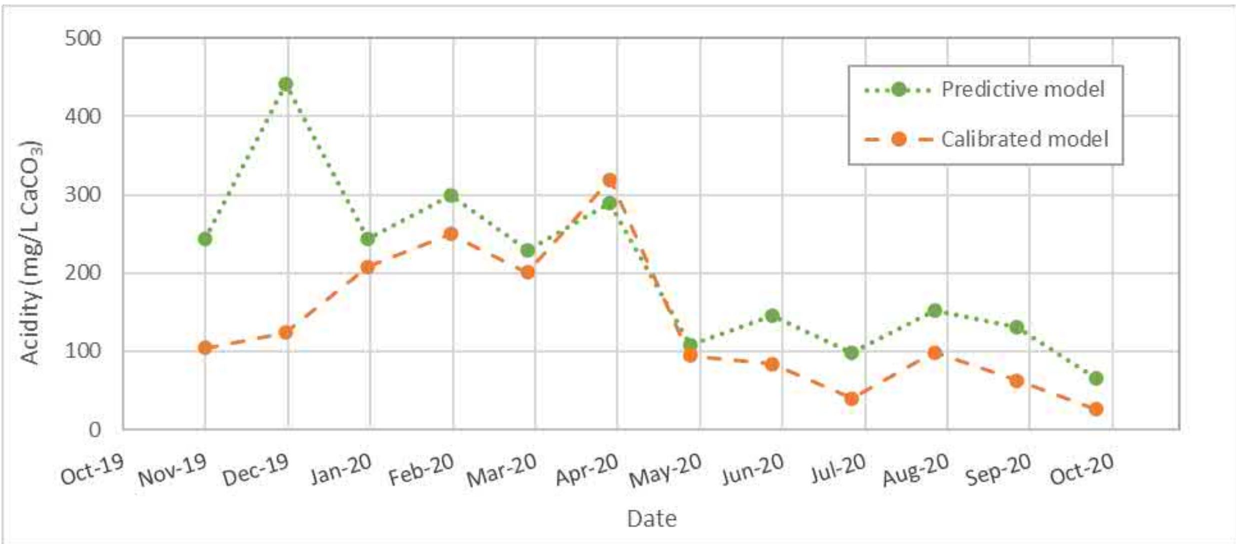

Figure 6-12 Calibrated versus predicted concentrations of acidity discharging from Big Swamp (predicted represents initial conditions following remedial action, see text)

Table 6-1 Estimated stores and rates of movement of acidity in Big Swamp with and without remediation

Scenario	Existing groundwater acidity	Existing soil acidity	Potential soil acidity	Net store of soil acidity	Discharge rate	Remediation duration
Unit	**Tonnes $CaCO_3$**	**Tonnes $CaCO_3$**	**Tonnes $CaCO_3$**	**Tonnes $CaCO_3$**	**Tonnes $CaCO_3$ / year**	**Years**
Current	126	3,900	4,000	8,026	80	100
Remedial	126	3,900	1,600	5,626	160	35

6.3 Model uncertainty and sensitivity

This section considers the relative uncertainty of the components in Table 6-1 including aquifer porosity, soil density, the distribution of acidity concentrations applied to generate mass estimates and the modelled discharge water chemistry used to generate acidity discharge rates.

As discussed in section 3.1.2, the porosity of the alluvial aquifer adopted was 0.4, however a range of 0.34 to 0.61 is reasonable for silts and clays (Morris and Johnson, 1967). This would yield a range in the acidity stored in groundwater of 107 to 192 tonnes as $CaCO_3$ equivalent. This yields a range in the remediation duration of 100-101 years under current conditions and 35-36 years under the remedial scenario. As such, the model is relatively insensitive to uncertainties associated with aquifer porosity. Furthermore, this illustrates the insensitivity of the model to the mass of acidity stored in the groundwater system due to its relative contribution of acidity in the model. As such, uncertainties associated with the distribution of groundwater acidity concentrations has not been considered.

The soil density adopted for the above estimates was 1,400 kg/m^3. While this is a reasonable estimate in the absence of site data, a reasonable range for the soil types identified in Big Swamp is considered to be 1,200 to 1,600 kg/m^3 (though densities can vary beyond this, particularly in peaty soils which may be even lower than this range). The range of existing soil acidity based on the range of likely soil densities is 3,300 to 4,400 tonnes $CaCO_3$ equivalent. The range of potential soil acidity based on the range of likely soil densities is 3,400-4,500 tonnes $CaCO_3$ equivalent under current conditions and 1,400-1,800 tonnes $CaCO_3$ equivalent under the remedial scenario. This yields a range in the potential remediation duration of 85-113 years under current conditions and 30-40 years under the remedial scenario. As such, the model is moderately sensitive to uncertainties associated with soil density. This could be reduced by the collection and analysis of samples to characterise soil density properties.

The uncertainty associated with the distribution of acidity concentrations applied to generate existing soil acidity mass estimates has been assessed by varying the adopted concentration of acidity in areas where sampling is more sparse, including the area to the west of BH18 and the area between and to the north of BH12 and BH10. In these areas, the concentration of acidity adopted the average of the interval between contours (i.e. if the area was in the middle of the 30 and 40 kg $CaCO_3$/t interval, a concentration of 35 kg/t $CaCO_3$ was adopted), however given the sparsity of data in these areas, concentrations could be represented by either of the upper or lower intervals. Accordingly, by adopting these upper and lower intervals, the mass of existing acidity may range between 3,100-4,300 tonnes $CaCO_3$ equivalent. This yields a range in the remediation duration of 90-105 years under current conditions and 30-38 years under the remedial scenario. As such, the model is moderately sensitive to uncertainties associated with soil acidity concentrations. This could be reduced by the collection and analysis of samples to characterise soil acidity in these key areas.

A similar approach to above was undertaken to assess the uncertainty associated with the distribution of potential acidity in Big Swamp. In particular, the concentration of potential acidity adopted in the area to the west of BH18 area was 55 kg $CaCO_3$/t, but is potentially skewed by elevated potential acidity concentrations in one bore, BH18. If concentrations in this area were more consistent with the majority of the swamp (approximately 20 kg $CaCO_3$/t), this would yield a reduction in the mass of potential acidity from 4,000 tonnes $CaCO_3$ equivalent under current conditions to 3,300 tonnes $CaCO_3$ equivalent and an associated reduction in remediation duration from 100 to 92 years. Similarly, this would yield a reduction in the mass of potential acidity from 1,600 tonnes $CaCO_3$ equivalent to 1,300 tonnes $CaCO_3$ equivalent associated with the remedial scenario and an associated reduction in remediation duration from 35 years to 33 years. As such, the model is moderately sensitive to uncertainties associated with potential soil acidity concentrations. This could be reduced by the collection and analysis of samples to characterise potential soil acidity in these key areas.

The uncertainty associated with the predicted mass of acidity discharging via the groundwater system has been assessed by varying the solubility of key minerals participating in geochemical reactions in PHREEQC. As discussed in section 4, amorphous forms of iron and aluminium hydroxide minerals were selected for modelling simulations and are reasonable given the kinetics associated with the system. However, there is a range in solubility reported in the literature for the iron hydroxides and aluminium hydroxides that may form. The current model assumes solubilities for these minerals at the higher end of the range; using lower solubility will result in the simulated discharge of water with lower concentrations of iron and aluminium and lower pH values. To assess the effect of lower solubilities, model runs were undertaken with less soluble forms of iron and aluminium hydroxide minerals ($Fe(OH)_3$_Maj and Gibbiste, respectively, as named in the PHREEQC input file). The effect of this on the predicted acidity concentrations over the model period is illustrated in Figure 6-13 which shows the outcomes of the original predictive model compared to that associated with uncertainties related to mineral solubility. This indicates that the acidity in groundwater discharging from Big Swamp may be lower than predicted in the model. This could reduce the mass of acidity discharging from Big Swamp per annum from approximately 160 tonnes $CaCO_3$ equivalent per year to approximately 140 tonnes $CaCO_3$ equivalent per year, resulting in an increase in the remediation duration from 35 to 40 years.

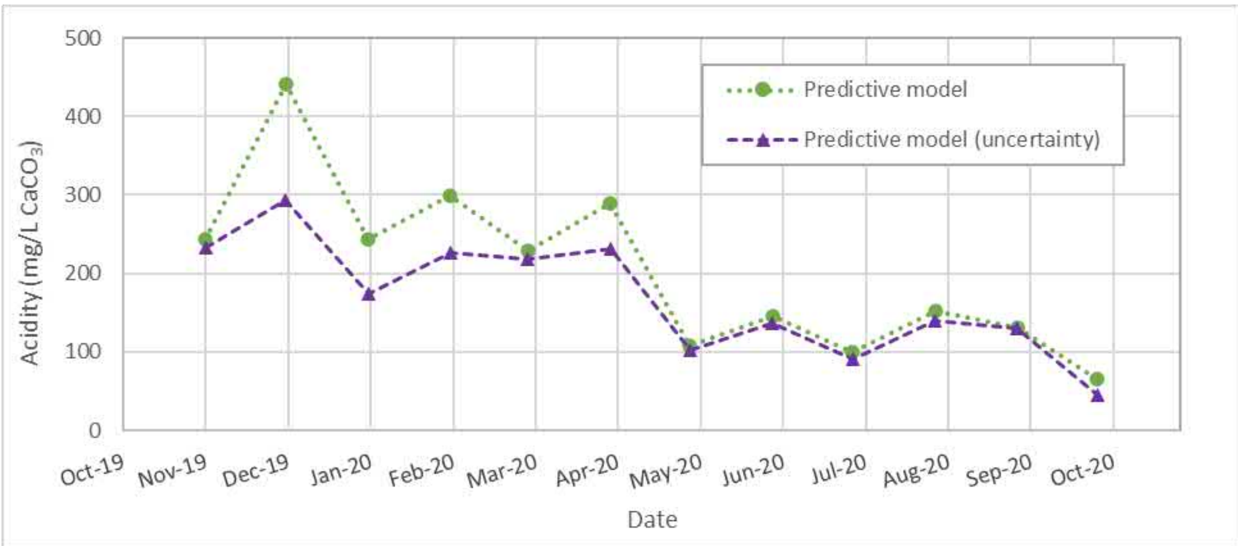

Figure 6-13 Predicted concentrations of acidity discharging from Big Swamp and uncertainty associated with mineral solubility (predicted represents initial conditions following remedial action, see text)

The sources of uncertainty and relative effect on remediation duration discussed above have been summarised in Table 6-2 below. This shows that soil density and the distribution of existing soil acidity in Big Swamp present the greatest level of uncertainty with respect to estimating remediation duration.

It is noted that the kinetics associated with sulfide oxidation have not been considered in this model based on the assumption that the minimum remediation duration is approximately 35 years and would provide sufficient time for pyrite oxidation above the watertable to occur. It is possible that this is not the case and that the rate of acidity movement through Big Swamp exceeds the rate at which pyrite may release acidity via oxidation. If this is the case, it is possible that improvements in water quality could occur over a shorter timeframe than estimated following the removal of existing acidity (approximately 25 years) and that subsequent improvements in water quality would be more incremental over the following years.

Regardless, the model provides a useful first order estimate of the relative timing of likely water quality improvement in Boundary Creek in the presence and absence of remediation and suggests that acidity will be reduced approximately 3 times quicker if remediation is undertaken.

Table 6-2 Sources of potential uncertainty and relative effect on remediation duration

Scenario	Existing groundwater acidity	Soil density	Distribution of existing soil acidity	Distribution of potential soil acidity	Discharge rate
Current	100-101 years	85-113 years	90-105 years	100-92 years	n/a
Remedial	35 -36 years	30-40 years	30-38 years	33-35 years	35-40 years

6.4 Summary

The calibrated hydrogeochemical model was used in conjunction with the CSM presented in Section 3 and the groundwater surface water model (GHD,2020) to predict the water quality changes with the installation of the hydraulic barrier. The key outcomes from this modelling are:

- Approximately 56 tonnes per year of acidity $CaCO_3$ equivalent is added to the groundwater system via rainfall recharge, compared to 80 tonnes per year of acidity $CaCO_3$ equivalent being discharged. This suggests that the Swamp may have established a dynamic equilibrium over the last 30 years since acidification processes began.

- Modelling indicates that concentrations of acidity discharging from Big Swamp are likely to increase following remediation in response to enhanced groundwater discharge from the western portion of the swamp, where concentrations of groundwater acidity are higher than those in the east. The annual mass of acidity discharging from Big Swamp following remediation is estimated to be approximately 160 tonnes of acidity as $CaCO_3$ and is approximately double that in the absence of remediation.

- In the absence of remediation, the combined mass of existing acidity in groundwater and soils and potential acidity in soils would take approximately 100 years before they are removed from Big Swamp.

- With remediation, the time taken to remove the existing and potential acidity is reduced to 35 years. The reduction in time associated with remediation is related to a combination of:

  - Reducing the mass of potential acidity available for oxidation via watertable rise and

  - An increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation.

- Soil density and the distribution of existing soil acidity in Big Swamp present the greatest level of uncertainty with respect to estimating remediation duration.

- These results suggest that either a downstream contingency measure or introduction of a treatment system upstream of Big Swamp may be required to mitigate potential risks to the Barwon River.

7. Potential Upstream Treatment Option

The hydrogeochemical modelling undertaken to inform the potential outcomes of installation of hydraulic barriers as a remediation action for Big Swamp indicates the water quality benefits could take 35 years to be realised. This highlights the importance of either a downstream contingency measure or a potential upstream treatment solution to advance remediation.

On June 17 2021, the Independent Technical Review Panel (ITRP) recommended that an upstream treatment system using caustic magnesia (MgO) as a pH correction chemical be considered. The focus of this system would be to treat the acidity stored in soils and pore water throughout the swamp. There is limited information available in the public domain regarding this treatment option and therefore it was not possible for Jacobs (2021a) to consider it in detail as a field trials would need to be undertaken to confirm the feasibility of the option.

This section describes the seasonal variability in treatments rates and annual treatment loads for the upstream treatment option involving magnesium oxide.

The input of alkalinity into surface water upstream of Big Swamp is likely to be effective in the longer term by treating acidic surface soils in the swamp which would limit the ongoing leaching of acidity from those soils into groundwater (provided the alkaline water could be effectively distributed across acidic soils).

7.1 Approach to estimate magnesium oxide treatment rates

The approach used to estimate the treatment rates of magnesium oxide upstream of the swamp was similar to the approach used to estimate the treatment rates of sodium hydroxide (summarised in Section 5.1). PHREEQC was used to achieve a variety of different pH end points using the pH_fix function with magnesium oxide in excess. For simplicity, it has been assumed that the alkalinity released via the dissolution of magnesium oxide would be 100% effective in water discharging from Big Swamp. This is unlikely to be true as losses of alkalinity to the groundwater system will occur. As such, the mass of magnesium oxide given by these simulations are likely to represent minimum values and may underestimate the true masses required to achieve downstream water quality objectives.

The same flow rates and acidity concentrations were selected for the simulations to reflect the range in conditions as shown in Figure 5-1.

7.2 Predicted Magnesium oxide treatment rates

7.2.1 **Seasonal variability in treatment rates**

The simulated mass of magnesium oxide dissolved into Boundary Creek required to achieve different pH end points during initial flush, ongoing flush winter-spring high flows and summer low flows is summarised in Table 7-1 and Figure 7-1 below.

This shows that under summer low flow and initial flushing conditions, dissolution rates are less than 16 Kg/day to achieve pH 6 or less. Under winter-spring high flow conditions, dissolution is not required to achieve pH values of less than 5 as the discharge pH is already 4.9, however rates increase up to 40 kg/day to achieve a pH of 6 under these conditions. The highest dissolution rates are required during ongoing flushing conditions, with rates increasing from approximately 80 kg/day to achieve a pH of 5 and 145 kg/day to achieve a pH of 6.

Table 7-1 Simulated MgO treatment rates to achieve different pH outcomes downstream of Big Swamp

Summer Low 0.42 ML/day		Initial Flush 0.06 ML/day		Ongoing Flush 5.3 ML/day		Winter-Spring High 18.87 ML/day	
pH	Kg/day	pH	Kg/day	pH	Kg/day	pH	Kg/day
3.7	0	3.3	0	3.3	0	3.5	0
4	1	4	3	4	57	4	0
4.5	2	4.5	4	4.5	67	4.5	0
5	3	5	5	5	77	5	0
5.5	13	5.5	6	5.5	101	5.5	28
6	16	6	7	6	143	6	40
6.5	17	6.5	7	6.5	155	6.5	56
7	18	7	7	7	164	7	79

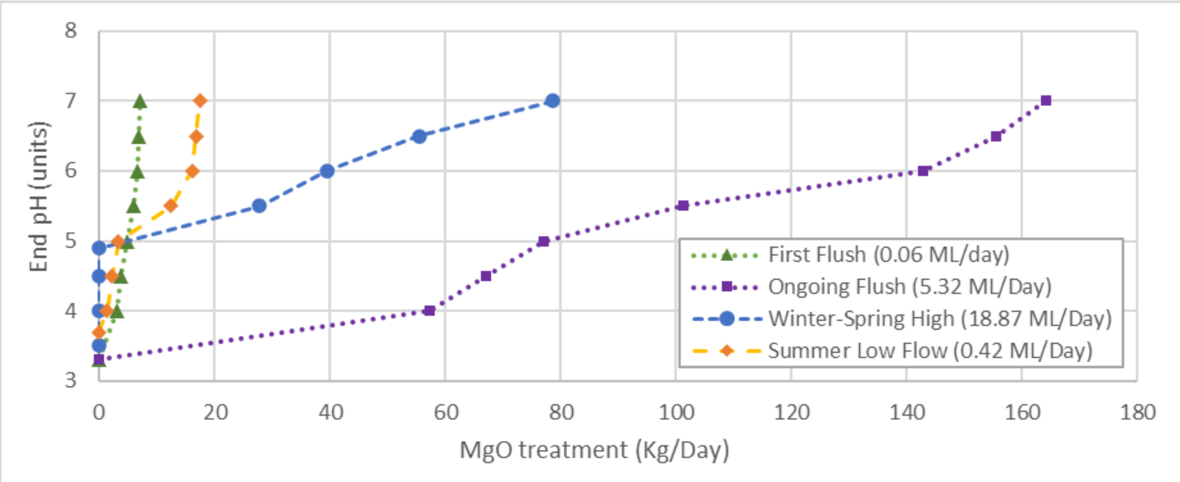

Figure 7-1 Simulated MgO treatment rates to achieve different pH outcomes downstream of Big Swamp

7.2.2 Total annual treatment load

The estimated monthly and annual volumes of magnesium oxide required to yield a pH of 5 and 6 downstream of Big Swamp are illustrated in Figure 7-2 and Figure 7-3 respectively. These indicate that based on the typical flow conditions and the concentrations of analytes observed during 2019-2020, monthly mass estimates required to achieve a pH of 5 downstream of Big Swamp range from 4 kg in March to 1,400 kg in July. The total annual mass required to achieve a pH of 5 is approximately 6,000 kg, with the majority (4,200 kg) required between the months of May and September.

To achieve a pH of 6 downstream of Big Swamp, masses range from 13 kg in March to 2,700 kg in July. The total annual mass required to achieve a pH of 6 is approximately 14,000 kg, with the majority (9,500 kg) required between the months of May and September.

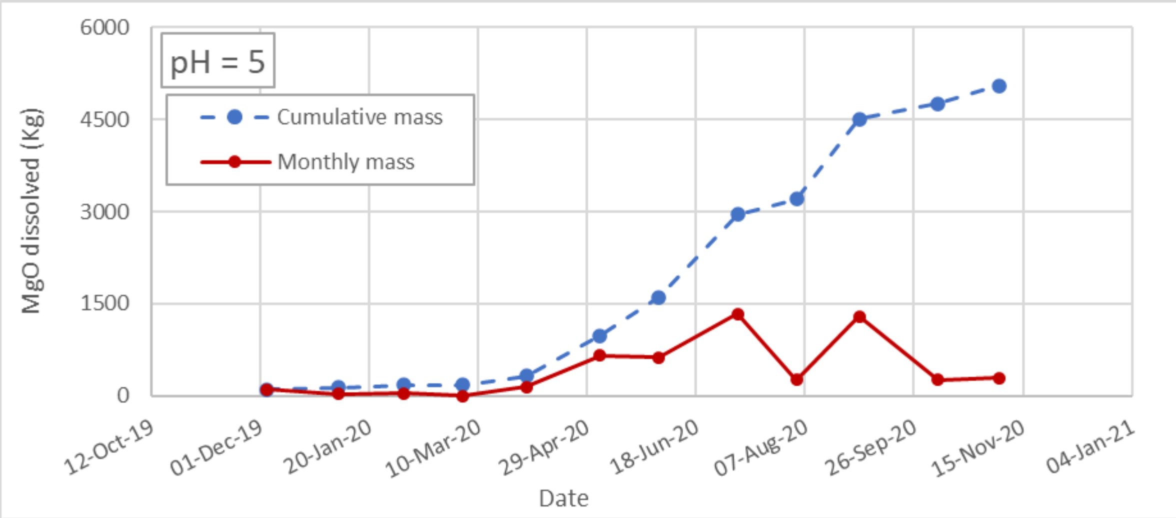

Figure 7-2 Estimated monthly and annual NaOH treatment volumes to yield a pH of 5 downstream of Big Swamp

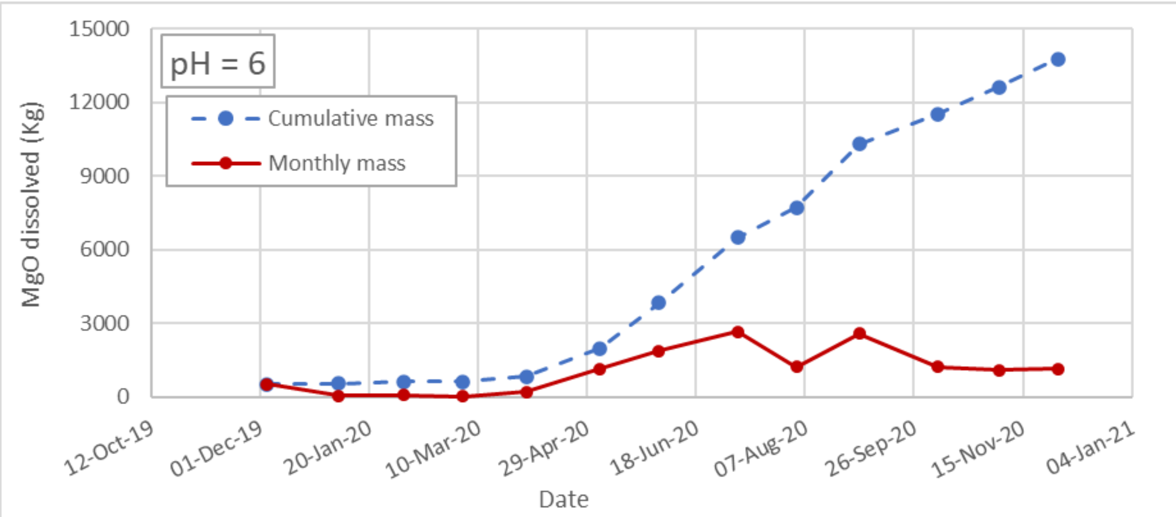

Figure 7-3 Estimated monthly and annual NaOH treatment volumes to yield a pH of 6 downstream of Big Swamp

7.3 Comparison of treatment options

Following the above, this section provides a brief comparison between the potential upstream treatment system and the downstream contingency measure, focussing on their treatment rates, sludge management, their relative effectiveness and/or certainty of effectiveness and environmental risks associated with overdosing.

As discussed in section 3, the primary pathway by which acidity is discharged to Boundary Creek appears to be via groundwater discharge. As such, the input of alkalinity into surface water upstream of Big Swamp may have a reduced effectiveness in the short term as surface water is lost to the groundwater system via infiltration. However, the modelling undertaken in section 6 suggests that for much of the year, the discharge of acidity from groundwater would occur in the western end of the swamp and be enhanced following barrier installation, so alkalinity inputs to the western end of the swamp may be effective.

Additionally, an upstream system could provide benefits in the longer term by treating acidic surface soils in the swamp which would limit the ongoing leaching of acidity from those soils into groundwater (provided the alkaline water could be effectively distributed across acidic soils). In addition, alkalinity dissolution rates vary widely across different systems, which highlights the importance of a trial to assess the rate of alkalinity dissolution, as well as the overall feasibility of the treatment system.

Conversely, as a sodium hydroxide dosing plant would aim to treat the load of acidity discharging from the swamp and given such measures are implemented routinely, there is high confidence that such a system could be installed and operated effectively, regardless of the pathway by which acidity enters Boundary Creek. However, such a system would have no effect on treating the source of acidity (i.e. the soils) in Big Swamp.

Treatment of discharge water with sodium hydroxide may result in the formation of 8 to 24 m^3 of sludge annually via the precipitation of iron and aluminium hydroxides. Management of sludge by its collection (via the installation of a silt curtain, settlement pond or similar) and its subsequent removal (by a sucker truck or similar) may warrant consideration to prevent enhanced build-up of sludge in the lower reaches of Boundary Creek or the Barwon River. Conversely, the addition of alkalinity upstream of Big Swamp is likely to result in the formation of iron and aluminium hydroxides within the swamp itself. Precipitates are likely to be fine grained in nature and while minor amounts of sludge may build up in the swamp, a significant proportion are likely to be discharged to the Barwon River and subsequently offshore.

Another consideration between the two systems is the relative environmental risks associated with sodium hydroxide and caustic magnesia, respectively. For sodium hydroxide, while its high solubility in water means it can effectively neutralise high concentrations of acidity discharging from the swamp, this also means that it is possible to overdose discharge water, resulting in a saturation pH of 14 which may cause ecological risks downstream of Big Swamp. Thus the system would require safety measures to ensure overdosing did not occur. Conversely, caustic magnesia reaches saturation at lower concentrations than sodium hydroxide with a saturation pH of 9.5-10.8 (Taylor et al., 2005) and thus, presents a lower ecological risk downstream of Big Swamp.

The above discussed factors have been summarised in Table 7-2 below.

Table 7-2 Overview of upstream and downstream treatment technologies

Consideration	Downstream NaOH dosing	Upstream MgO leaching
Daily treatment rates (pH range 5-6)	0-700 L/day	0-140 kg/day
Annual volume/mass estimate (pH range 5-6)	28,000-67,000 L/year	6,000-14,000 Kg/year
Effectiveness of alkalinity reaching acidity	Effective	Uncertain – would require trials
Effectiveness in dissolving required alkalinity	Effective	Some uncertainty – would require trials
Sludge management	8-24 m^3/year to be managed downstream of Big Swamp	Sludge would discharge via Barwon River offshore with some sludge formation in swamp
Environmental risks (overdosing)	Higher (max pH = 14)	Lower (max pH = 9.5-10.8)

7.4 Summary

A summary of the potential upstream treatment option using magnesium oxide is below:

- To achieve a pH of 6, mass ranges between less 16 kg/day under summer low flow and initial flushing conditions, to 40 kg/day during winter-spring high flows conditions and 80 kg/day during ongoing flushing conditions.

- To achieve a pH of 6, the mass ranges from 13 kg in March to as much as 2,700 kg in July. The total annual mass required to achieve a pH of 6 is approximately 14,000 kg, with the majority (9,500 kg) required between the months of May and September.

- The upstream treatment option provides benefits by way of reduced sludge management and environmental risks associated with overdosing, however dissolution rates, alkalinity loads and the ability for alkalinity to reach areas of acidic discharge need to be proofed with field trials.

8. Summary and conclusions

The objective of this study is to combine monitoring data with the current understanding of hydrogeochemical processes occurring in the swamp and the results of the groundwater surface water modelling to undertake hydrogeochemical modelling to estimate the changes in water quality in Boundary Creek in response to remediation.

A summary of the key findings is provided in the following sections.

8.1 Surface water quality

To help inform the hydrogeochemical conceptual site model, surface water sampling was undertaken to assess changes in water chemistry along surface water flow paths through Big Swamp and the key outcomes were:

- Two flow paths were observed during the event including the northern “primary” channel and a southern flow path which diverts water through the interior of the swamp. This suggests that the northern flow path not the primary flow path, which was a key assumption in the groundwater surface model by GHD.

- The greatest increase in surface water acidity occurred in the eastern portion of the swamp, suggesting that increased groundwater discharge in the eastern end of the swamp was the primary pathway for acidity mobilisation into surface water during the sampling event.

- Surface water pH declines as water moves through the swamp and continues to decline in Reach 3 of Boundary Creek as the groundwater discharge from the swamp is oxidised.

8.2 Conceptual site model

Key outcomes from the conceptual site model:

- The greatest store of acidity in Big Swamp appears to be soil acidity in the upper soil profile, which has been estimated to contain 810 tonnes of $CaCO_3$ equivalent. However, the timing of acidic discharge with respect to periods of high and low runoff suggest this is not the primary mechanism by which acidity is discharged to Boundary Creek.

- Groundwater acidity stored in the shallow alluvial aquifer represents the second largest store of acidity in Big Swamp (126 tonnes of acidity as $CaCO_3$ equivalent) and modelling suggests that this is the primary mechanism by which acidity is discharged into Boundary Creek and would be sustained by the infiltration of acidity from the upper soils.

- Pore water acidity in the unsaturated zone represents a minor store of acidity in Big Swamp (estimated to represent 11 tonnes of $CaCO_3$ equivalent) and leaching of soil moisture from the unsaturated zone appears to be a negligible process for further consideration as part of hydrogeochemical modelling.

- The groundwater model combined with monitoring groundwater acidity can be used to characterise discharge of acidity from Big Swamp into Boundary Creek under current conditions and assess how this may change in response to barrier installation.

8.3 Potential impacts on the Barwon River from Boundary Creek

The key outcomes from a review of the potential impacts to fish in the Barwon River are:

- pH, iron and aluminium pose the greatest ecological risk to the Barwon River, including the greatest risk of fish kills related to acute toxicity associated with respiratory failure due to low pH conditions and high aluminium concentrations.

- Simulations via the modelling package PHREEQC and comparison of flows in Boundary Creek and Barwon River suggest ecological risks to the Barwon River are highest during May and June, when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase. Higher flow periods (July-August) tend to represent lower risks to the Barwon River due to lower concentrations of parameters of concern due to the effects of dilution. Lower flow periods (December-March) also tend to represent lower risks to the Barwon River due to the reduced flow contribution from Boundary Creek. This is consistent with sampling undertaken to date by Austral (2020).

- The only recorded fish kill event in the Barwon River occurred in June 2016 when flows from Boundary Creek represented ≥40% of those in the Barwon River. This period represents a flow event following flow cessation in Boundary Creek (known as a first flush). While other first flush events have yielded a similar contribution of flows to the Barwon River, these were preceded by 4 months or less of flow cessation in Boundary Creek, whereas the June 2016 event was preceded by more than 8 months of flow cessation in Boundary Creek. This suggests that the Barwon River is at the greatest risk of a fish kill event following an extended period of flow cessation in Boundary Creek (>4 months) when flows from Boundary Creek represent ≥40% of those in the Barwon River.

8.4 Predicted dosing requirements for the downstream contingency measure

A summary of the dosing requirements for the downstream contingency measure using sodium hydroxide is below:

- To achieve a pH of 6, dosing rates range between less 80 L/day under summer low flow and initial flushing conditions, to 200 L/day during winter-spring high flows conditions and 700 L/day during ongoing flushing conditions.

- To achieve a pH of 6, dosing rates range from as little as 64 L in March to as much as 12,800 L in July. The total annual volume required to achieve a pH of 6 is approximately 68,000 L, with the majority (47,000 L) required between the months of May and September.
- The annual build-up of aluminium and iron hydroxide sludge in response to sodium hydroxide dosing is estimated to be 24 m^3 assuming treatment to pH of 6.

8.5 Predicted water quality outcomes of inundation

The calibrated hydrogeochemical model was used in conjunction with the CSM presented in Section 3 and the groundwater surface water model (GHD,2020) to predict the water quality changes following the installation of hydraulic barriers. The key outcomes from this modelling are:

- Approximately 56 tonnes per year of acidity $CaCO_3$ equivalent is added to the groundwater system via rainfall recharge, compared to 80 tonnes per year of acidity $CaCO_3$ equivalent being discharged. This suggests that the Swamp may have established a dynamic equilibrium over the last 30 years since acidification processes began.

- Modelling indicates that concentrations of acidity discharging from Big Swamp are likely to increase following remediation in response to enhanced groundwater discharge from the western portion of the swamp, where concentrations of groundwater acidity are higher than those in the east. The annual mass of acidity discharging from Big Swamp following remediation is estimated to be approximately 160 tonnes of acidity as $CaCO_3$ and is approximately double that the absence of remediation.

- In the absence of remediation, the combined mass of existing acidity in groundwater and soils and potential acidity in soils would take approximately 100 years before they are removed from Big Swamp.

- With remediation, the time taken to remove the existing and potential acidity is reduced to 35 years. The reduction in time associated with remediation is related to a combination of:

- Reducing the mass of potential acidity available for oxidation via watertable rise and
- An increased rate of acidity discharge from the system associated with increased groundwater discharge following barrier installation and enhanced flow supplementation.

- These results suggest that either a downstream contingency measure or introduction of a treatment system upstream of Big Swamp may be required to mitigate potential risks to the Barwon River.

8.6 Predicted requirements for the upstream treatment option

The hydrogeochemical modelling undertaken to inform the potential outcomes of installation of hydraulic barriers as a remediation action for Big Swamp indicates the water quality benefits could take 35 years to be realised. This highlights a potential upstream treatment solution to advance remediation. The Independent Technical Review Panel (ITRP) recommended that an upstream treatment system using caustic magnesia (MgO) as a pH correction chemical be considered.

A summary of the requirements for the potential upstream treatment option using magnesium oxide is below:

- To achieve a pH of 6, mass ranges between less 16 kg/day under summer low flow and initial flushing conditions, to 40 kg/day during winter-spring high flows conditions and 80 kg/day during ongoing flushing conditions.
- To achieve a pH of 6, the mass ranges from 13 kg in March to as much as 2,700 kg in July. The total annual mass required to achieve a pH of 6 is approximately 14,000 kg, with the majority (9,500 kg) required between the months of May and September.
- The upstream treatment option provides benefits by way of reduced sludge management and environmental risks associated with overdosing, however dissolution rates, alkalinity loads and the ability for alkalinity to reach areas of acidic discharge need to be proofed with field trials.

9. Recommendations

This section provides a series of recommendations based on the above, which could be used to improve the hydrogeochemical understanding of Big Swamp and refine the remedial approaches considered. Recommendations have been made with respect to sampling, laboratory analysis, groundwater-surface water modelling and consideration of treatment options.

1. **Additional surface water sampling near BH02 or BH03 is recommended in preference to BH01 to target better mixed water along the primary flow path.**

The undertaking of surface water sampling through Big Swamp during April 2021 indicated an increase in acidity through the eastern portion of the swamp via groundwater discharge in this area. Modelling results suggest significant inputs of acidity in the western portion of the swamp. Additional sampling under different flow conditions is recommended to further confirm the location of acidity discharge to surface water in Big Swamp.

2. **A sampling run be undertaken using finer mesh filters for analysis of dissolved metals (0.2 µm or smaller)**

The hydrogeochemical modelling undertaken as part of this study underestimates the concentration of dissolved analytes (primarily aluminium) compared to dissolved concentrations in samples provided by laboratory analysis. This may be a result of fine-grained particulate matter in water samples and may result in overestimating the risk that such analytes pose to aquatic ecology downstream of Big Swamp. To resolve this, it is recommended that a sampling run be undertaken using finer mesh filters (0.2 µm or smaller) for analysis of dissolved metals.

3. **Collection of nutrients and chlorophyll analytical data in the Barwon River**

The assessment of broader ecological risks (such as eutrophication) in the Barwon River was impeded by the absence of nutrients and chlorophyll analytical data in the Barwon River. Collection of these data would enable this assessment if deemed warranted.

4. **Additional samples collected for chromium reducible sulfur suite of analysis**

The greatest source of uncertainty with respect to estimating the duration of remediation of Big Swamp are the spatial distribution of soil acidity in areas which have not been sampled and the density of the soils within the swamp. To resolve this, it is recommended that additional samples be collected for chromium reducible sulfur suite of analysis to the west of BH18 and in between (and to the north) of BH12 and BH10. In addition, the collection of undisturbed samples for soil density analysis is recommended. Sampling could target the upper 3 m of the soil profile to estimate the mass of acidity stored above the watertable.

5. **Undertake soil leach tests on soil samples**

Estimates regarding the mass of acidity entering the groundwater system via recharge have been made using shallow groundwater concentrations during recharge conditions. This approximation could be validated by undertaking soil leach tests on soil samples to understand whether the system is in dynamic equilibrium or if the input of acidity to the groundwater system may limit the rate of acidity discharging from the system.

6. **Consider revised flow paths through Big Swamp and LTA recovery in future iterations of the groundwater-surface water model**

The undertaking of surface water sampling through Big Swamp during April 2021 indicated that the northern channel does not appear to be the primary surface water flow path through Big Swamp. The representation of flows paths through the swamp should be re-considered during future iterations of groundwater-surface water modelling.

Additionally, it is recognised that if recovery if the LTA occurs in the western portion of the swamp and yields groundwater level increases in this area, it may have a similar effect to the installation of barriers. Future iterations of the groundwater-surface water model should consider these implications

7. **Assess ecological risks to the Barwon River following the installation of hydraulic barriers**

Section 4 provides an indication of potential risks to fish in the Barwon River. The subsequent modelling in Section 6 suggests that following the installation of barriers and enhanced flow supplementation, the concentrations of acidity and other analytes of concern may increase in Boundary Creek due to increased groundwater discharge from the western part of the swamp where concentrations of groundwater acidity are higher. Assessment of such risks following barrier installation may be warranted depending on the timing and effectiveness of contingency measure implementation.

8. **Field trials to confirm the feasibility of the upstream treatment option**

The results presented in Section 6 indicate that the installation of barriers is likely to enhance the discharge of acidity from groundwater in the western end of the swamp and that remediation may take decades to yield improved water quality outcomes in Boundary Creek, even in the presence of hydraulic barriers. As such, the addition of alkalinity upstream of the swamp to treat this additional acidity input and enhance the rate of remediation carries merit. However, given the limited literature available regarding such a system, there remains uncertainty in the feasibility to generate the necessary concentrations and loads of alkalinity, as well as its effectiveness in delivering alkalinity throughout the swamp where acidity inputs occur. As such, if this option is pursued, a field trial is recommended that is capable of assessing these uncertainties.

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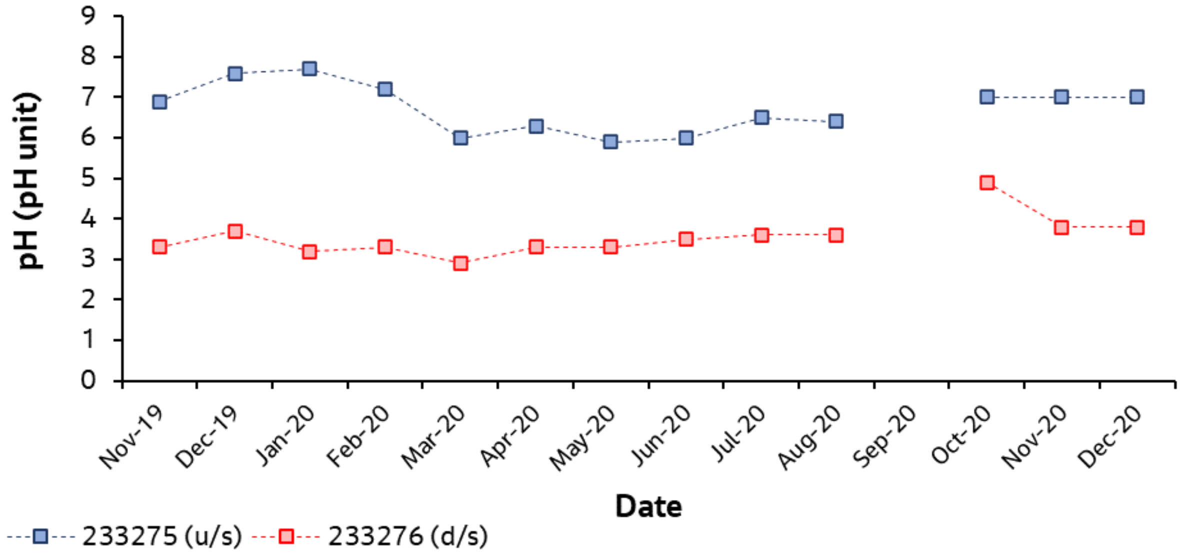
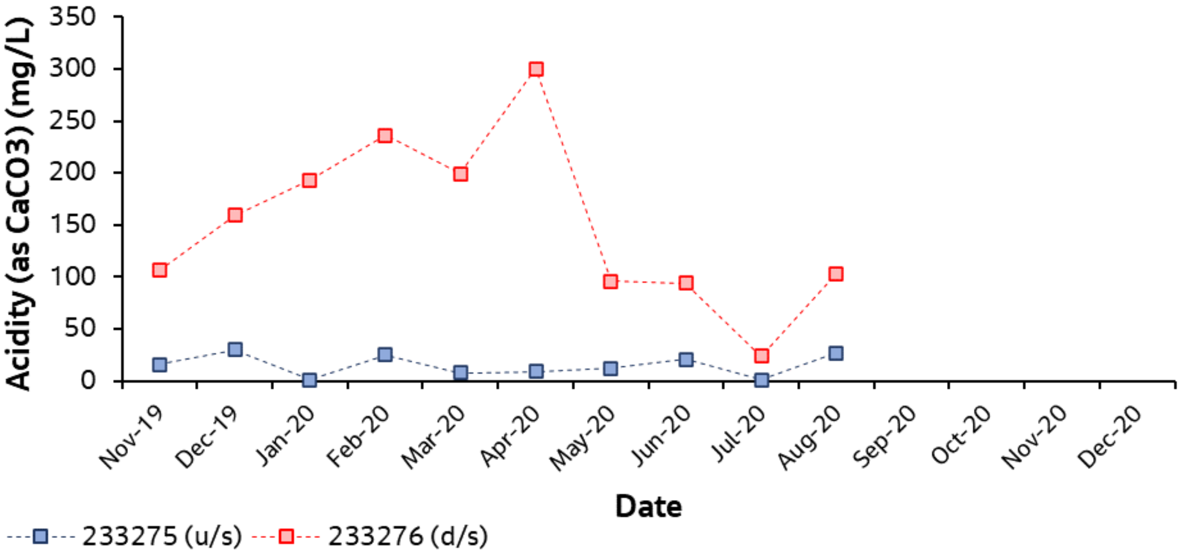
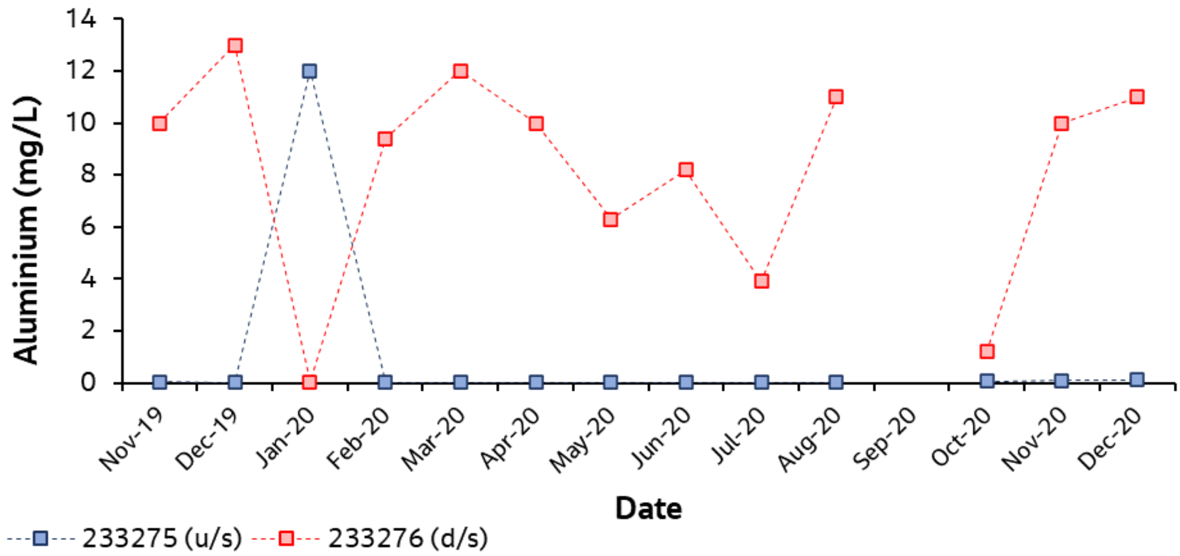
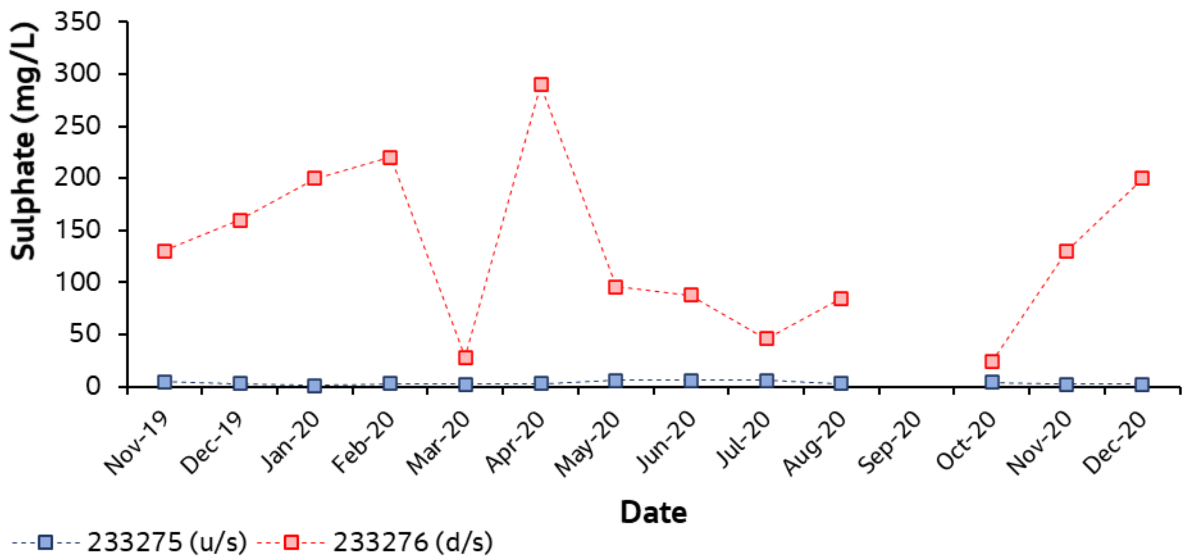
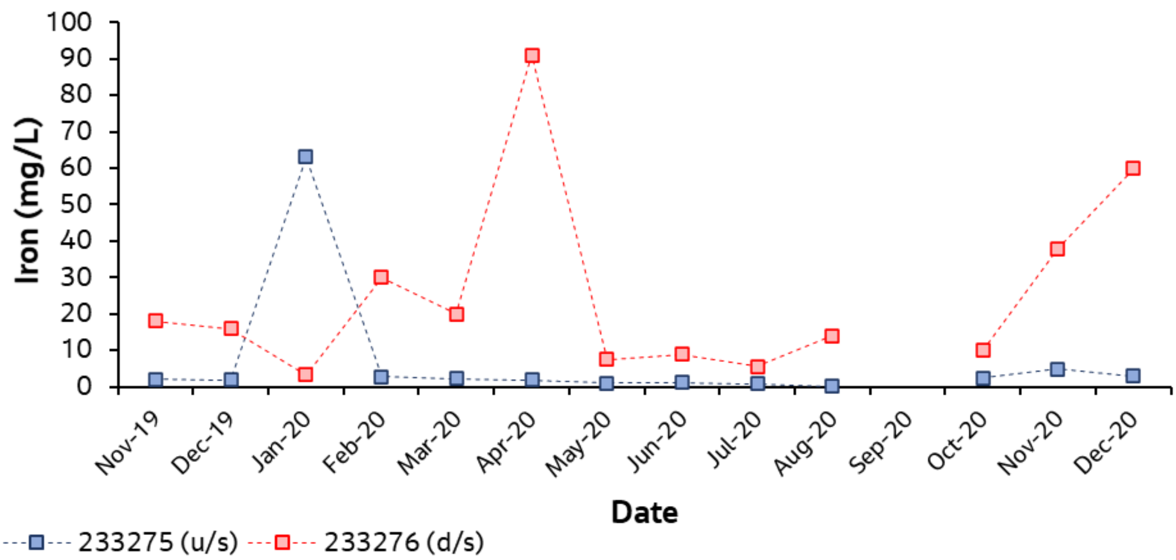
Appendix A. Surface water monitoring

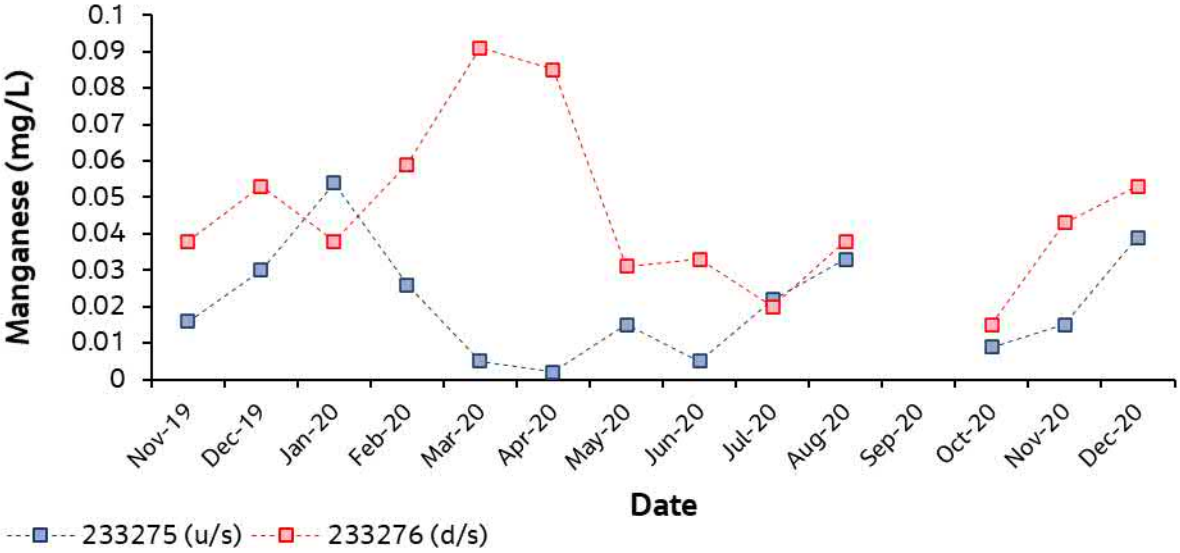


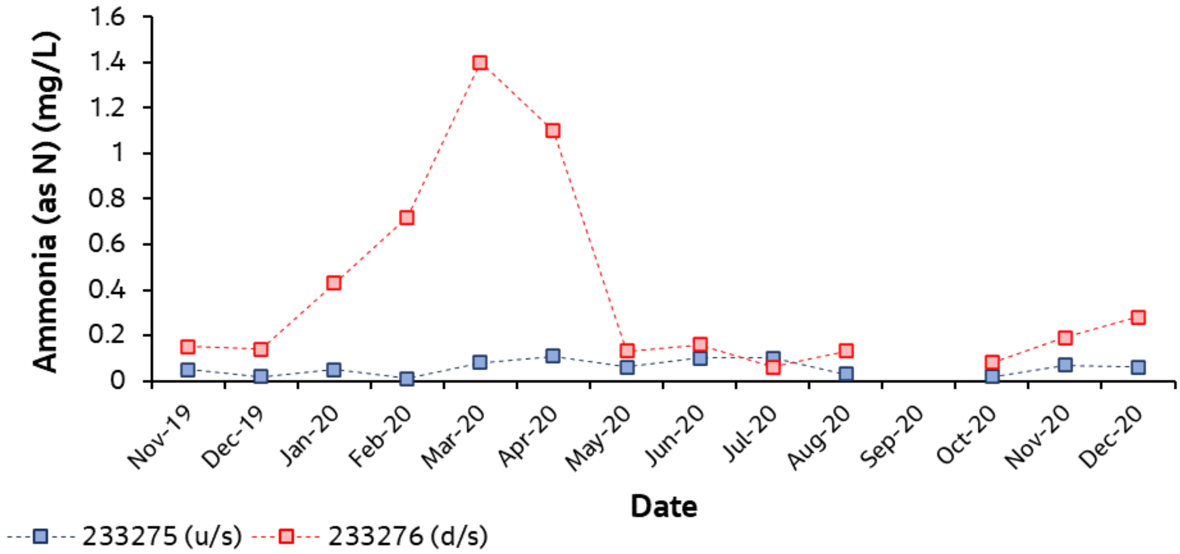


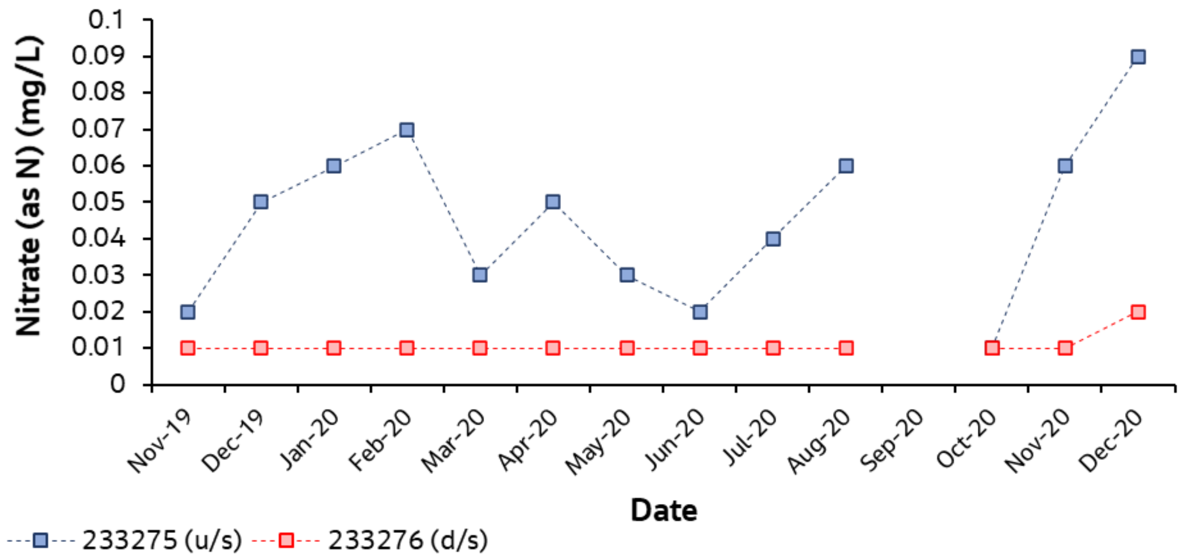

Aluminium (mg/L)
0
2
4
6
8
10
12
14
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

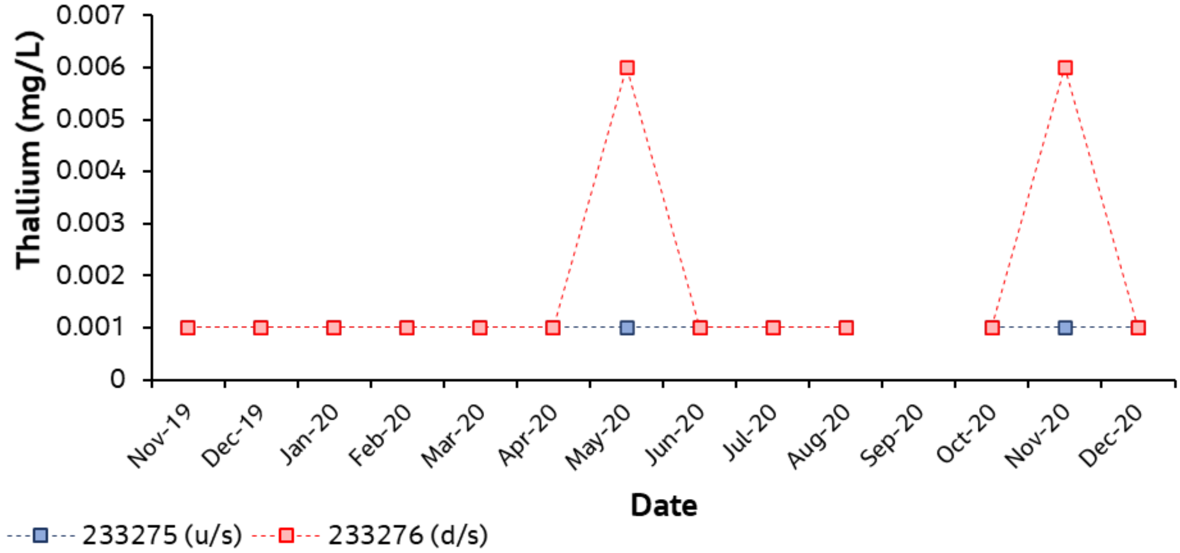

Sulphate (mg/L)
0
50
100
150
200
250
300
350
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

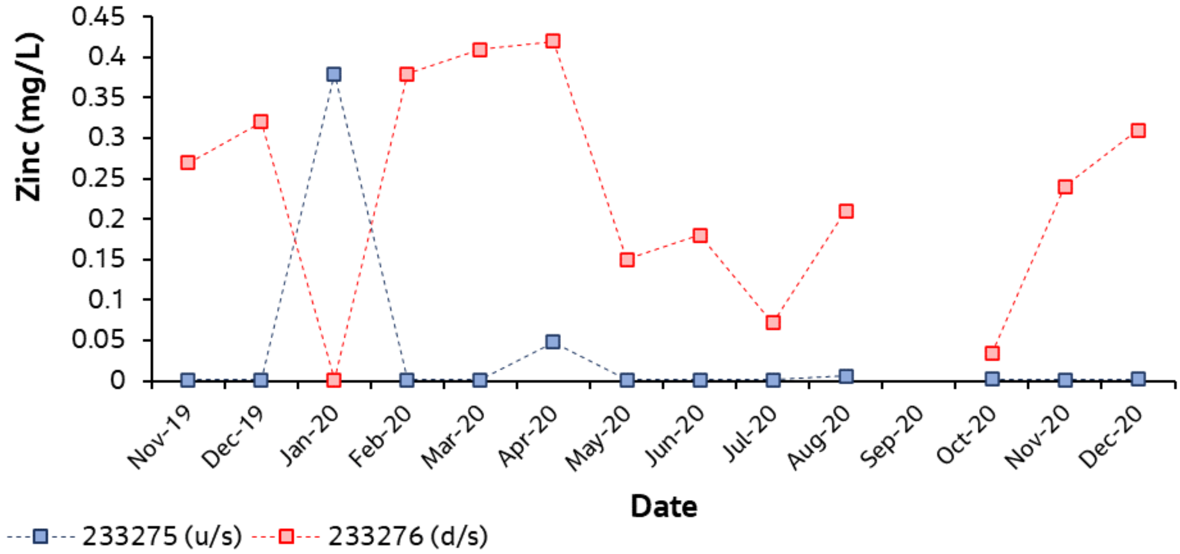

Iron (mg/L)
0
10
20
30
40
50
60
70
80
90
100
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)


Manganese (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

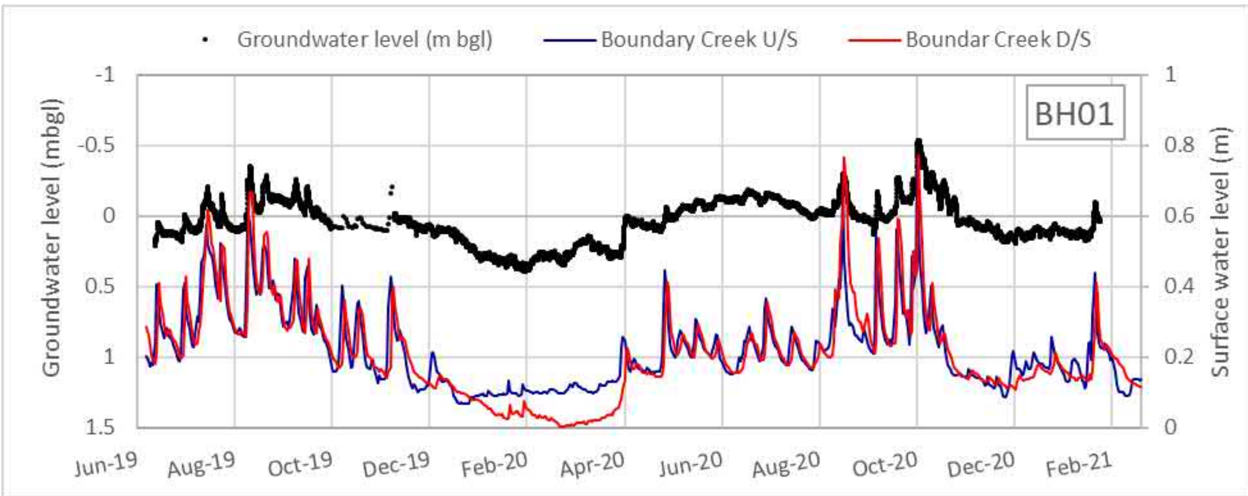

Ammonia (as N) (mg/L)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

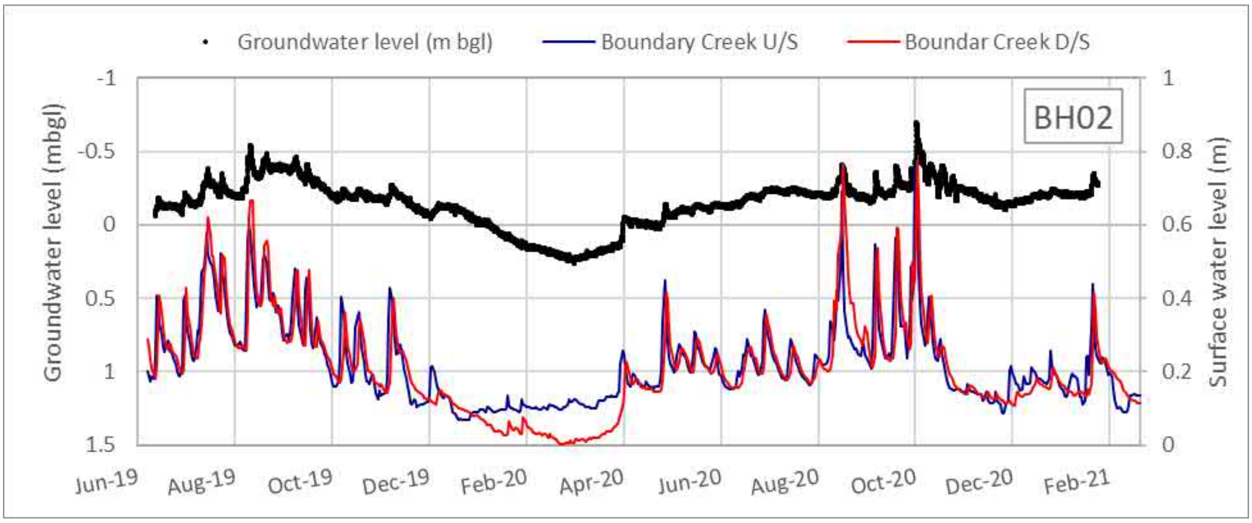

Nitrate (as N) (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

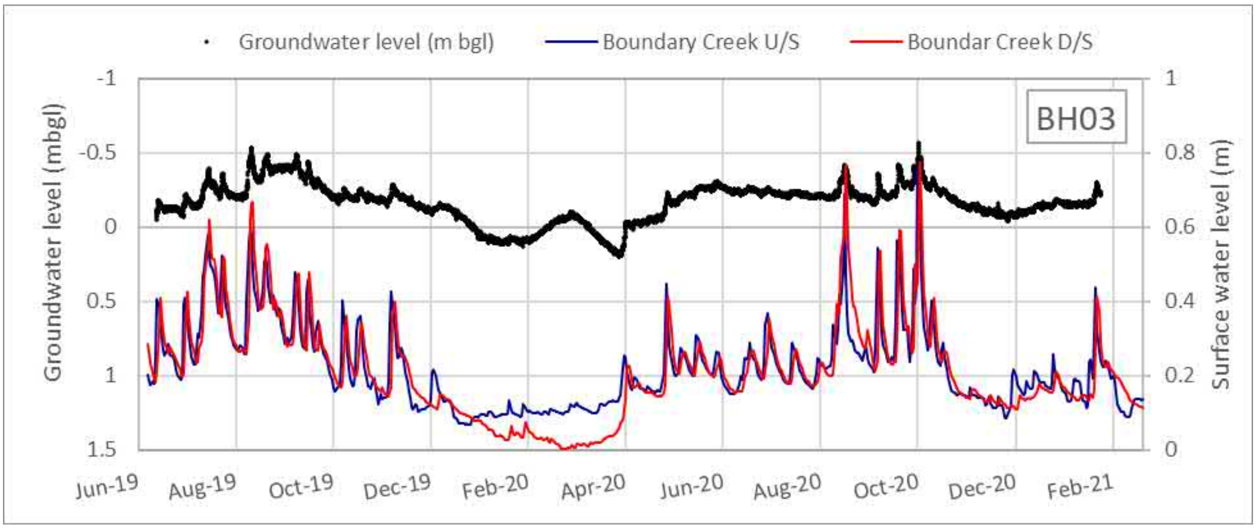

Thallium (mg/L)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

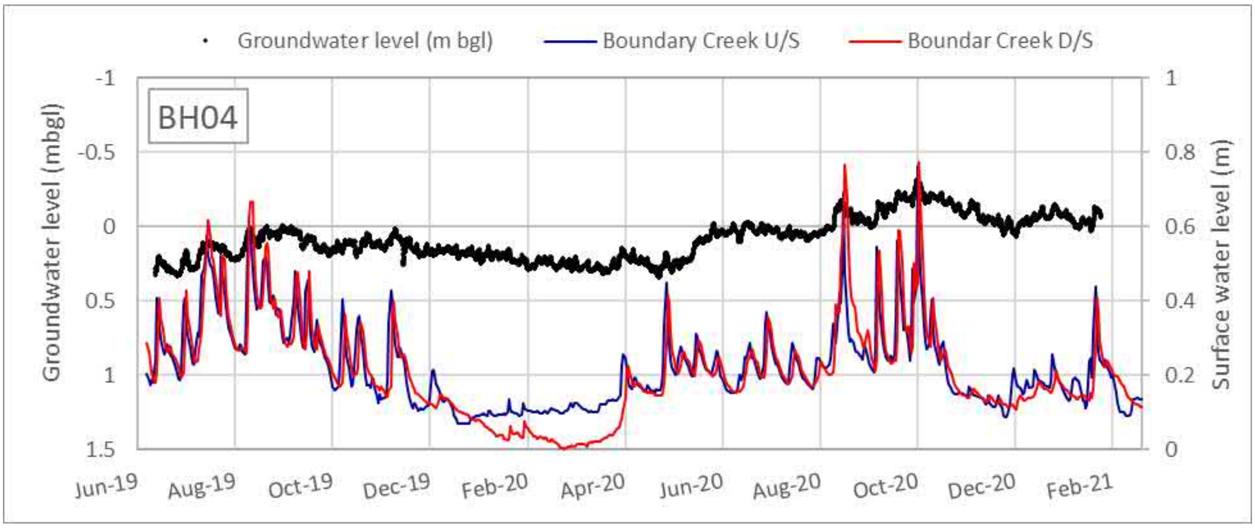

Zinc (mg/L)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Date
233275 (u/s)
233276 (d/s)

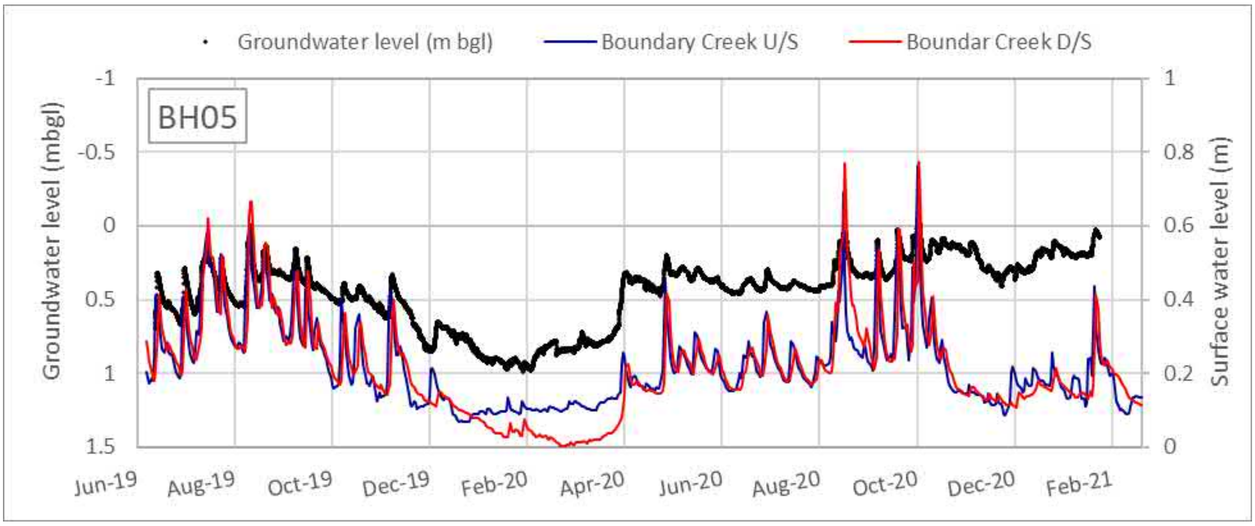
Appendix B. Groundwater-surface water hydrographs

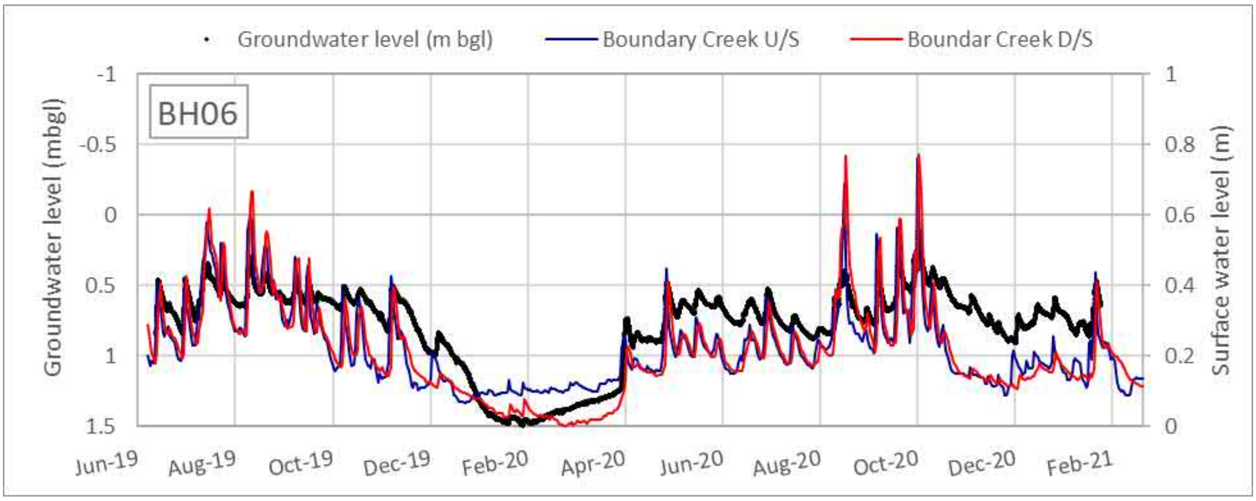


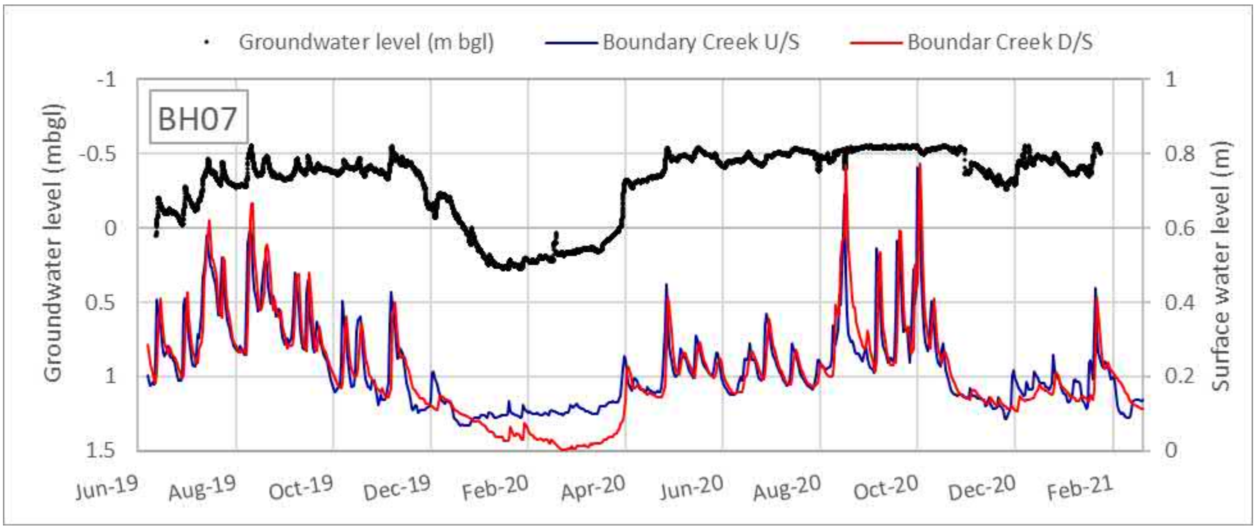


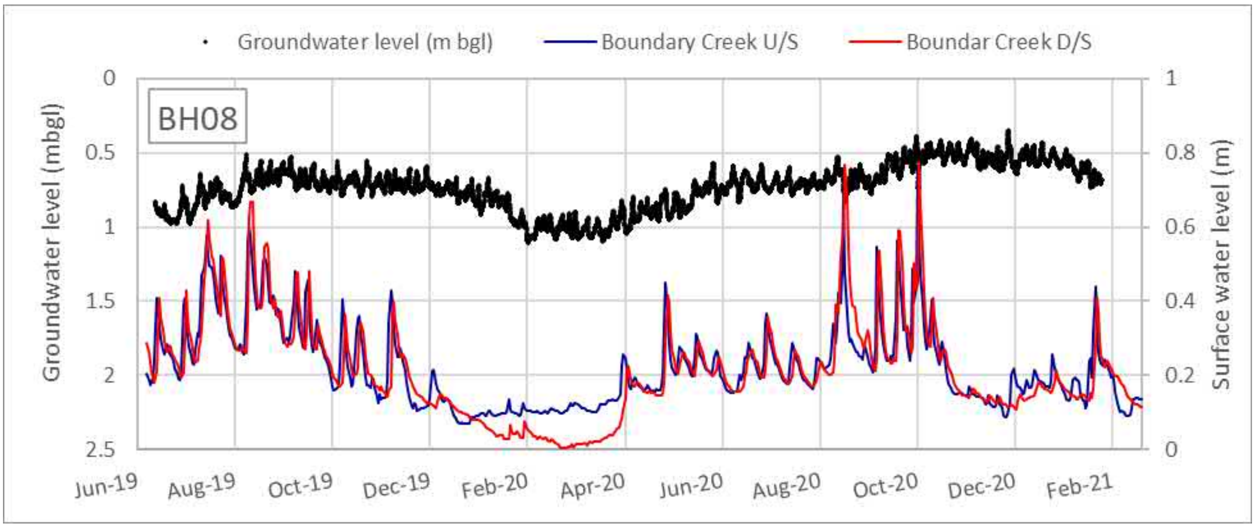


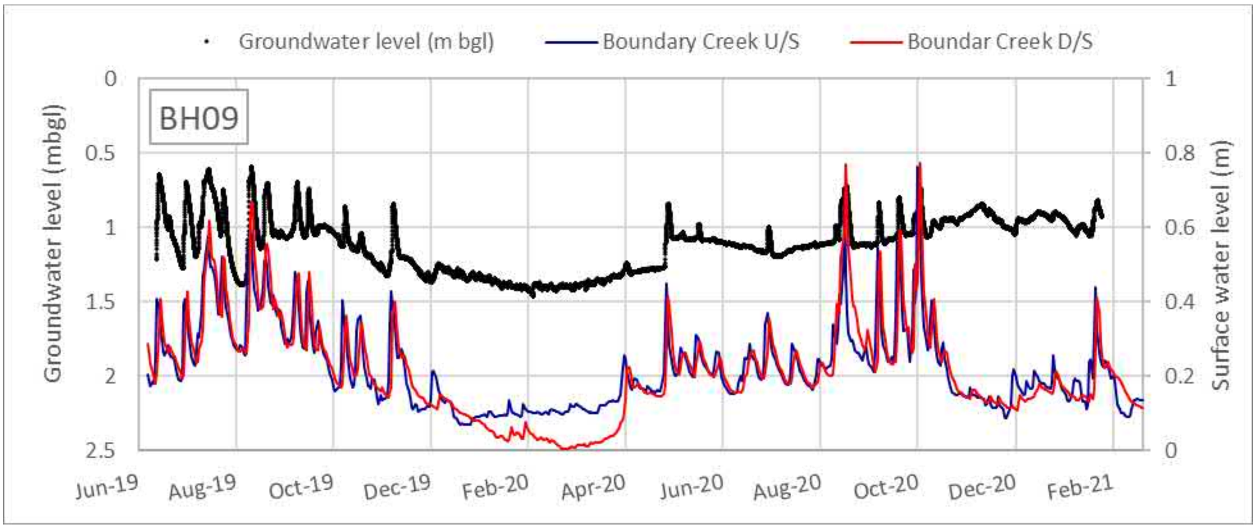

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH04
Groundwater level (mbgl)
Surface water level (m)
-1
-0.5
0
0.5
1
1.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

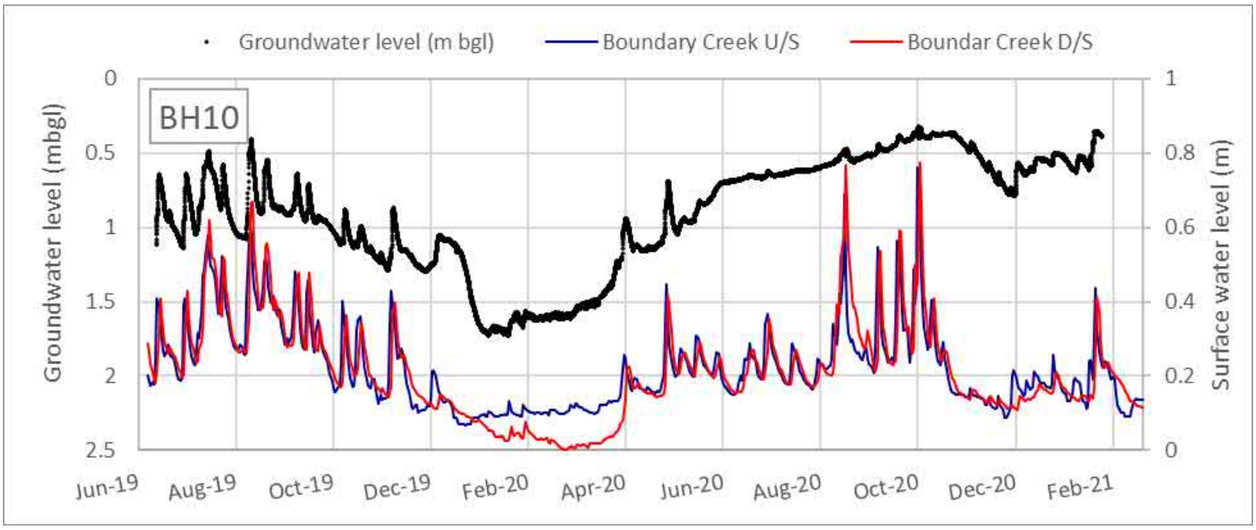

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH05
Groundwater level (mbgl)
Surface water level (m)
-1
-0.5
0
0.5
1
1.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

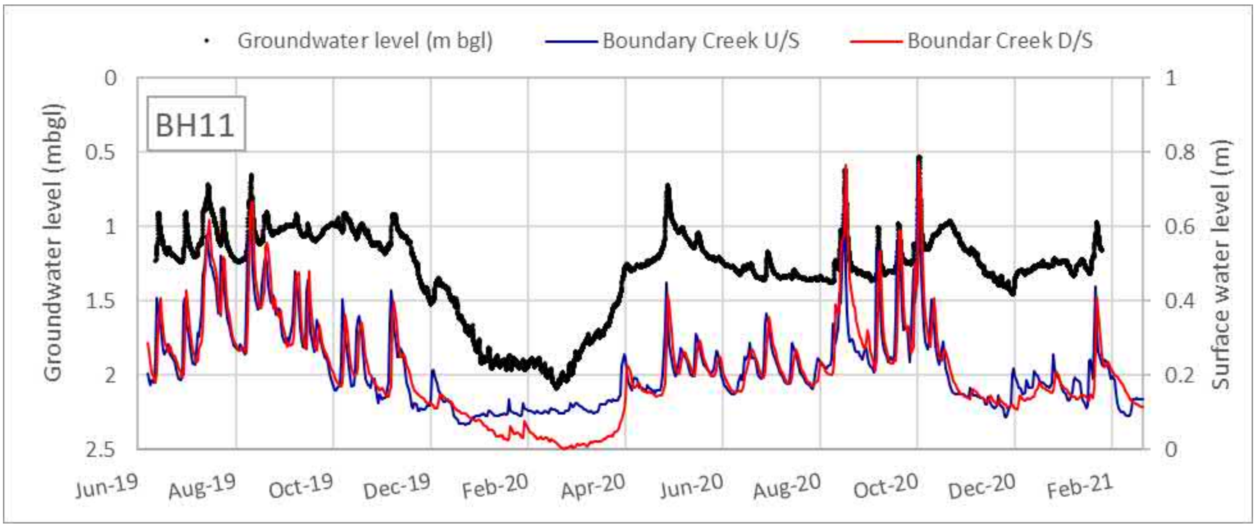

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH06
Groundwater level (mbgl)
Surface water level (m)
-1
-0.5
0
0.5
1
1.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

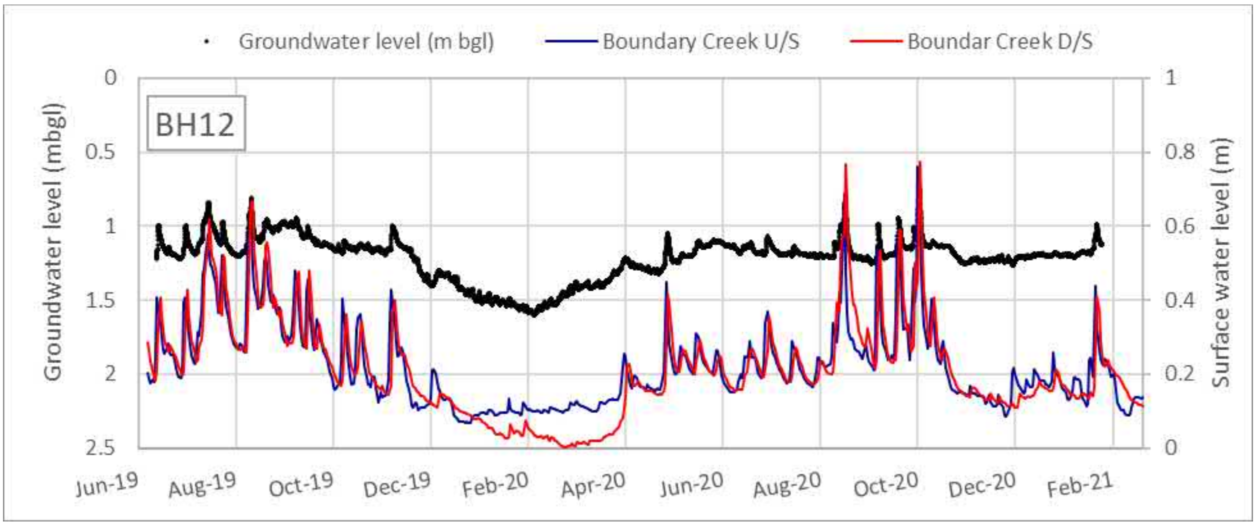

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH07
Groundwater level (mbgl)
Surface water level (m)
-1
-0.5
0
0.5
1
1.5
0.8
0.6
0.4
0.2
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

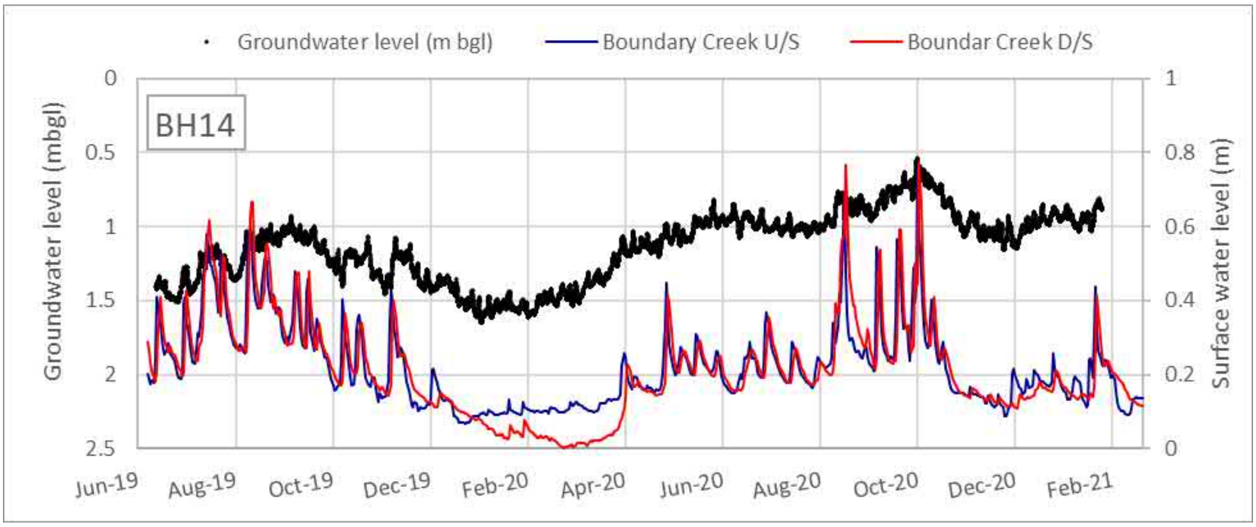

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH08
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
0.8
0.6
0.4
0.2
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21


Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH09
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
0.8
0.6
0.4
0.2
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

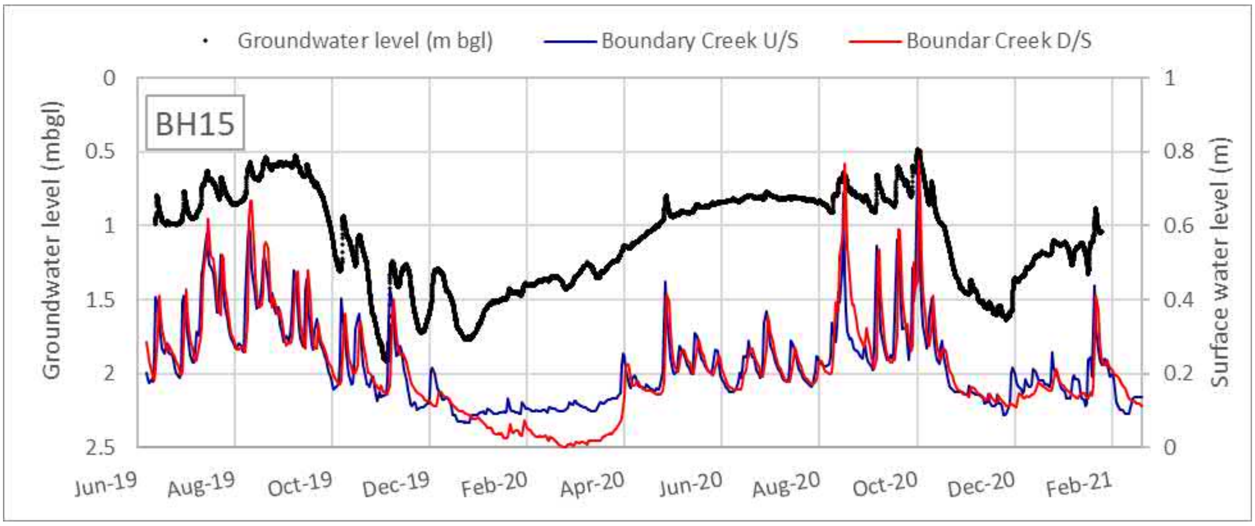

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH10
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21


Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH11
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

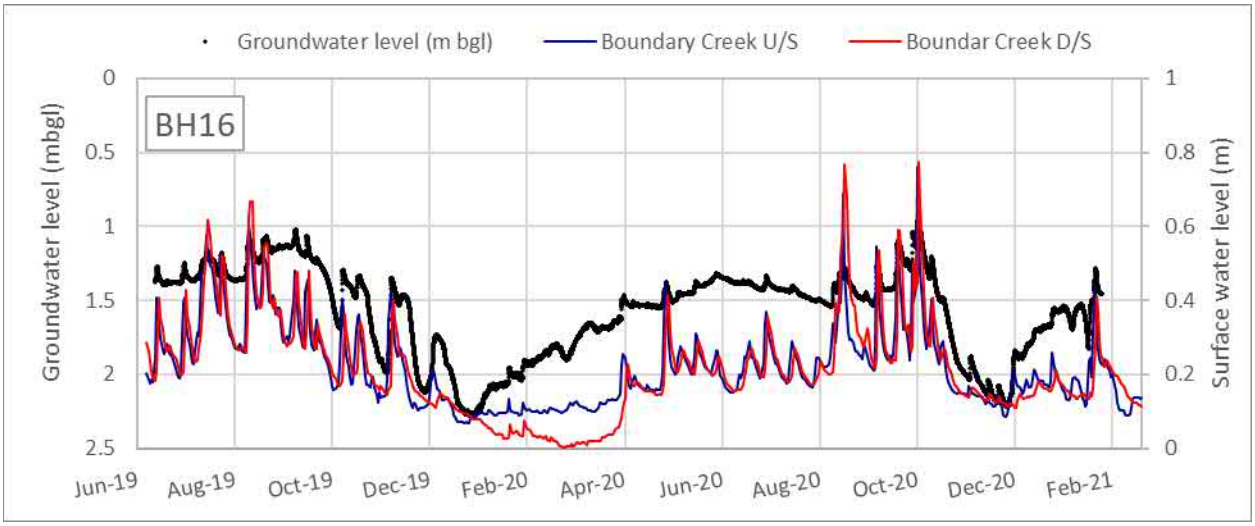

Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH12
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21



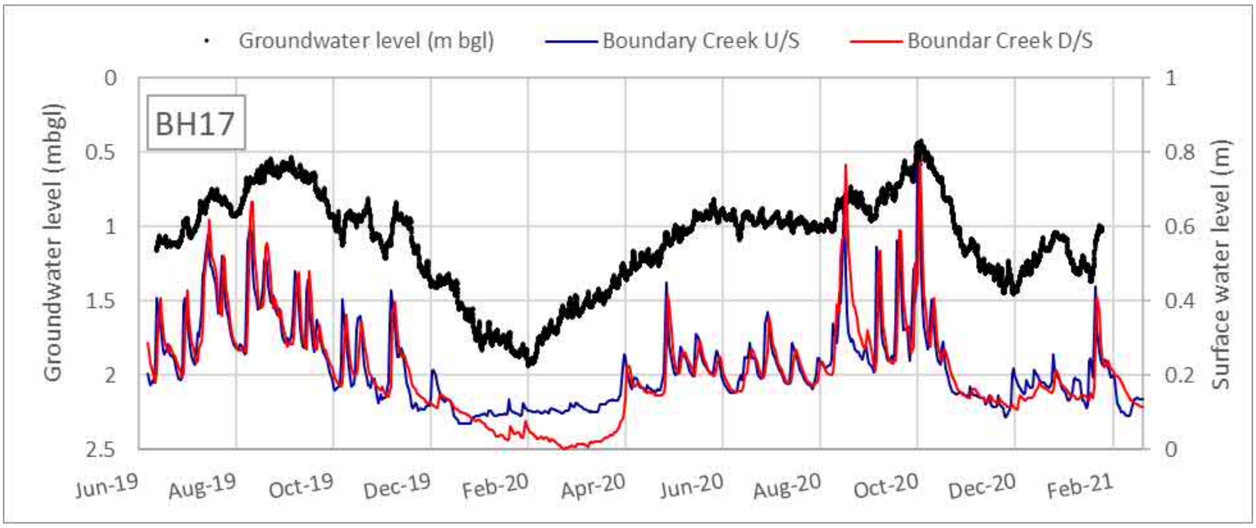
Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH14
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

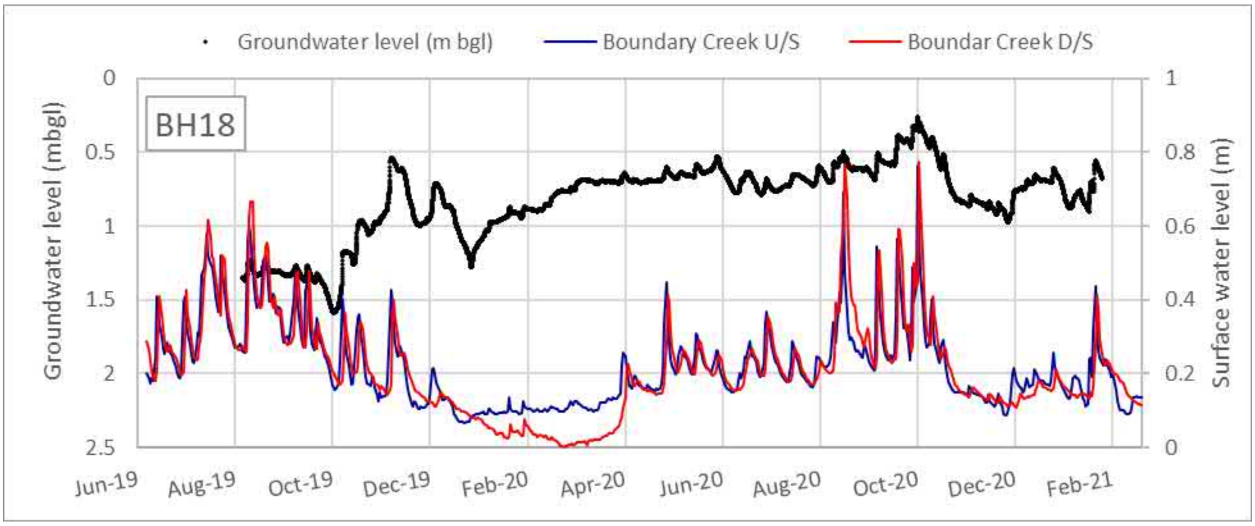


Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH15
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21



Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH16
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21


Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH17
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21


Groundwater level (m bgl)
Boundary Creek U/S
Boundar Creek D/S
BH18
Groundwater level (mbgl)
Surface water level (m)
0
0.5
1
1.5
2
2.5
1
0.8
0.6
0.4
0.2
0
Jun-19
Aug-19
Oct-19
Dec-19
Feb-20
Apr-20
Jun-20
Aug-20
Oct-20
Dec-20
Feb-21

Appendix C. Additional groundwater chemistry time series

C.1 Time series plots by transect

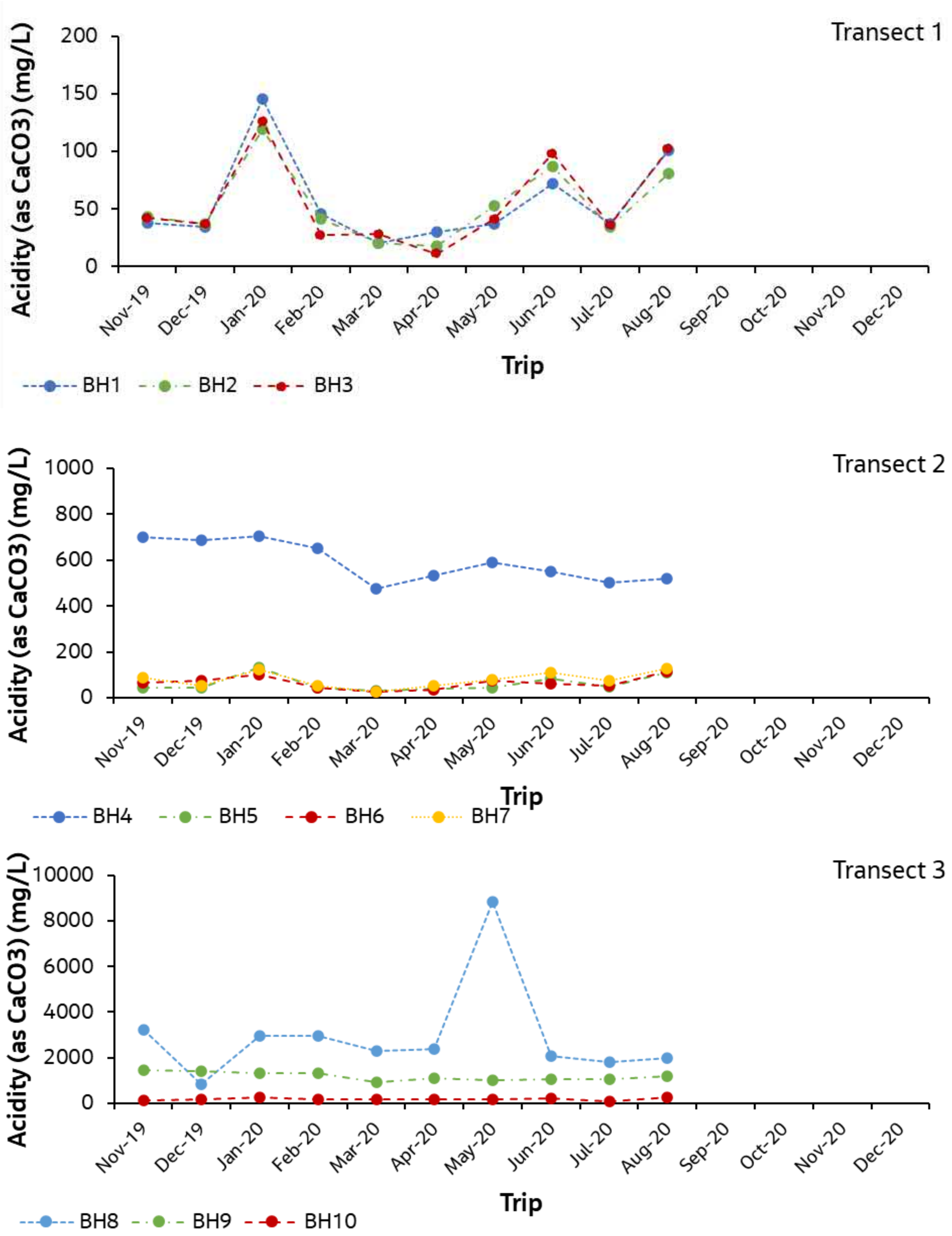
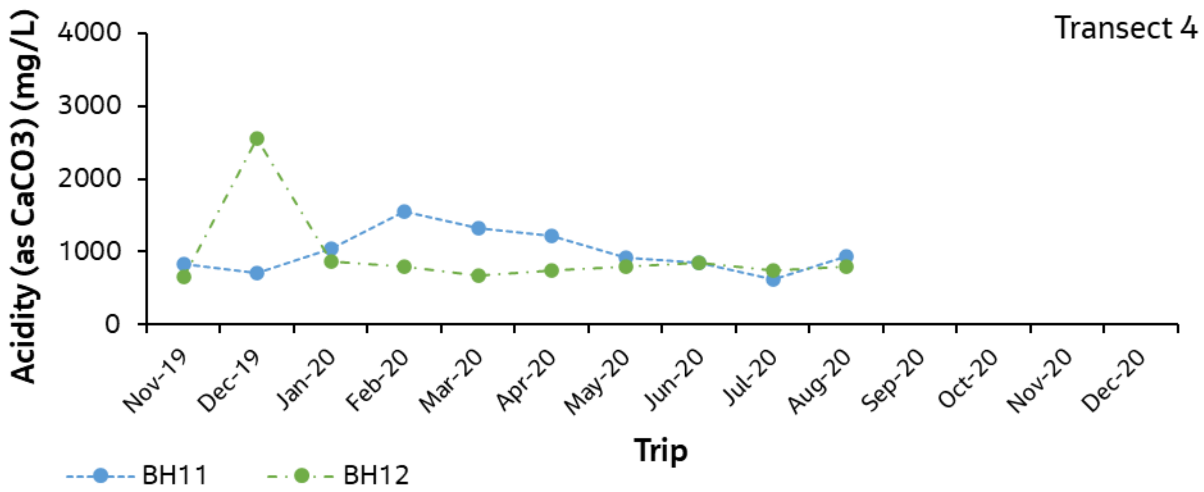


Figure 10-1: Time series of groundwater acidity plotted by transect. The scale of the y-axis varies by transect.



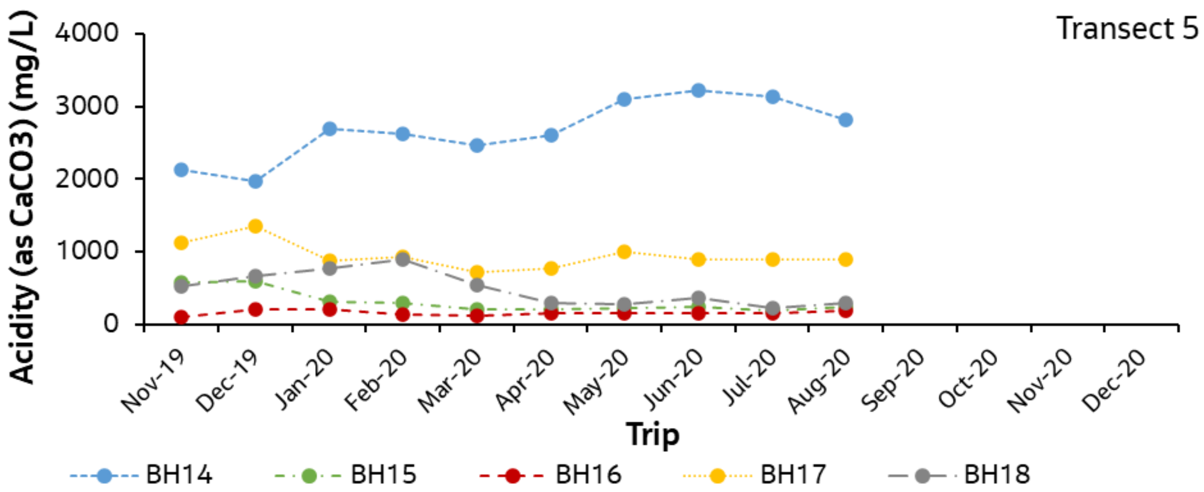


Figure 10-1 (continued): Time series of groundwater acidity plotted by transect. The scale of the y-axis varies by transect.

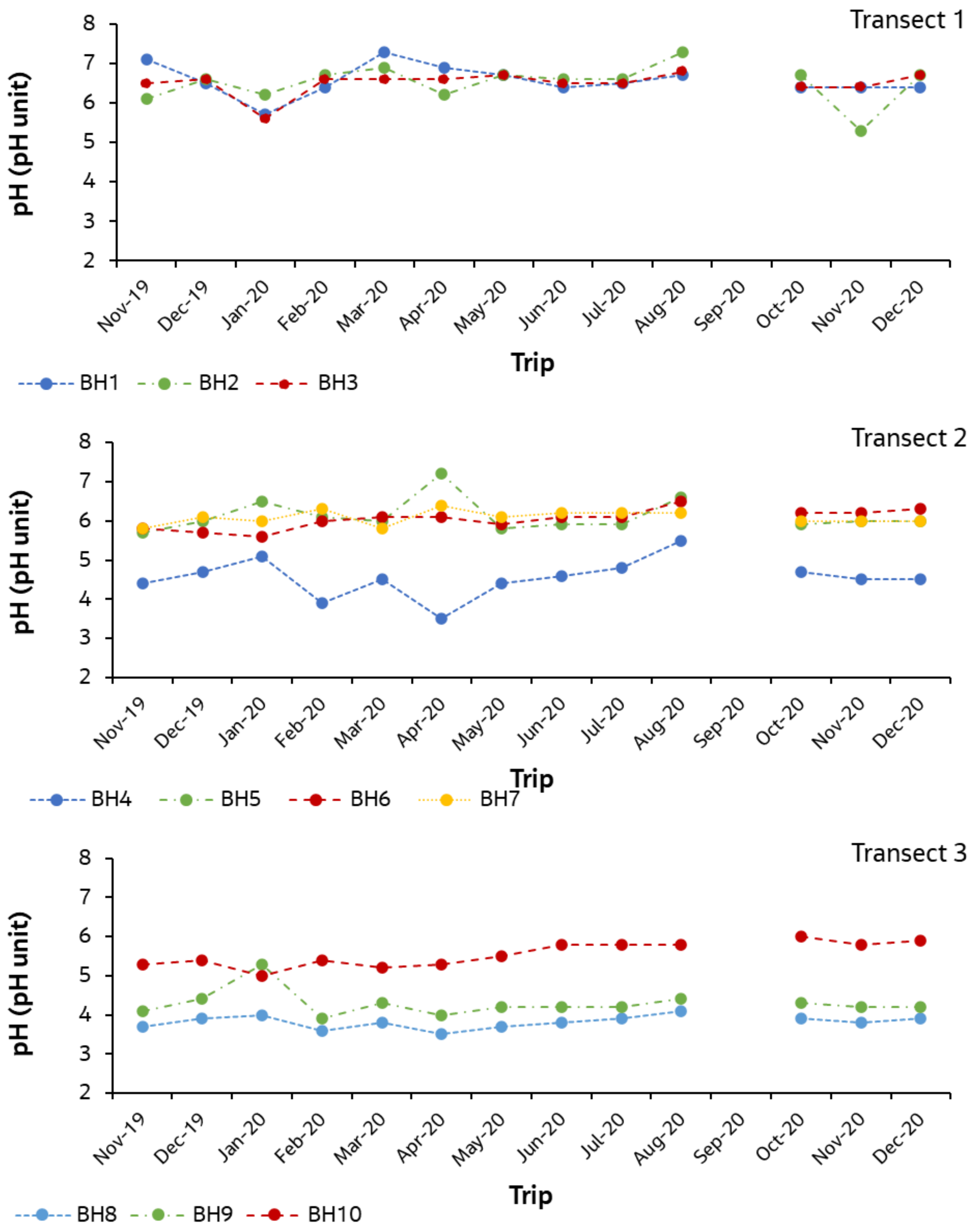
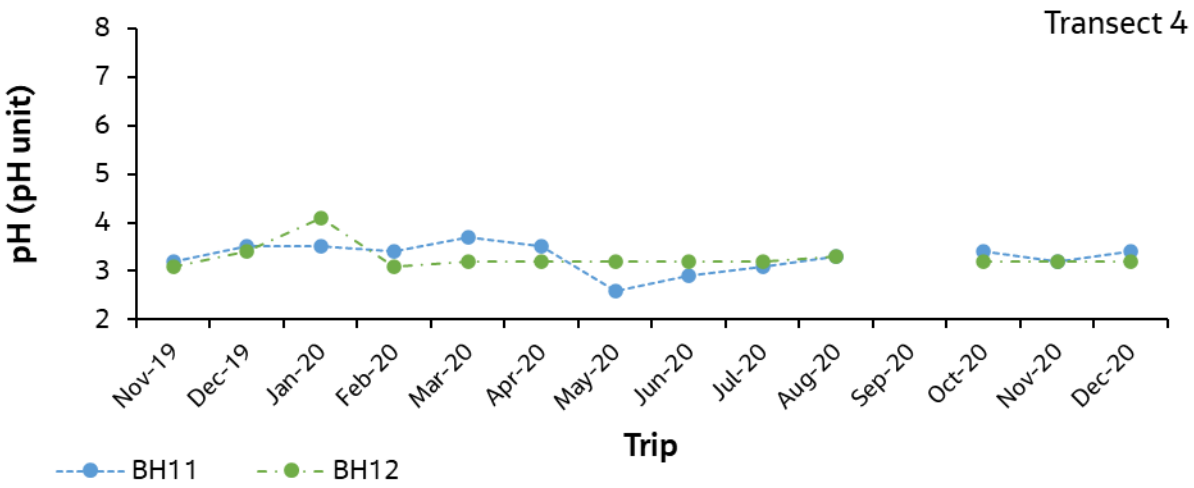


Figure 10-2: Time series of groundwater pH plotted by transect.



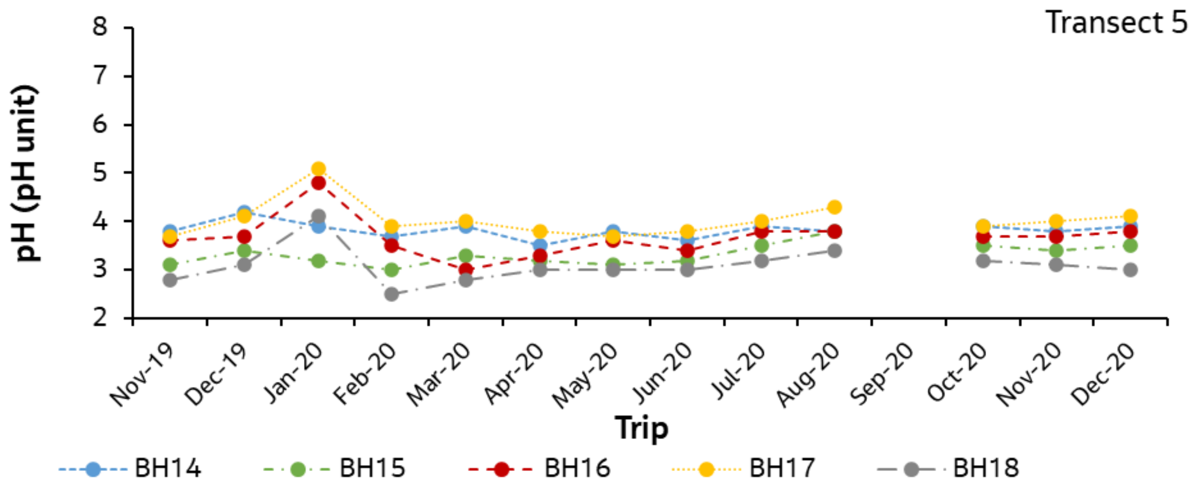


Figure 10-2 (continued): Time series of groundwater pH plotted by transect.

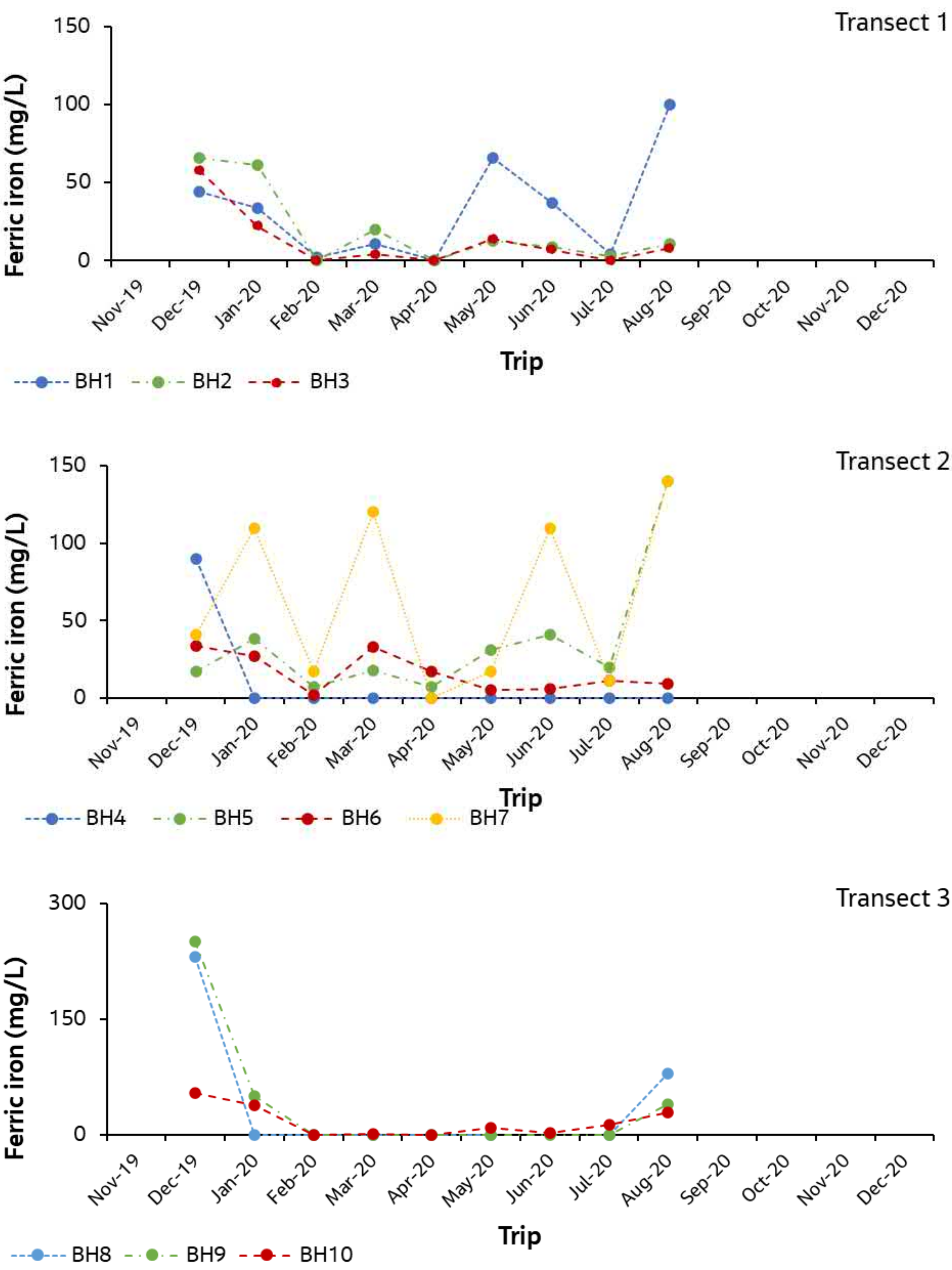
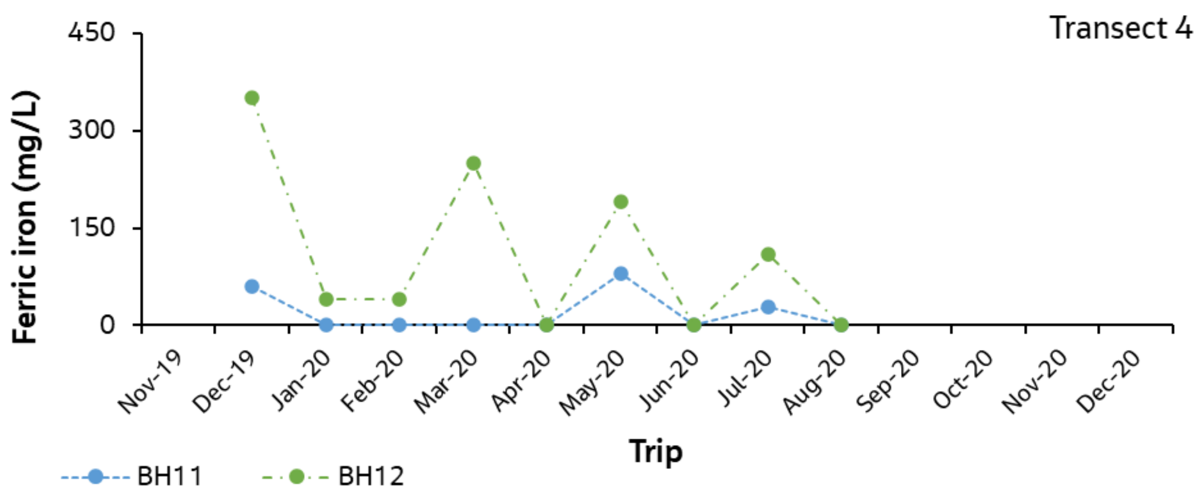


Figure 10-3: Time series of groundwater ferric iron (Fe^{3+}) concentrations plotted by transect. The scale of the y-axis varies by transect.



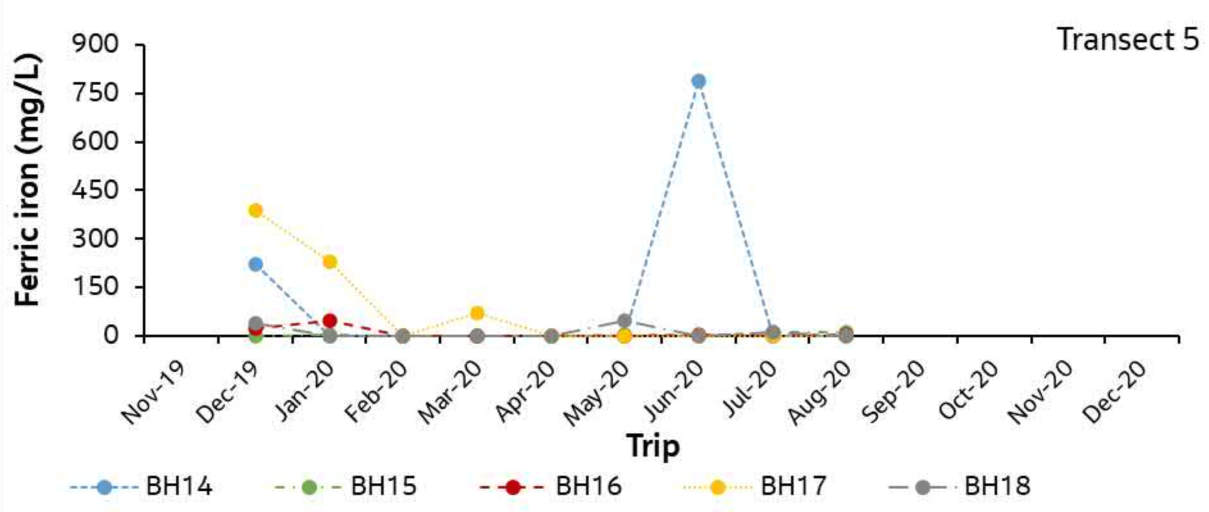


Figure 10-3 (continued): Time series of groundwater ferric iron (Fe^{3+}) concentrations plotted by transect. The scale of the y-axis varies by transect.

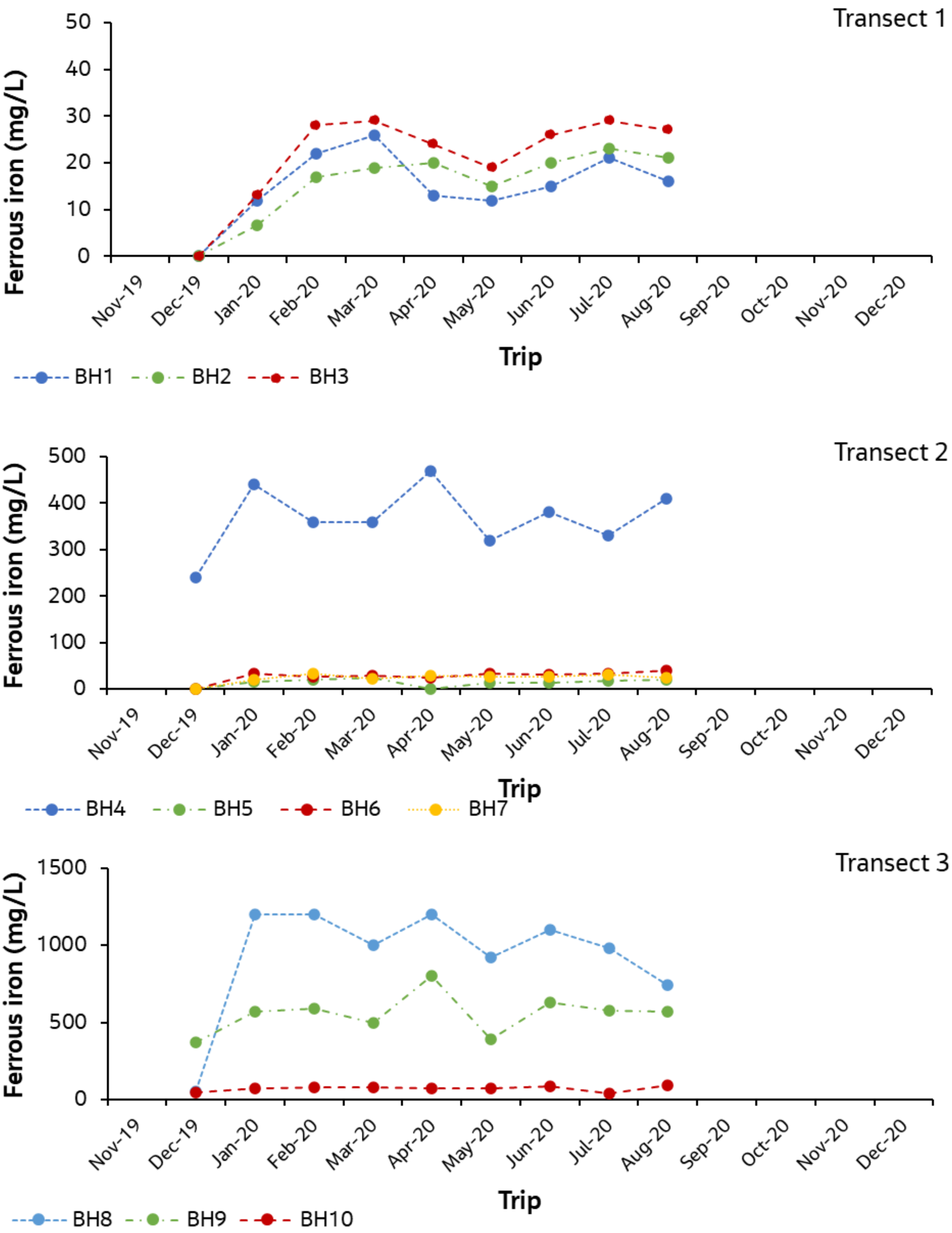
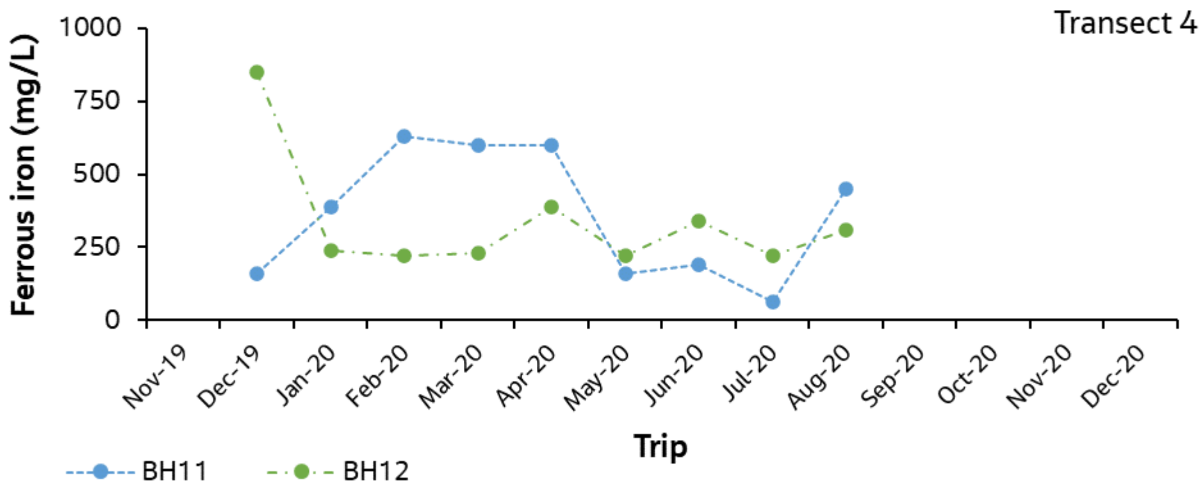


Figure 10-4: Time series of groundwater ferrous iron (Fe2+) concentrations plotted by transect. The scale of the y-axis varies by transect.



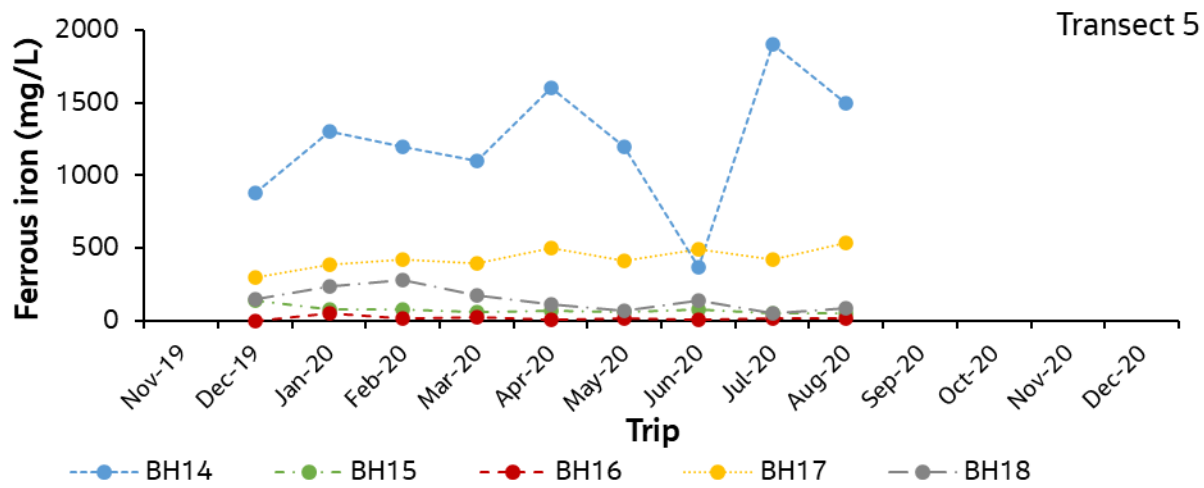


Figure 10-4 (continued): Time series of groundwater ferrous iron (Fe2+) concentrations plotted by transect. The scale of the y-axis varies by transect.

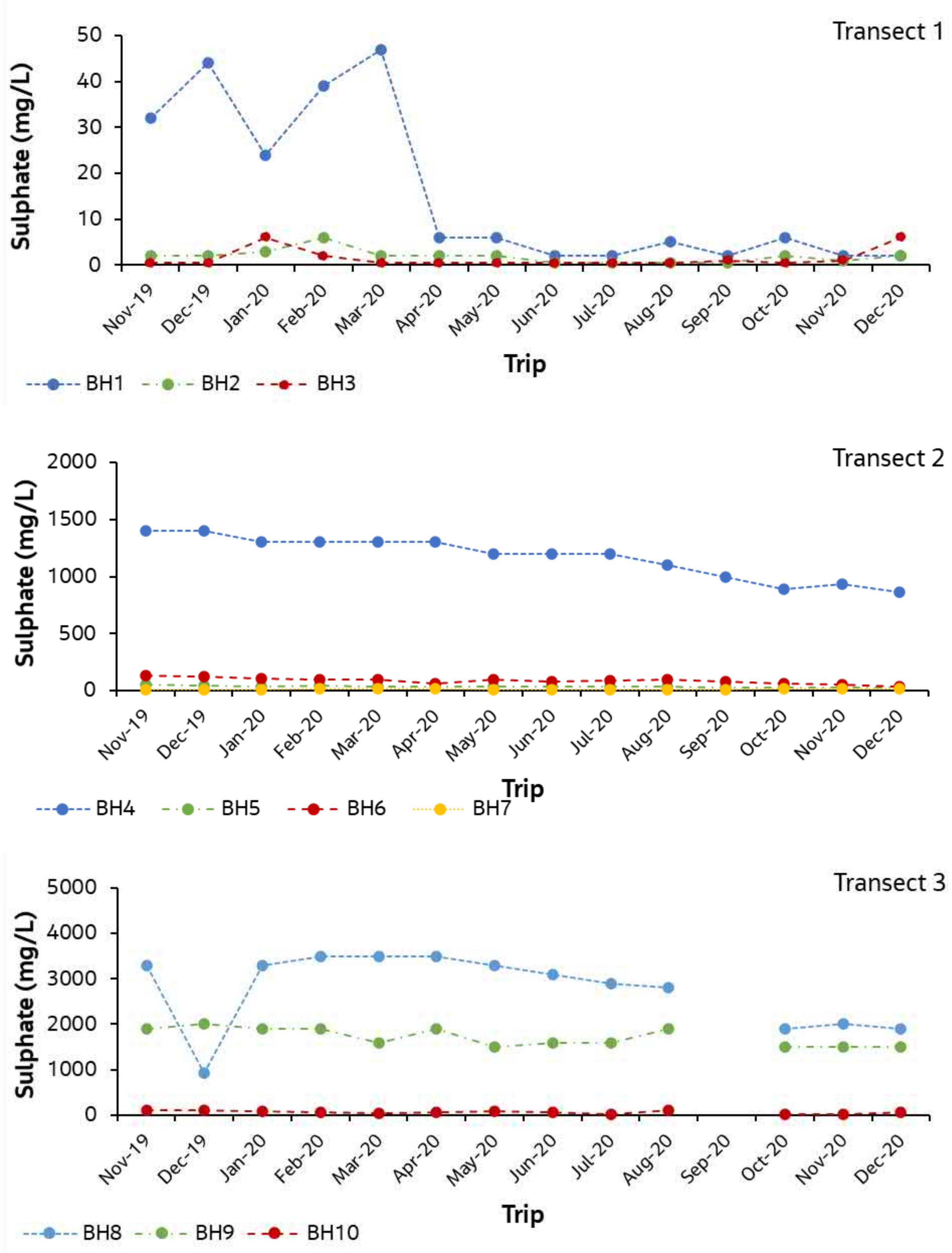
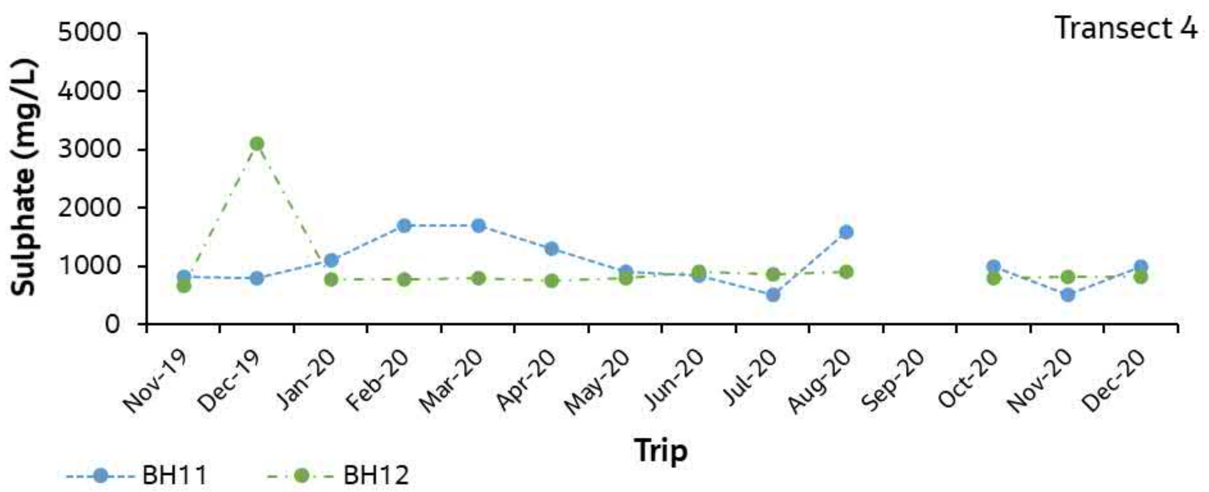


Figure 10-5: Time series of groundwater sulphate concentrations plotted by transect. The scale of the y-axis varies by transect.



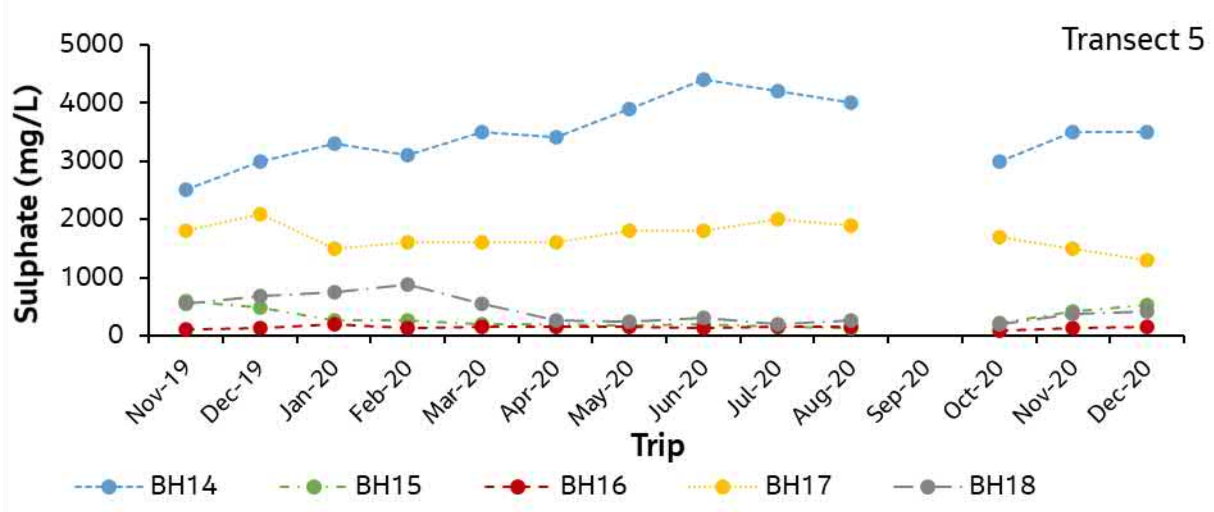


Figure 10-5 (continued): Time series of groundwater sulphate concentrations plotted by transect. The scale of the y-axis varies by transect.

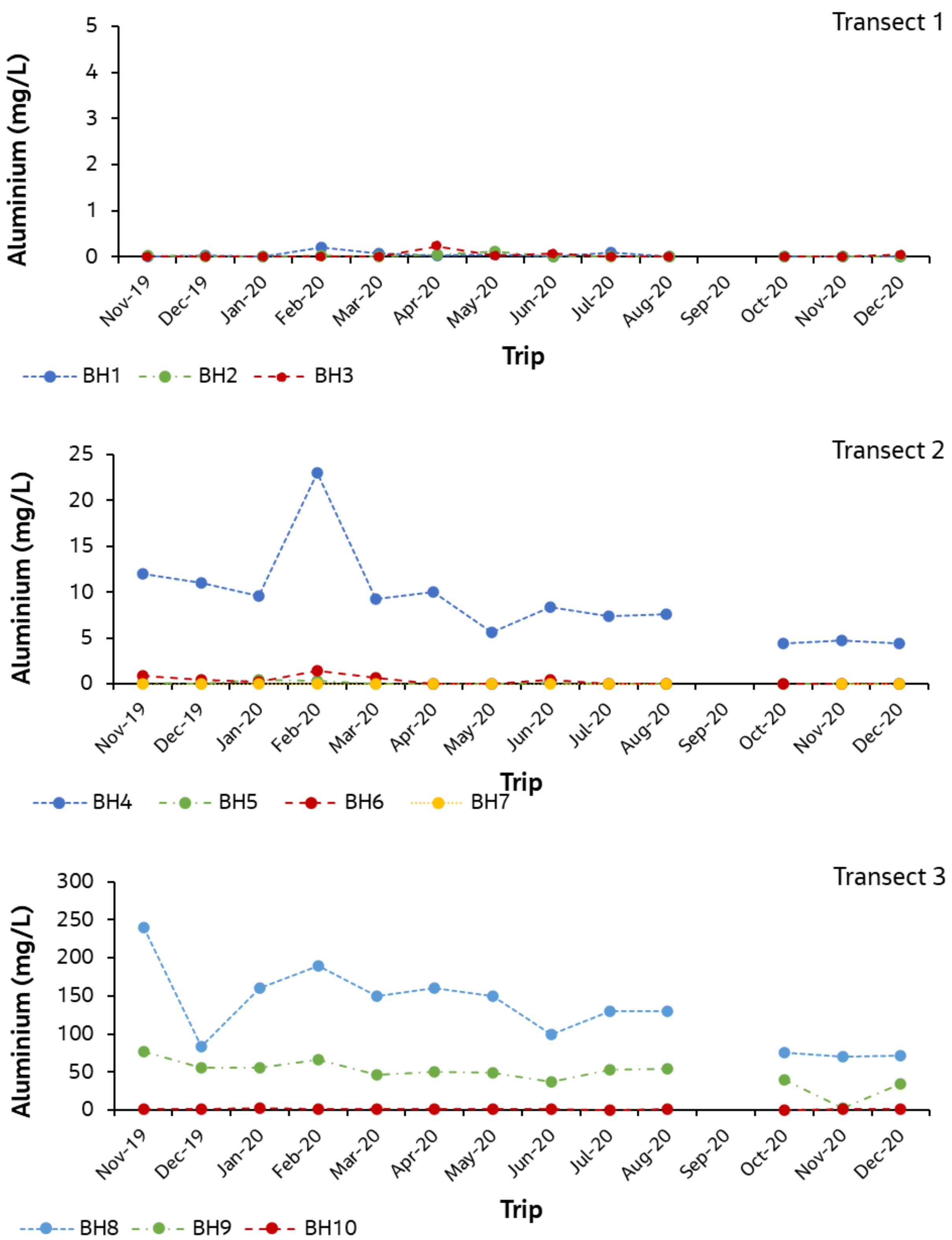
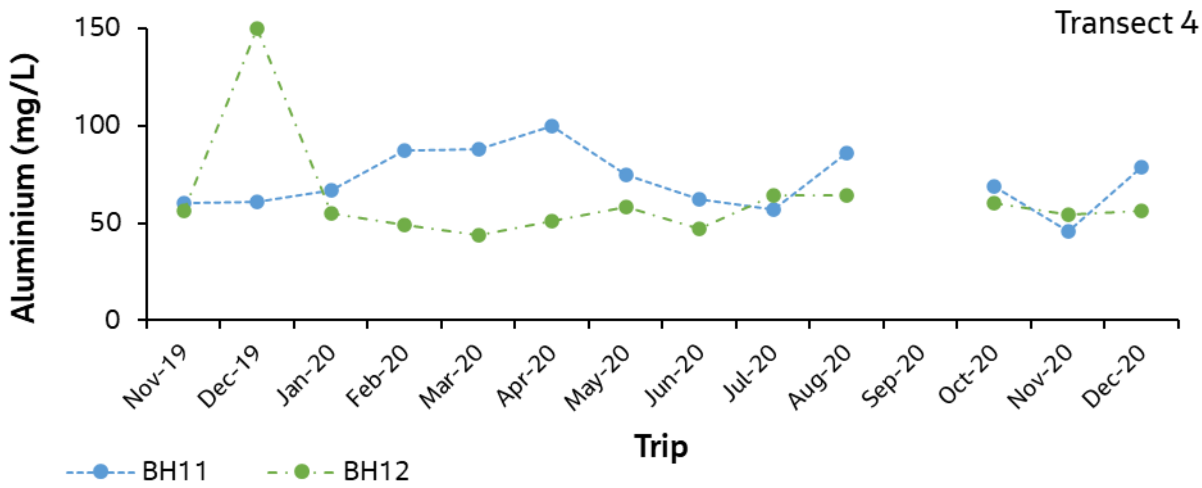


Figure 10-6: Timeseries of groundwater aluminium concentrations plotted by transect. The scale of the y-axis varies by transect.



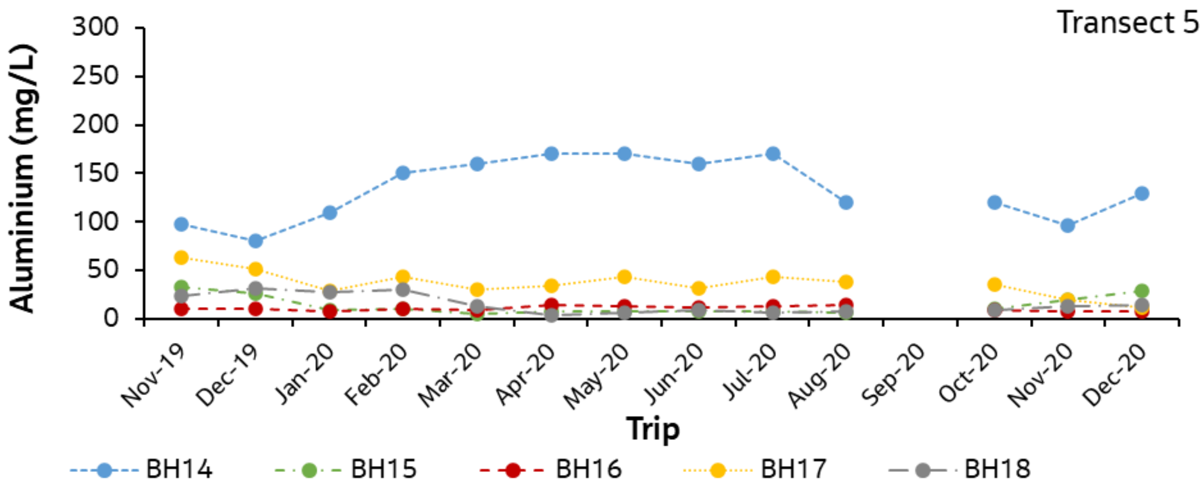


Figure 10-6 (continued): Timeseries of groundwater aluminium concentrations plotted by transect. The scale of the y-axis varies by transect.

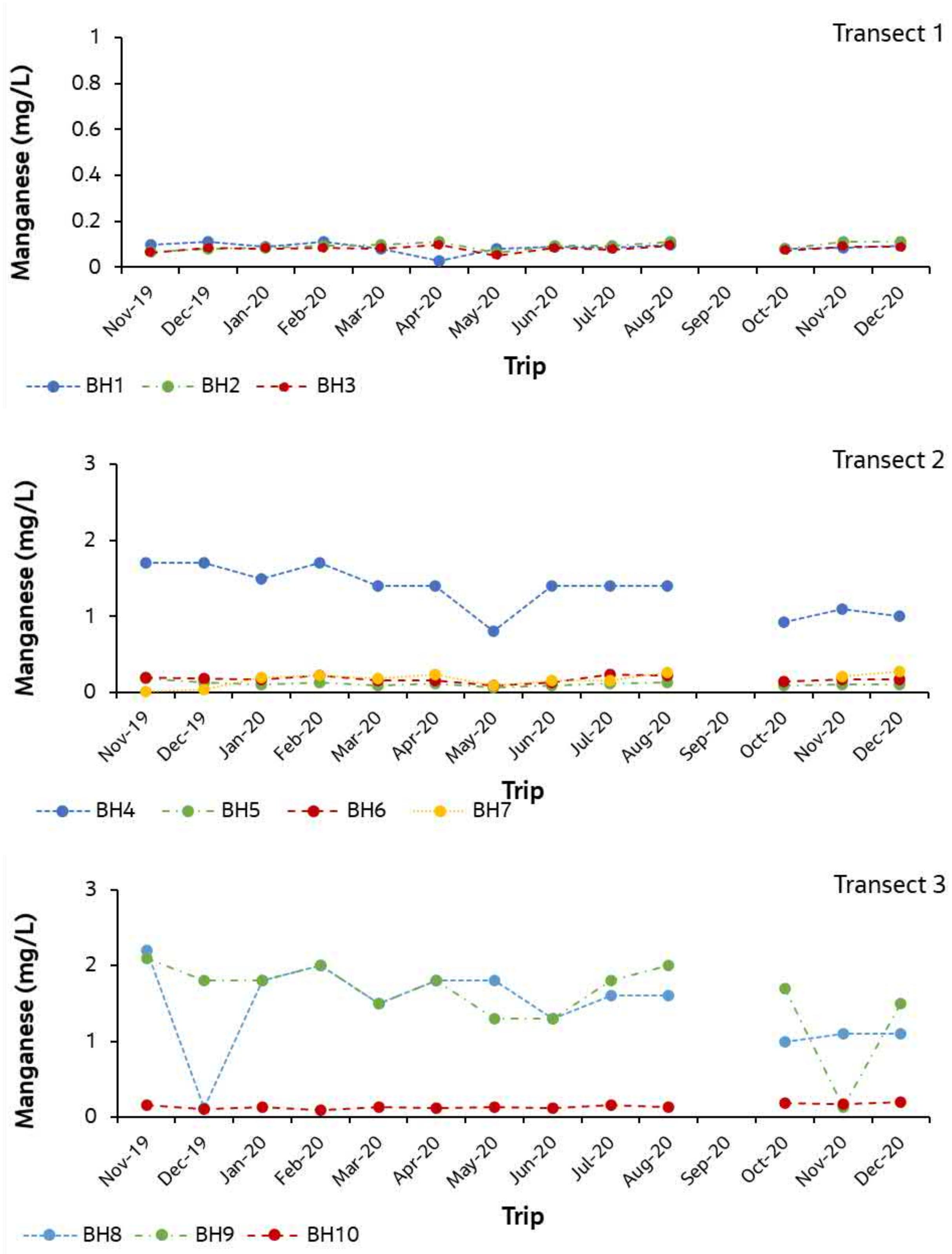


Figure 10-7: Time series of groundwater manganese concentrations plotted by transect. The scale of the y-axis varies by transect.

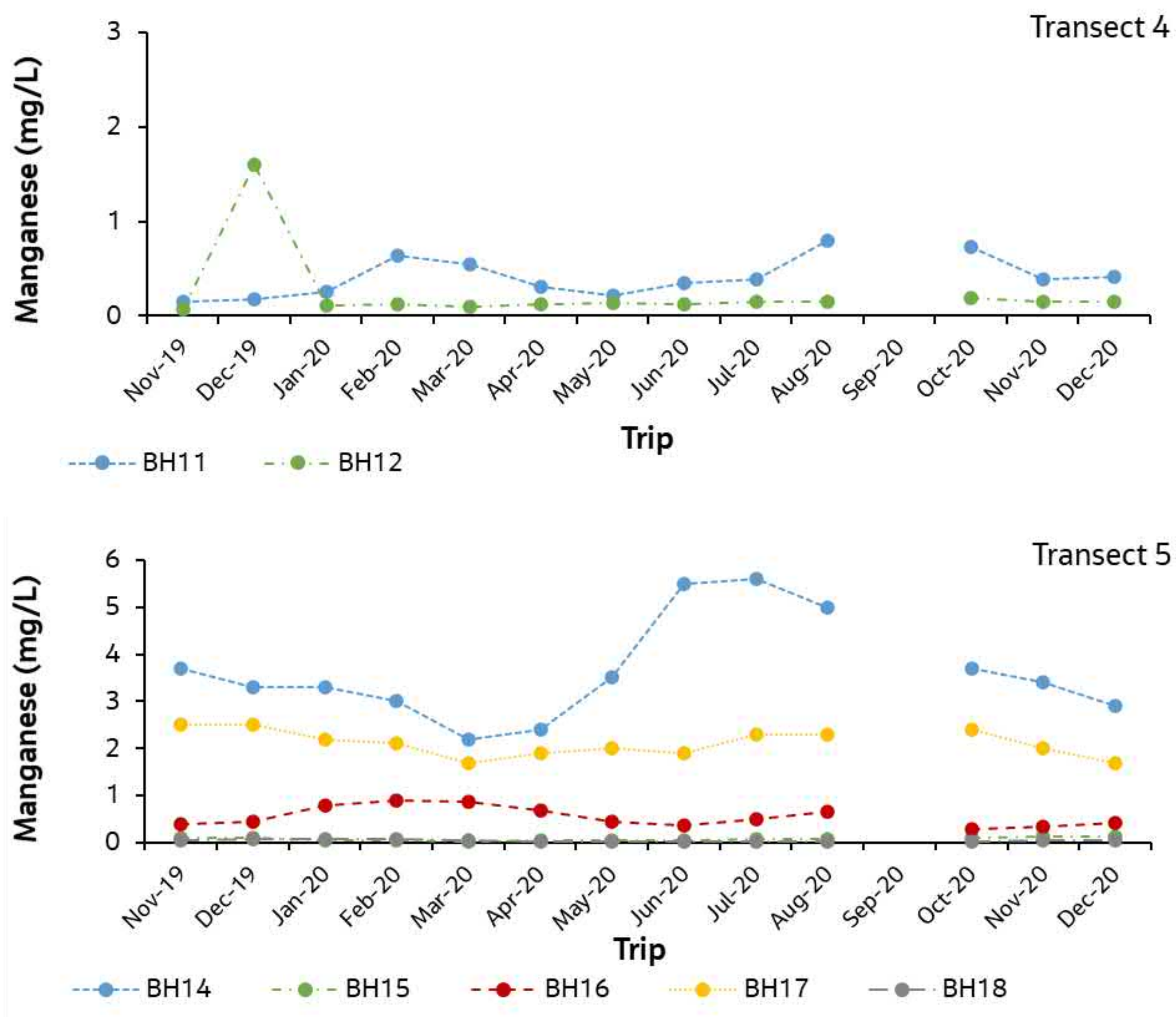


Figure 10-7 (continued): Time series of groundwater manganese concentrations plotted by transect. The scale of the y-axis varies by transect.

Appendix D. Additional information for ‘Risks to fish in the Barwon River’ assessment

This appendix provides more detail of the methods used to asses the nature of the risk posed by acidic discharge from Boundary Creek on fish, and more specifically fish kill events, in the Barwon River (section 4).

Table 10-1 provides the WQGVs used in the assessment, as well as the source of the WQGV, potential limitations associated with the WQGV and the ‘test metric’.

The ‘test metric’ is the metric of test site data which is compared to the WQGV in a water quality assessment. In the screening assessment, Boundary Creek downstream of Big Swamp is used as the test site. Generally, the test metric for toxicants (parameters that can cause toxic effects and ultimately death) is the 95th percentile value (ANZG 2018)[3]. The exception to this is when a site-specific WQGV is required because the ambient condition does not meet the WQGV. In the screening assessment (section 4.1.1), the 95th percentile concentration of aluminium and iron in the Barwon River upstream of the Boundary Creek confluence are above the ‘default’ WQGV. For these metals, a site-specific WQGV is required.

The ANZG (2018) recommends that the 80th percentile of reference site data collected at monthly intervals over a 2-year period be used to set site specific WQGVs.[4] The ANZG (2018) further recommends that for a slightly to moderately modified ecosystem, the median of the test site (Boundary Creek downstream of the swamp) should be compared to the site specific WQGV[4] (80th percentile of Barwon River upstream of Boundary Creek). The site-specific WQGV is considered as ‘interim’ as EPA Victoria requires that site-specific WQGVs only be adopted where default WQGVs cannot be met due to naturally high concentrations. The source of aluminium and iron in the Barwon River upstream of Boundary Creek is currently not characterised.

For ecosystem stressors (parameters that cause stress but usually not death) the metric varies depending upon whether low or high values are the cause of stress. The test metric for ecosystem stressors used in the assessment comes from the ERS.

As there are only 13 measurements from Boundary Creek downstream of the swamp there may be insufficient data to calculate percentiles with a 95% level of confidence. For example, Goudey (1999) states that 12 samples are sufficient to calculate 25th or 75th percentiles with a 95% level of confidence. Using the same method, at least 59 samples would be required to calculate a 95th percentile value with a 95% level of confidence.

All data reported as below the limit of reporting was treated as 0.5 x the limit of reporting for calculation of percentiles using default Excel formulae.

Table 10-1: Water quality guideline values used in ‘Risks to fish in the Barwon River’ assessment

Parameter	Type	Unit	Value	Source	Test Metric	Comment
Aluminium	Toxicant	mg/L	0.055	ANZG	95th percentile	WQGV is for waters >pH 6.5. The pH of the Barwon River upstream of the Boundary Creek confluence (the ambient condition) is >pH 6.5.
			0.15	ss-WQGV	50th percentile	80th percentile value from Barwon River upstream of Boundary Creek confluence.
Ammonia (as N)	Toxicant (and stressor, see comment)	mg/L	0.9	ANZG	95th percentile	Only the WQGV from ANZG (2018) for action of ammonia as a toxicant is adopted. The WQGV for physical and chemical stressors for south-east Australia was not adopted (Table 3.3.2

[3] https://www.waterquality.gov.au/anz-guidelines/monitoring/data-analysis/derivation-assessment
[4] https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive/reference-data

Parameter	Type	Unit	Value	Source	Test Metric	Comment
						for ANZECC & ARMCANZ 2000). The stressor WQGV is intended to assess the risk of adverse effects due to nutrients as ecosystem stressors (i.e. eutrophication). The ERS provides a WQGV for total nitrogen for this purpose and Table 3.3.2 of ANZECC & ARMCANZ (2000) is not listed as an objective for surface waters in Tables 5.7 or 5.8 of the ERS. Also, ANZG (2018) states that "*localised (geographically derived) guideline values and advice targeted to the local scale will always be more accurate than, and should take precedence over, using default guideline values (DGVs) provided in the Water Quality Guidelines*". The WQGVs provided in the ERS are more localised than the WQGVs provided in ANZECC & ARMCANZ (2000).
Antimony	Toxicant	mg/L	0.009	ANZG	95th percentile	WQGV is of unknown reliability and is associated with an unknown level of species protection. Should be considered an interim indictive working level until more data is collected.
Arsenic	Toxicant	mg/L	0.013	ANZG	95th percentile	WQGV is for AsV as the WQGV for AsIII is higher (0.024 mg/L).
Boron	Toxicant	mg/L	0.94	ANZG	95th percentile	
Cadmium	Toxicant	mg/L	0.0002	ANZG	95th percentile	
Chromium	Toxicant	mg/L	0.001	ANZG	95th percentile	WQGV is for CrVI as the WQGV for CrIII is higher (0.0033 mg/L). The CrIII WQGV is also of unknown reliability and is associated with an unknown level of species protection.
Cobalt	Toxicant	mg/L	0.0014	ANZG	95th percentile	WQGV is of unknown reliability and is associated with an unknown level of species protection. Should be considered an interim indictive working level until more data is collected.
Copper	Toxicant	mg/L	0.0014	ANZG	95th percentile	
Dissolved Oxygen	Stressor	% saturation	70-130	ERS	25th percentile - maximum	
Electrical conductivity	Stressor	µS/cm	2,000	ERS	75th percentile	
Iron	Toxicant	mg/L	0.3	ANZECC	95th percentile	Iron does not appear in ANZG (2018) and Table 3.4.1 of ANZECC & ARMCANZ (2000) states there is insufficient data to derive a WQGV for iron. In the technical brief for iron in ANZECC & ARMCANZ (2000) (section 8.3.7), a WQGV of 0.3 mg/L is provided as an indicative interim working level until more data is obtained. This WQGV was taken from the Canadian guidelines current at the time of publication.

Parameter	Type	Unit	Value	Source	Test Metric	Comment
			1.4	ss-WQGV	50th percentile	80th percentile value from Barwon River upstream of Boundary Creek confluence.
Iron (total dissolved)	Toxicant	mg/L	0.3	ANZECC	95th percentile	As above for iron.
			1.4	ss-WQGV	50th percentile	
Lead	Toxicant	mg/L	0.0034	ANZG	95th percentile	
Manganese	Toxicant	mg/L	1.9	ANZG	95th percentile	
Mercury	Toxicant	mg/L	0.00006	ANZG	95th percentile	The WQGV is the value for 99% level of species protection. This value is recommended for slight to moderately disturbed ecosystems by ANZG (2018) due to the potential for bioaccumulation.
Molybdenum	Toxicant	mg/L	0.034	ANZG	95th percentile	WQGV is of unknown reliability and is associated with an unknown level of species protection.
Nickel	Toxicant	mg/L	0.011	ANZG	95th percentile	
Nitrate (as N)	Toxicant (and stressor, see comment)	mg/L	2.4	ANZG	95th percentile	ANZG (2018) refers to NIWA (2013) for this WQGV. The same comment as for ammonia applies for nitrate.
pH	Stressor	pH units	6.8-8.0	ERS	25th percentile – 75th percentile	
Selenium	Toxicant	mg/L	0.005	ANZG		The WQGV is the value for 99% level of species protection. This value is recommended for slight to moderately disturbed ecosystems by ANZG (2018) due to the potential for bioaccumulation.
Silver	Toxicant	mg/L	0.00005	ANZG		
Thallium	Toxicant	mg/L	0.00003	ANZG	95th percentile	WQGV is of unknown reliability and is associated with an unknown level of species protection.
Total Nitrogen	Stressor	mg/L	1.1	ERS	75th percentile	
Total Phosphorus	Stressor	mg/L	0.06	ERS	75th percentile	
Turbidity	Stressor	NTU	25	ERS	75th percentile	
Vanadium	Toxicant	mg/L	0.006	ANZG	95th percentile	WQGV is of unknown reliability and is associated with an unknown level of species protection. Should be considered an interim indictive working level until more data is collected.
Zinc	Toxicant	mg/L	0.008	ANZG	95th percentile	

Notes:

Sources of WQGVs:

- ANZG – Australian & New Zealand guidelines for fresh & marine water quality default guideline values for slightly to moderately modified freshwater ecosystems (https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/search). Last viewed 26/07/2021. The default guideline value for slightly to moderately modified ecosystems is generally the value associated with a 95 % level of species protection, the level of species protection specified by the ERS.
- ss-WQGV – Site specific water quality guideline value. For this assessment, the 80th percentile value from the Barwon River upstream of the Boundary Creek confluence was used to set an interim ss-WQGV. The 80th percentile value was used in line with guidance from the ANZG (https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive/reference-data).

Parameter	Type	Unit	Value	Source	Test Metric	Comment

- ERS – Environment Protection Act 2017 Environment Reference Standard, Table 5.8: Rivers and streams – Indicators and objectives, Central Foothills and Coastal Plains segment, Lowlands of Barwon, Moorabool, Werribee and Maribyrnong basins and the Curdies and Gellibrand Rivers.
- ANZECC - Australian & New Zealand guidelines for fresh & marine water quality published by ANZECC & ARMCANZ in 2000 (superseded by the ANZG).

Test Metric – this is the metric of test site data which is compared to the WQGV in a water quality assessment.

Jacobs have developed a method that uses the mixing equation to assess the level of dilution required for concentrations of indicators in a discharge stream to meet WQGVs in a receiving water. This method is based on the following equations:

Equation D1 $C_{UPSTREAM}V_{UPSTREAM} + C_{DISCHARGE}V_{DISCHARGE} = C_{DOWNSTREAM}V_{DOWNSTREAM}$

Equation D2 $V_{UPSTREAM} + V_{DISCHARGE} = V_{DOWSTREAM}$

Equation 1 (section 4.1.1 and reproduced below) is obtained by combining and re-arranging equations D1 and D2, and substituting the concentration in the Baron River upstream of the Boundary Creek confluence for $C_{UPSTREAM}$, the concentration in Boundary Creek downstream of Big Swamp for $C_{DISCHARGE}$ and the WQGV for $C_{DOWNSTREAM}$.

Equation 1

where, S_{req} = required dilution factor to meet WQGV

$C_{Boundary\ Creek}$ = concentration in Boundary Creek downstream of Big Swamp

C_{wqgv} = water quality guideline value

$C_{Barwon\ River}$ = ambient concentration in Barwon River, i.e. upstream of Boundary Creek confluence.

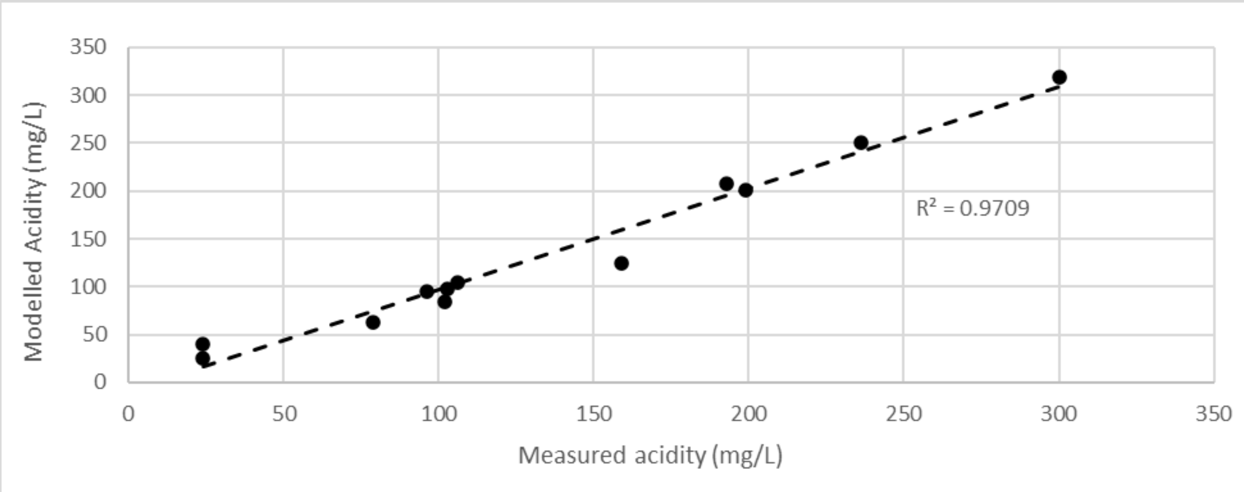
The test metric required for $C_{Boundary\ Creek}$ and $C_{Barwon\ River}$ varies depending upon the water quality indicator. For toxicants, the 95th percentile value is generally used for both $C_{Boundary\ Creek}$ and $C_{Barwon\ River}$ as (i) the ANZG (2018) states that the metric for comparison of toxicant concentrations at a test site (Boundary Creek) should be the 95th percentile (as above) and (ii) using the 95th percentile for the ambient condition (Barwon River) represents a conversative estimate of the dilution capacity of the receiving water – the higher the concentration in the receiving water, the lower the dilution the dilution capacity of the receiving water. The conservative nature of the dilution requirement caused by using the 95th percentile value for the ambient condition is considered warranted given the potential effects of toxicants on aquatic biota.

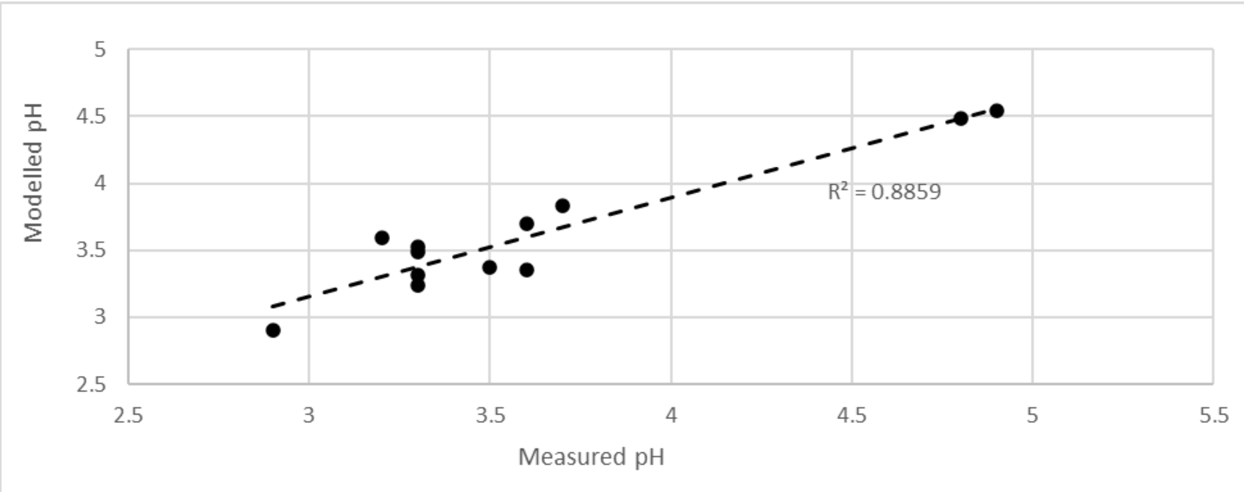
The exception to use of the 95th percentile value for $C_{Barwon\ River}$ for toxicants where the ambient condition (Barwon River upstream of the Boundary Creek confluence) does not meet the WQGV. Here, the 80th percentile value of the Barwon River upstream of the Boundary Creek confluence is adopted as the interim site-specific WQGV and therefore, the 95th percentile value of the Barwon River would exceed C_{WQGV}. In this situation, the 50th percentile value is used for $C_{Barwon\ River}$. The 95th percentile value of Boundary Creek downstream of Big Swamp is still used for $C_{Boundary\ Creek}$ in order to obtain a conservative dilution requirement.

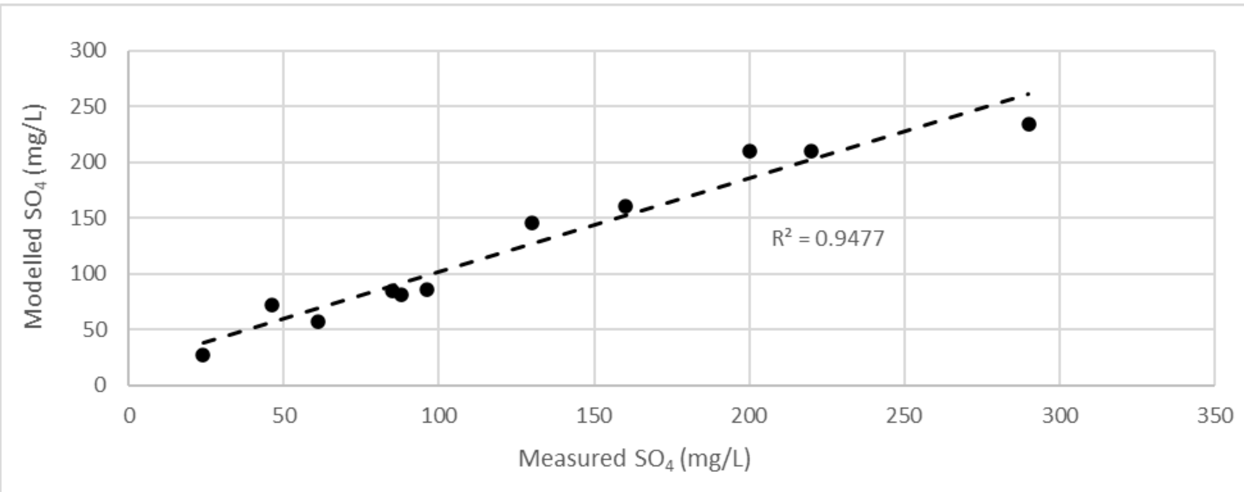
As discussed above, there are only 13 data points for the Boundary Creek dataset. There are also 1 or 2 data points for the Barwon River for most indicators other than pH, electrical conductivity, aluminium, iron and manganese (n=70) and dissolved oxygen (n=35). This means that for Boundary Creek and the metals in the Barwon River with 1 or 2 measurements that although 95th percentile values can be calculated using Excel, the confidence interval associated with the 95th percentile may be low. For Boundary Creek, the 75th or 95th percentile value calculated using Excel was used to calculate Sreq (as above for comparison to WQGVs). For metals in the Barwon River with 1 or 2 measurements, the single value or maximum of the two available values was used to calculate Sreq.

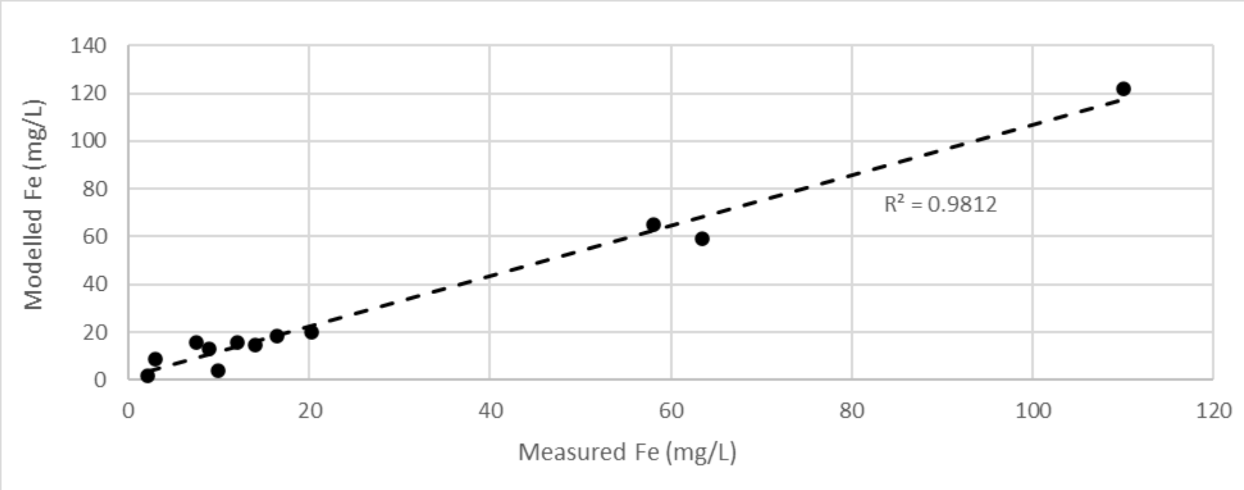
For ecosystem stressors, the percentile value required for comparison of a ‘test site’ to the WQGV is used for Boundary Creek. For example, the75th percentile would be used for total nitrogen and the 25th percentile value would be used for the lower limit of pH. For $C_{Barwon\ River}$, the 50th percentile value is used for stressors in the calculation of Sreq as this represents a ‘typical’ concentration.

Appendix E. Hydrogeochemical model calibration co-variance plots

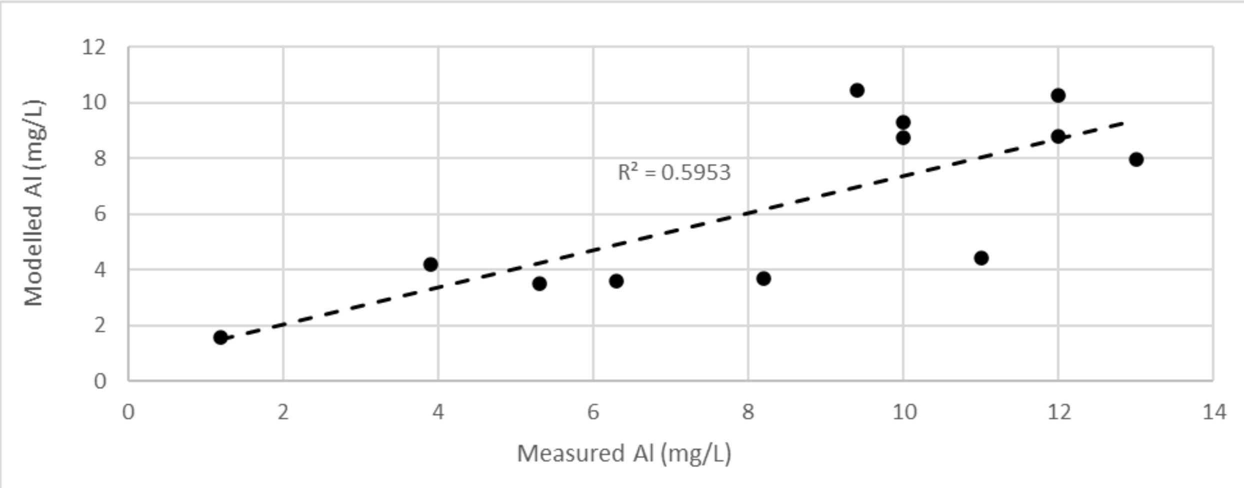




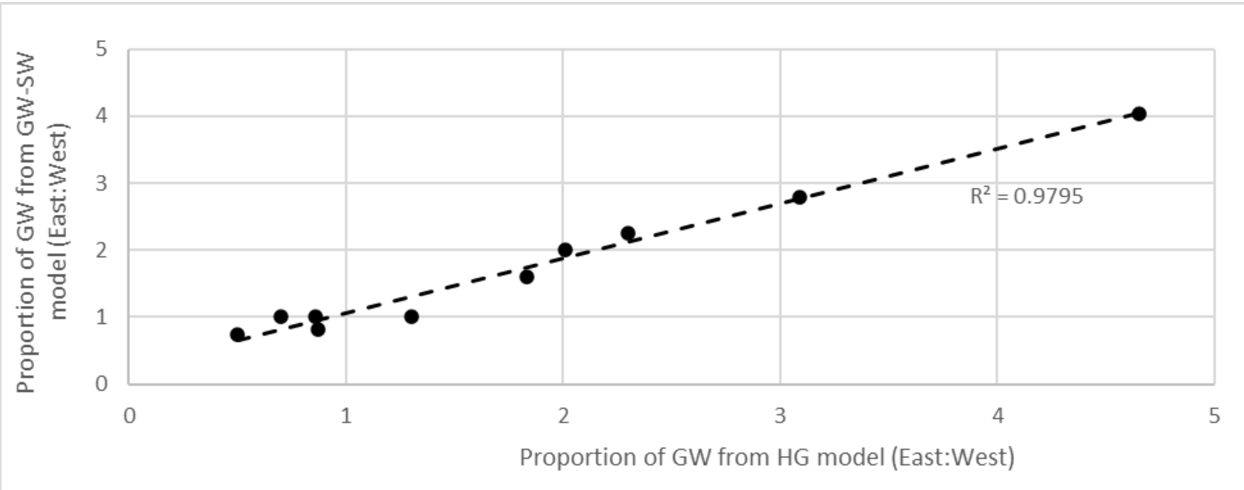




Modelled Fe (mg/L)
Measured Fe (mg/L)
R² = 0.9812
0
20
40
60
80
100
120
140



Modelled Al (mg/L)
Measured Al (mg/L)
R² = 0.5953
0
2
4
6
8
10
12
14



Proportion of GW from GW-SW model (East:West)
Proportion of GW from HG model (East:West)
R² = 0.9795
0
1
2
3
4
5

Appendix B: Design of Downstream Contingency Measure

Big Swamp

Contingency Measures Design Report

IA258200-RPT-004 | Final

30 July 2021

Barwon Water

Big Swamp

Project No:	IA258200
Document Title:	Contingency Measures Design Report
Document No.:	IA258200-RPT-004
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Jacobs Australia Pty Ltd.

33 Kerferd Street
Tatura, VIC 3616
PO Box 260
Tatura, VIC 3616
Australia
T +61 3 5824 6400
F +61 3 5824 6444
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
1	22/7/2021	Draft Report for Client Review	TF	NU	NU	NU
2	27/08/2021	Report for Client Submission	TF	NU	LL	LL

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Executive Summary

Jacobs has been engaged by Barwon Water to provide a design for the Big Swamp active treatment contingency measure under the Boundary Creek, Big Swamp and Surrounding Environment Remediation an Environmental Protection Plan.

The objective of the contingency measure is to chemically improve low pH flows leaving the Big Swamp in the short term if determined to be required until other remedial actions including the installation of the hydraulic barriers can take effect. In addition to this work, the hydrogeochemical modelling undertaken by Jacobs has also considered the ability to treat acidity within Big Swamp using magnesium oxide, as recommended by the Independent Technical Review Panel. Upstream treatment potentially could reduce the need for implementation of an active treatment contingency measure, however field trials are required to confirm its feasibility.

In assessing options for an appropriate active treatment contingency measure, the type of treatment chemical and site location were considered as key factors.

The contingency measure assessment found that using Caustic Soda (NaOH) through a pH adjustment – flow plant (PAF) within a containerised system located at the downstream end of the Big Swamp to treat discharge flows is recommended. This system is a robust off the shelf solution that can be implemented in a short period of time, supported by existing Barwon Water operational experience. The system also allows for easy recovery for decommissioning.

A readily available off the shelf pH Adjustment – Flow (PAF) plant has been proposed. The PAF plant is designed to automatically adjust and maintain the pH level of pressurised raw water, prior to discharge to environment. The standard treatment process includes an inline pH analyser which monitors the pH level and a dosing pump to automatically dose liquid alkali. The system components provides flexibility to suit the raw water flow rate and daily usage. Chemical storage tank(s) are provided with 110% bunding in compliance with AS1940-2004 (relevant standard for storage and handling of flammable and combustible liquids). PAF plants are available as skid mounted or containerised systems for easy deployment to remote locations.

This system further provides for diesel generator and solar powered elements, with options for equipment upgrades to meet Barwon Water's requirements.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to document the design of the Boundary Creek – Big Swamp Contingency Measure. This report has been prepared in accordance with the scope of services set out in Contract between Jacobs and Barwon Water.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and 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 conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Barwon Water and available in the public domain at the time or times 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 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 any other context.

Project specific limitations which should be considered are:

- *Project time limitations have not allowed ground feature survey. The design is based on Airborne Lidar Survey, provided by Barwon Water, and adjusted during a previous hydraulic modelling phase. This data is known to be affected by the presence of thick vegetation and possibly standing water.*

This report has been prepared on behalf of, and for the exclusive use of 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

Jacobs has been engaged by Barwon Water to provide a design for the Big Swamp active treatment contingency measure under the Boundary Creek, Big Swamp and Surrounding Environment Remediation an Environmental Protection Plan.

The objective of the contingency measure is to chemically neutralise low pH flows leaving the Big Swamp in the short term, if determined to be required, until other remedial actions including the installation of the hydraulic barriers can take effect. The contingency measure has been assumed to be independent of other remedial actions including the installation of the hydraulic barriers.

1.1 Previous options assessments

CDM Smith (2019) completed a remediation options assessment to support the REPP. Seventeen options were identified for preliminary screening, of which seven options were considered for a detailed assessment. These included:

- Aerial liming - direct treatment of soils with neutralising agents.
- Flooding of Big Swamp and managing groundwater levels – create permanently waterlogged areas where microbially mediated iron reducing and sulfate reducing reactions increase alkalinity, raise pH and remove dissolved metals by precipitation.
- Soil excavation, disposal, and rehabilitation - removal of the oxidised ASS sediments within Big Swamp.
- Soil mixing – use large diameter hollow flight auger fitted with mixing paddles to mix neutralising agent with the oxidised sediments.
- Active treatment system - treat water quality in Boundary Creek downstream of swamp.
- Constructed aerobic wetland – remove metals by oxidisation and hydrolysis.
- Reducing and Alkalinity producing systems – a vertical flow anaerobic wetland to increase alkalinity, raise pH and remove metals by precipitation of insoluble hydroxides, carbonates and sulfides.

The options were assessed against the specified criteria and the top three options using a weighted assessment were:

- Flooding of Big Swamp and managing groundwater levels
- Wetland liming
- Active treatment system

The recommended preferred remediation option was flooding Big Swamp and managing groundwater levels, as this is the only option with the ability to achieve all three project objectives which included maintaining minimum groundwater levels and flow in Boundary Creek and reducing peat/fire risk (CDM Smith, 2019). Aerial liming and an active treatment system were recommended as contingency measures, or alternatively to be implemented in conjunction with the preferred option, depending on their effectiveness.

On June 17 2021, the Independent Technical Review Panel also recommended that an active treatment system upstream of the swamp using caustic magnesia (MgO) as a pH correction chemical be considered. The focus of this system would be to treat the acidity stored in soils and pore water throughout the swamp. This option has been further reviewed as part of separate report on the hydrogeochemical assessment of the Big Swamp. There is limited information in the public domain to consider this upstream treatment option in detail and field trials are recommended to confirm its feasibility (Jacobs, 2021a).

The objective of this study is to consider the contingency measure options to provide for pH correction on surface flows leaving the Big Swamp. This is to avoid low pH flows entering the Barwon River, resulting in potential environmental impacts such as fish kills.

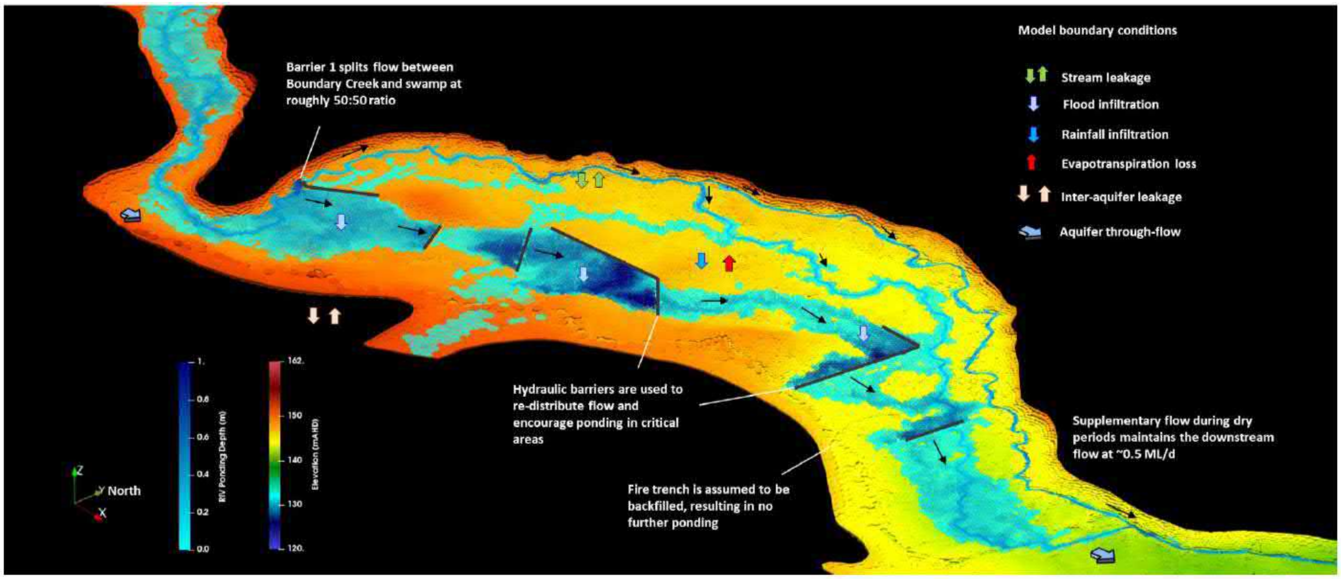


Figure 1.1: Location of hydraulic barriers (GHD, 2021)

1.2 Purpose of this report

The purpose of this report is to document the investigations, options assessment, and design of the contingency measure for Big Swamp. This information is to provide detail to allow Barwon Water to:

- Submit the project for Southern Rural Water (SRW) review and endorsement.
- Undertake procurement of the proposed works to construct the contingency measure if determined to be required.

The following work is being undertaken in parallel, and will be reported separately:

- Hydrogeochemical modelling of Big Swamp and Boundary Creek (Jacobs, 2021a)
- The consideration and design of hydraulic barriers within Big Swamp (Jacobs, 2021b)
- Relevant approvals including, but not limited to cultural heritage, flora and fauna, statutory planning, works on waterway and land access agreements.

Jacobs used Barwon Water LIDAR survey information, completed a geotechnical investigation and site visit. No further assessments were undertaken as part of this design process.

1.3 Hydrogeochemical report (Jacobs, 2021a)

Jacobs (2021a) completed hydrogeochemical modelling to estimate the changes in water quality in Boundary Creek in response to remediation. A hydrogeochemical conceptual site model was developed and confirmed that although soils contain the majority of the acidity in Big Swamp, acidity stored in groundwater is the primary mechanism by which acidity is discharged into Boundary Creek.

A review of the potential impacts on the downstream Barwon River using the modelling package PHREEQC highlighted that pH, iron and aluminium pose the greatest ecological risk to the Barwon River. The highest risk occurs during the months of May and June when discharge from the creek contains higher concentrations of parameters of concern and flows from the creek begin to increase.

This study also used hydrogeochemical modelling to confirm the likely water quality outcomes from preferred remediation option involving the installation of hydraulic barriers. The modelling indicated that without the hydraulic barriers installed, the combined mass of acidity in the groundwater and soils would take approximately 100 years to be removed from Big Swamp. The installation of the hydraulic barriers is predicted to reduce the time to remove the acidity to approximately 35 years.

This highlights that a potential upstream treatment may be required to improve the timeframe for remediation and the potential dosing requirements of such a scheme were outlined in the report. Jacobs (2021a) note that there is limited information in the public domain on this option and field trials would need to be undertaken to confirm the feasibility.

The hydrogeochemical model was also used to confirm the dosing requirements of the downstream contingency measure to inform the design. The model estimated that between 80 and 800 L/day would be required to improve the water quality in Boundary Creek depending on the flow, which equates to 68,000 L/year. The majority of this is required between May and September.

2. Site Conditions

Big Swamp is located on private property approximately 2 km South West of Yeodene (refer figure 2.1). It is approximately 900 m long and up to180 m wide. The easiest access is to the south east corner via a gravel driveway off Colac-Forrest Road. This continues through farmland after which it becomes heavily treed before continuing to the Swamp. Several tracks were constructed on the swamp for the installation of monitoring bores in 2019. The tracks are unformed earth construction and approximately 3 m wide. Two tracks run parallel to the Southern side of the swamp, one of which follows the fire trench that was constructed to prevent spread of a historical peat fire within the swamp. These tracks are suitable for occasional light vehicle (Ute) access. The tracks are rutted in sections, occasionally steep and with fine sand and silt. They may be erodible and access difficult during wet weather and winter.

Big Swamp receives water from Boundary Creek, which continues along the north side of the swamp. In places the boundary between the creek and swamp is not distinct. At the Eastern end of the Swamp, the flow paths converge. A cutting which runs along the eastern fenced boundary channels the swamp outfall back to the creek.

Hydrographic Stations (stream gauge) in Boundary Creek immediately to the east and west measure inflow to and outflow from the swamp, and the respective pH, and EC. The two monitoring stations are triangular V notch weirs, formed from a stainless steel plate mounted in concrete box culvert structures measuring 1.2 m wide and 0.9 m deep. Downstream of the eastern hydrographic station the creek continues East under the Colac – Forrest Road bridge where a third concrete weir with monitoring station is located.

A fire trench runs along the southern side of the swamp and then turns north along the east boundary. A track runs parallel along the southern side of the trench. The trench was dry when inspected. Historically, it would have acted as a flow path for surface runoff from the hill to the south of the swamp, however, it is blocked in places at more recently constructed track crossings. The surface soil (trench excavation) appeared as dry unconsolidated organic silt. The trench was overgrown in the bed and banks. It is possible that some of the larger trees neighbouring the trench may have predated the trench and had spoil mounded around them.

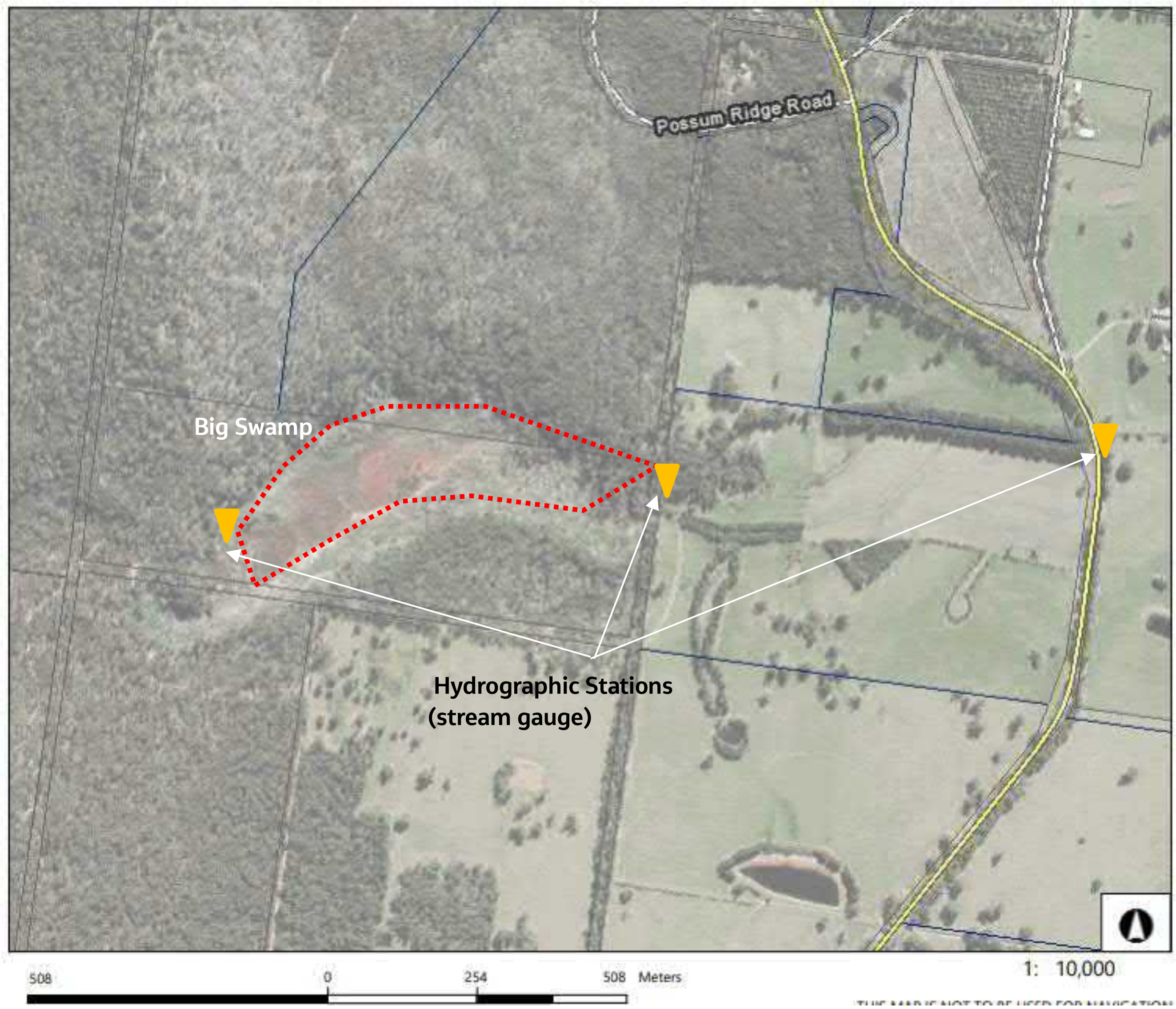


Figure 2.1: Big Swamp Location Plan

3. Contingency Measure - Options Assessment

The selection of the contingency measure type consisted of an initial screening process followed by more detailed assessment of the remaining options.

3.1 Initial Screening

A range of options were identified and considered as part of the initial option development and these were screened based on the functional requirements. The initial screening process was influenced by the practicability of installation, assuming that the contingency measure could be installed over summer 2021/22 if deemed to be required. The short timeframe for installation (if required) favors conventional approaches with known outcomes ahead of more novel methods with uncertain outcomes.

The options considered for the contingency measure were reviewed against three key functional aspects, which were:

- Location of the works,
- Method of treatment/application and
- Chemical used to improve pH in the water.

3.2 Location

The location of the contingency measure to improve the pH of the water entering the Barwon River could be situated in the following locations:

- Upstream of Big Swamp to pre-treat Boundary Creek flows entering the Big Swamp,
- Within the swamp to treat surface water before it leaves the swamp, or
- Downstream of the swamp treatment of the flow leaving the swamp.

Table 3.1 describes the considerations for location of the contingency measure.

The location of the contingency measure is proposed to be downstream of Big Swamp, due to ease of access and certainty around ability to mix and therefore treat all flows leaving the Swamp.

Further consideration for the location of the contingency measure may be required to support the construction of the hydraulic barriers if required. The hydraulic barrier works are proposed to be constructed while the swamp is as dry as possible and these works may expose PASS as a result of vegetation removal and soil disturbance, which has the potential to cause additional acidification. Treatment within the swamp could potentially mitigate some of this risk, however this option has not been considered in detail following comparison of the options as discussed in Table 3.1.

Table 3.1: Comparison of options for active treatment as a contingency measure

	Upstream Treatment	Treatment Within Swamp	Downstream Treatment
Access	Access to the entry and middle of the Big Swamp is via an unformed narrow rutted dirt tracks with thick vegetation close to the tracks, restricting vehicle turning and size. These tracks are likely of limited use during wet seasons. Upgrade works to the track are likely to require planning permit on vegetation removal, although it is noted that access to these areas will likely be improved for construction of the hydraulic barriers.		Access to the Boundary Ck downstream of the Swamp is via an open farm paddock.
Land ownership	Private Land	Private Land	Private Land
Ability to mix and treat all flows	Pre-treatment of the flows entering Big Swamp are likely to be difficult to estimate due to variable flow paths. This is further made difficult with potential for bypass flows around the Swamp to the Boundary Ck likely to take treated flows away from the Big Swamp area.	Mixing within the Swamp is likely to be problematic with the pools being slow moving and unable to move treated water throughout the water to correct the pH. Using mechanical mixers is not recommended due to the environmental conditions of the swamp and additional cost and power demand.	Mixing on discharge allows for the effective treatment of the surface flows on known pH measurements and total flow volume. This allows for target dosing and correction of pH levels. The Big Swamp downstream location has a weir that further provides a good location for mixing of flows to ensure the chemical is mixed through the surface flows.
Construction	The construction of the chemical treatment system at the entry or middle of the Big Swamp area is likely to require native vegetation removal, further works to improve access roads and may limit construction equipment such a crane operation near large trees.		The open paddock on the discharge end of the Big Swamp provides a good level of access and working space for construction.
Extreme Events	Location of the treatment works at the entry or middle of the Big Swamp requires the treatment process to be within a potential bush fire area. This increases the risk of the system being damaged during extreme events. Staff operating the system have increased risk with the access during code red days.		The Big Swamp discharge area is an open paddock with capacity to provide separation from surrounding bushland.
Operation	The operation of the treatment system at the entry or middle of the Big Swamp could be more challenging to resupply with chemical and diesel, due access issues. Chemical spills and vandalism are likely to be more difficult to manage in a site with poor access and visibility as it cannot be easily seen and heard compared to an open paddock. Access to site during night is expected to be hazardous when driving on a twisting narrow track near a swamp.		With the proposed site located in an open paddock, access for chemical and diesel resupply is easier. Management of chemical spills is likely to be manageable with soil removal, if required. Night access is expected to be easy with a short access route and open terrain.

3.3 Treatment Methods

The different treatment methods that have been considered for pH correction are outlined below.

3.3.1 Manual Chemical Application within Big Swamp

Periodic manual chemical treatment to the Boundary Creek system in Big Swamp to correct the pH is a potential option for the contingency measure. This could be done with dosing chemicals to the waterway from chemical containers to the required volume in response to pH levels of the Big Swamp. The dosing is proposed to be at the existing weirs as a mixing point for flows.

This method is labour intensive and is likely to provide pH spikes into the waterway. The operational cost of the labour is expected to be high and operation would be challenging to staff for long periods of time. The management of chemicals with resupply, staff facilities such as toilets and lunch room are likely to be required to support the onsite team. Risk management of chemical use is further unlikely to support this method. Chemical dosing at night is unlikely to be acceptable, leaving the Boundary Creek system vulnerable to low pH events outside of business hours.

3.3.2 Lime Bed

Lime could be placed within the Boundary Creek system, potentially downstream on a weir to provide a pH correction for passing flows. This method does not allow for variable control of the pH and risks creating high alkaline water within the system. It is expected to be difficult to manage replacement lime and to achieve a desired pH level consistently in the waterway. Lime beds are also likely to coat with iron and aluminium hydroxides rapidly and may require frequent ongoing maintenance and re-supply.

3.3.3 Chemical Dosing System

A chemical dosing system would draw flow from the Big Swamp system via a feed pump from upstream of a weir where a pool of water is formed. The flow would be dosed with chemical for return to the Big swamp system. This operation allows for consistent dosing, chemical storage and operation throughout the day and night. The system would provide for capacity to monitor dosing rates and volumes and responding pH levels during dosing, allowing for potential adjust by the system in response to pH changes in the discharge water.

This method has a greater capital cost, however, provides for reduced operational labour costs and greater level of control on chemical application to waterway.

3.4 Chemical Options

Common chemicals used for pH correction for increasing alkalinity are provided in Table 3.2, together the amount required. All these chemicals will neutralize acidity, so the selection of chemical to be used at Big Swamp was informed by Barwon Water's current experience with chemicals to leverage off existing supply chains and Barwon Water current capacity. Preliminary discussions with Barwon Water indicated that Caustic Soda is a common chemical in use within their water treatment plants.

Table 3.2: Alkalinity contributed per mg of pure product – Practical guide to the optimisation of chemical dosing, coagulation, flocculation, and clarification.

Chemical Agent	Alkalinity Added (mg $CaCO_3$ equivalent /mg pure chemical)
Soda Ash (Na_2CO_3)	0.94
Hydrated Lime ($Ca(OH)_2$)	1.35
Caustic Soda (NaOH)	1.25
Magnesium Hydroxide ($Mg(OH)_2$)	1.72
Sodium Bicarbonate ($NaHCO_3$)	1.19

3.5 Summary

A review of the options considered above indicate a chemical dosing system located on the discharge end of the Big Swamp (Eastern) using Caustic Soda as a pH correction chemical would be recommended for the following reasons:

- Preferred location due to accessibility, limited modifications and vegetation removal, reduced fire risk
- Certainty of the achieving the desired water quality outcomes downstream of the swamp and minimizing risk to the Barwon River
- Caustic soda is readily available and aligns with the Barwon Water current experience.

4. Contingency Measure - Basis of Design

The design criteria and assumptions for the contingency measures are outlined below in Table 4.1. The design life of the contingency measure is assumed to be 15 years on the basis that the remediation option would achieve the desired outcome in 10-15 years. However it is noted that Jacobs (2021a) has estimated that the current preferred remediation option involving hydraulic barriers may take 30 to 40 years to improve the water quality in Boundary Creek downstream of the swamp. This suggests that the remediation option may need to include an additional upstream or in-swamp treatment to improve the remediation timeframe. An upstream treatment option using magnesium oxide has been recommended by the Independent Technical Review Panel and is discussed in Jacobs (2021a). If the design life needs to be greater than 15 years, further consideration may need to given to a more permanent structure.

Table 4.1: Design criteria

Item:	Design Parameters:	Basis / Source:
Asset Life	15 years	Mechanical / Electrical design life 15 years
Vehicle Access	Rigid Truck	Access Road width: 3m Maximum Length: 12.5m
Chemical Dosing Rate	Min: 0 kg/day Max: 150 kg/day	Min: 0 L/day Max: 800 L/day
Chemical pH Correction	Caustic Soda (NaOH) 1kg = 2.5L Chemical	Chemical to be used is 40% (W/W) Weight for Weight
Chemical Storage Volume	2,500 Litres Intermediate Bulk Containers (IBC)	Minimum bund volume 2,750L Heating Element required
Operational Power Supply	Diesel Generator	For operation of the chemical dosing system
Monitoring Power Supply	Solar Panels	For monitoring of chemical dosing system
Building Enclosure	20-foot Shipping Container	Factory fitted plant
System Recovery	Design to allow for chemical dosing system to be removed from site. Avoid permanent foundation of concrete. Suggest gravel pad & road.	
Operating Duration between Visits	Minimum: 7 days Maximum: ≥40 days	This duration may vary depending on dosing rate for chemical usage.
Duty Only	Duty Only	It is proposed to have duty only system given the likely short operational life. Consideration could be given to having critical spares on site for quick replacement. This may include feed pump and dosing pump.

Further functional requirements for the purpose of designing include:

- Chemical Dosing
- Durability
- Constructability
- Minimising Vegetation Disturbance
- Rehabilitation
- Security

4.1 Chemical Dosing Requirements

The objective of the contingency measure is to chemically neutralise low pH flows leaving the Big Swamp in the short term if determined to be required until other remedial actions including the installation of the hydraulic barriers can take effect. Jacobs (2021a) calculated the dosing requirements of the downstream contingency measure using caustic soda, which was estimated to be up to 800L per day to achieve a pH of 7.

The chemical dosing requirements will vary depending on the flow conditions. Jacobs (2021) used a range of different flow rates and acidity concentrations to reflect the range in conditions which may occur in a given year and estimate the dosing requirement:

- **Initial flush**: represents higher concentrations of acidity discharging from Big Swamp as flows return following summer low flow conditions or flow cessation.
- **Ongoing flush**: represents higher loads of acidity discharging from Big Swamp as flows continue to increase while concentrations remain moderately high.
- **Winter-Spring high flow**: represents higher flow rates in which concentrations of acidity decline through flushing and or dilution, though loads remain relatively high due to high flow rates.
- **Summer low flow**: represents lower flow rates during summer when concentrations of acidity tend to increase while flow rates decline.

The contingency measure is proposed to have a self-priming pump to provide feed water and to dose caustic soda at a rate of up to 800L day. Table 4.2 to show the expected seasonal dosing rates based on the typical flow conditions and different pH end points.

The caustic soda 40% storage will require a heating element to prevent freezing at temperature below 15 degrees Celsius. Consideration could be given to using caustic soda 25% to reduce the potential for freezing, however this will increase the required storage of chemical on site.

Table 4.2: Seasonal Summary Table of expected dosing rates of NaOH

Summer Low 0.42 ML/day		Initial Flush 0.06 ML/day		Ongoing Flush 5.3 ML/day		Winter-Spring High 18.87 ML/day	
pH	**L/day**	**pH**	**L/day**	**pH**	**L/day**	**pH**	**L/day**
3.7	0	3.3	0	3.3	0	3.5	0
4	7	4	15	4	284	4	0
4.5	11	4.5	19	4.5	332	4.5	0
5	17	5	24	5	382	5	0
5.5	62	5.5	29	5.5	502	5.5	138
6	**80**	**6**	**33**	**6**	**709**	**6**	**197**
6.5	84	6.5	34	6.5	771	6.5	276
7	87	7	35	7	814	7	390

4.2 Durability – Parameters for Design

It is assumed that a maximum operational period of the contingency measure to be 15 years, which align with the operational life of electrical and mechanical equipment.

4.3 Vegetation Disturbance

The design should minimize the impact on the vegetation during construction and operation.

4.4 Rehabilitation Potential

It is desirable that, the contingency measure can be removed in the future with minimal disturbance. Design features that facilitate this are to be considered essential.

4.5 Constructability

The contingency measure needs to be quick and simple for installation and commissioning with operational activities to be minimized for delivery of chemicals, fuel, and inspections. The works need to be easily removed to allow the site to be return to farming paddocks.

4.6 Security

The security of the equipment on site is proposed to be within a shipping container to reduce unauthorized access to the equipment. For generator and chemical storage tanks, further security fencing may be considered necessary to provide additional level of protection. The generator can be further purchased with a protective enclosure and or placed within a shipping container, depending on risk assessment of the site.

5. Control Philosophy

The scope of this document is to convey the design intent for the operation of the contingency measure for Big Swamp under both normal and abnormal operating conditions.

5.1 Process Description

The active treatment contingency measure is to provide for pH correction of surface flows entering Boundary creek from Big Swamp to avoid environmental impacts downstream of the site. The pH correction of surface flows is proposed to be by chemical dosing. The proposed control philosophy of the plant is outlined below. Appendix B provides further detail on the MAK Water system.

1) Operational Input of field results of surface volume and pH of Big Swamp surface flows. ML/d + pH level.
2) Determine total chemical treatment volume required to pH correct to minimum pH 5, maximum pH7. Refer to field test data tables 5.1.
3) Start plant feed pump to provide dosing flows for chemical treatment.
4) Adjust dosing pumps within plant to achieve required chemical treatment volume for the daily flows over 24-hour period.
5) Monitor surface flows and pH levels at downstream station at Colac – Forrest Road bridge.
6) Provide adjustment of chemical dosing in step 4, in response to field results at monitoring station at Colac-Forrest Road bridge. Allow for delays in response due to distance from chemical treatment site and location on monitoring station.

Continuous monitoring is required during chemical dosing operation. Adjustments are to respond to changes at downstream monitoring site.

6. Implementation

As shown in figure 6.1 the contingency measure is proposed to be on the Eastern end of Big Swamp within a cleared paddock to facilitate direct access to Boundary Creek and Big Swamp.

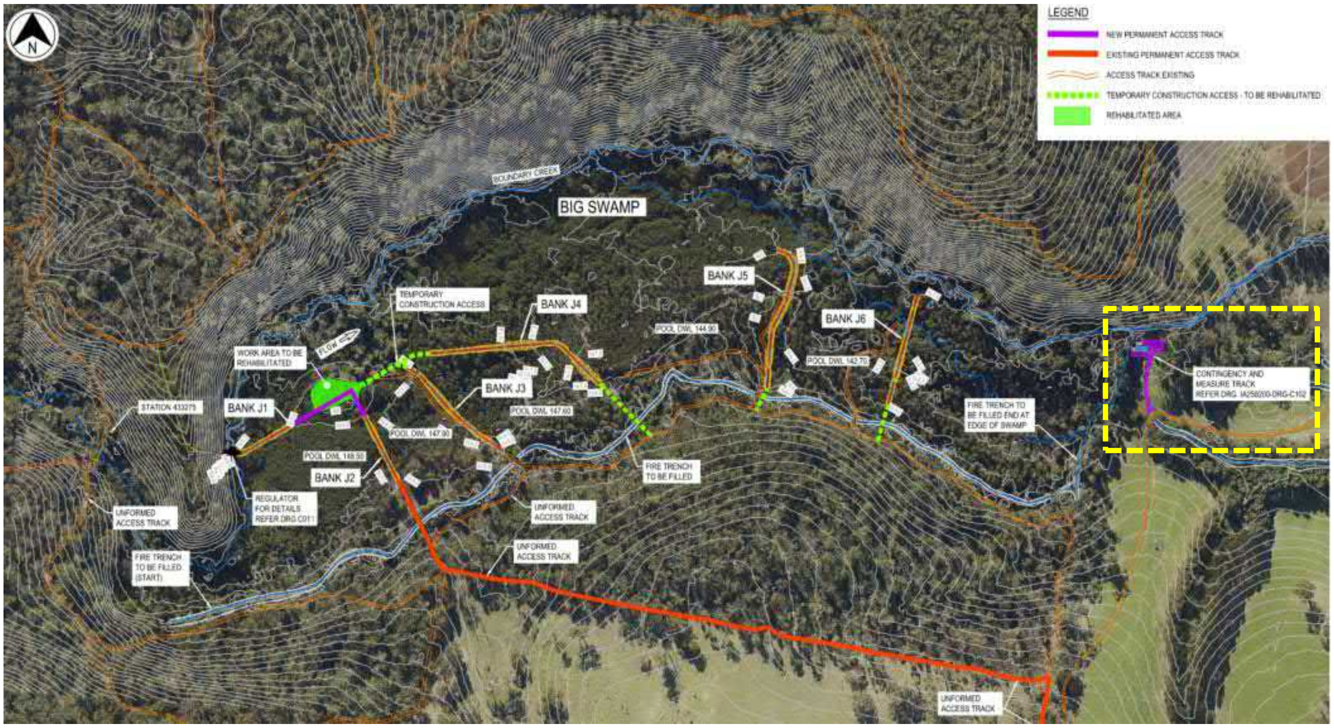


Figure 6.1: Annotated site plan of Big Swamp shown the location of the Contingency Measure area in yellow

In order to achieve a quick and simple construction process along with easy removal, a containerised package chemical treatment plan has been proposed with associated bunded chemical storage for caustic soda and diesel. This allows for factory fitout and testing with truck delivery to site and minimum works required before commissioning.

The components are proven available products that can be ordered and assembled on site for operation. Shown below in figure 6.2 is the proposed layout of the chemical dosing system, storage and bunding for chemical deliveries.

Figure 6.2: Contingency Measure Description

The contingency measure consists of the following main components:

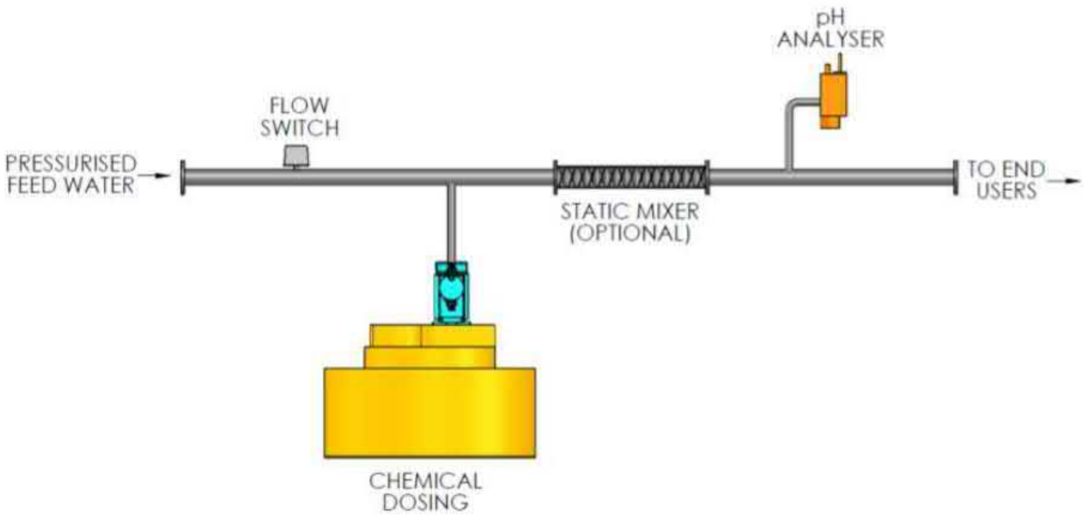
6.1 pH Adjustment – Flow (PAF) Plant

pH Adjustment – Flow (PAF) plants, as illustrated in Figure 6.3 are designed to automatically adjust and maintain the pH level of pressurised raw water, prior to discharge to the environment. The standard treatment process includes an inline pH analyser which monitors the pH level and a dosing pump to automatically dose liquid alkali. The system components are sized to suit the raw water flow rate and daily usage. Chemical storage tank(s) are provided with 110% bunding in compliance with AS1940-2004 (The storage and handling of flammable and combustible liquids). Optional equipment upgrades include a flow transmitter, a static mixer if required to improve mixing, duty standby dosing pumps, dual chemical dosing pumps (alkali). PAF plants are available as skid mounted or containerised systems for easy deployment to remote locations.

MAK Water is a manufacture of such plants and have provided a proposal which has been included in Appendix B. MAK Water is able to provide a turnkey solution to include chemical tank storage, diesel generator and telemetry. Barwon Water would be able to tailor the arrangement to meet Barwon Water preferences on the containerized plant. This would further be supported with installation, commissioning, and servicing support from MAK Water.

Further refinements and options such as containerising the diesel generator and fuel, upgrading telemetry to Barwon Water requirements and redundancy in equipment may be considered.

Figure 6.3: pH Adjustment – Flow (PAF) plant



6.2 Additional Site Considerations

In addition to the chemical dosing plant, additional site works are required for the operation of the facility. This includes:

- Bunding for Chemical Delivery – The truck delivery of caustic soda requires chemical bunding to prevent accidental chemical spills. Given the nature of the works a portable chemical bund is proposed for the facility. Appendix C provides supplier information of portable spill bunds that can be made to size the site. The chemical storage tanks may be considered to be placed within a secondary bund.

- Chemical Safety Shower – The delivery and handling of chemical at the site requires a chemical safety shower. The ET1400 has been designed to provide remote workers with an easily deployed permanent or semi-permanent emergency safety shower in locations where suitable infrastructure such as power and water is not available. The ET1400 is a robust, reliable, and highly visible first response emergency shower and eye wash station. Further information on the ET1400 safety shower is in Appendix C.

- Silt Curtain – The use of caustic soda to correct the low pH in the flows leaving Big Swamp is expected to generate sediment through the chemical reaction. In order to manage the sediment, it is proposed to install a silt curtain on the Boundary Creek, downstream of the treatment process. This is expected to concentrate the sediment for collection using a vacuum truck. The proposed location is shown in figure 6.2. The silt curtain would likely be anchored either side of the Boundary Creek with star pickets and hung into the water to filter flows by a cable within the silt curtain. Weights in the bottom on the silt curtain shall weigh down the curtain to prevent flows passing under. Appendix C provides supplier information.

- Site Access - Access to the location is proposed to be improve with a gravel road and turning area for the delivery of chemical and fuels. The alignment of the roads is shown in appendix A. The road is proposed to be removed at a future point when the chemical treatment plant is no longer required, in agreement with the landowner.

7. Summary

The implementation of a chemical dosing system is expected to provide a suitable contingency measure to mitigate the risk of low pH water entering Boundary Creek, downstream of the Big Swamp, should it be required. The use of readily available off the shelf systems is expected to save time and cost with the implementation, compared to a bespoke system. The proposed arrangement allows for removal and remediation of the site when the contingency measure is no longer required.

The use of caustic soda provides for an alkali agent that can correct low pH. However, it does have residual risk with overdosing into the water, which can be managed with existing pH sensors and appropriate chemical dosing, commissioning, and operational supervision. While other chemicals could be used, consideration was given to chemicals that are already used by Barwon Water and have staff familiar and trained in the chemical use.

The location of the contingency measure on the Eastern end of the Big Swamp provides opportunity to treat all flows coming from Big Swamp, prior to entering Boundary Creek.

8. References

CDM Smith, 2019 Boundary Creek and Big Swamp Remediation Options Assessment

GHD, 2019 A basic conceptual geochemical model of Big Swamp

GHD, 2021 Revised groundwater-surface water model of Boundary Creek and Big Swamp by GHD

Jacobs, 2018 Technical Works Program: Yeodene Swamp Study 2016 - 2017

Jacobs, 2019a A comprehensive soil sampling program aimed at refining the soil geochemistry in the swamp

Jacobs, 2019b Preliminary groundwater-surface water model of Boundary Creek and Big Swamp to assess the viability of maintaining inundation in the swamp as a remediation strategy

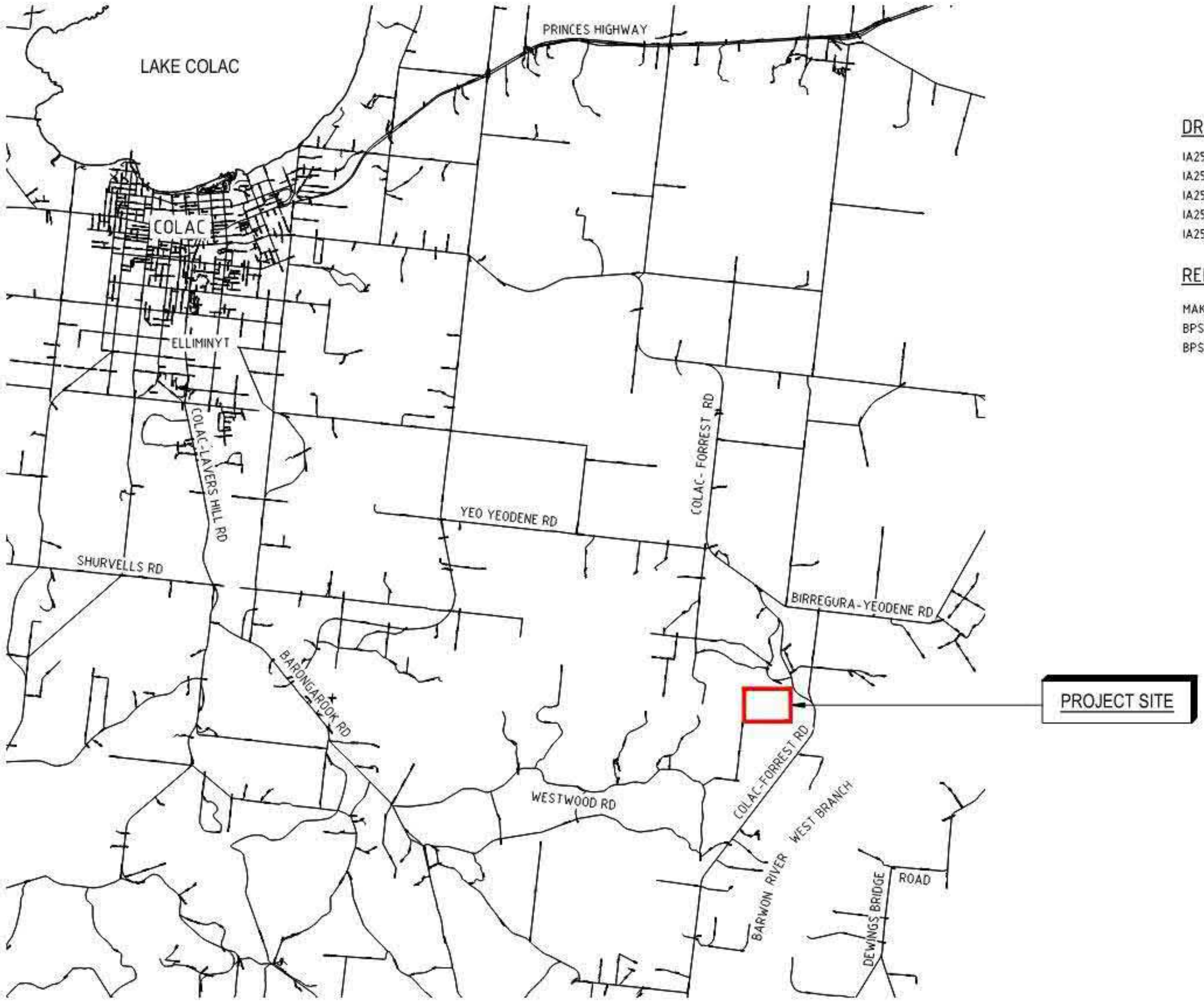
Jacobs, 2021a Hydrogeochemical model of Big Swamp and Boundary Creek

Jacobs, 2021b Detailed design of hydraulic barriers in Big Swamp

Monash University, 2019 Soil incubation tests which simulated the soils geochemical response to inundation

Appendix A. Design Drawings

BIG SWAMP CONTINGENCY MEASURES



LOCALITY PLAN
SCALE 1:50000

DRAWING LIST

IA258200-DRG-C100	CONTINGENCY MEASURE - COVER SHEET - LOCALITY PLAN AND DRAWING LIST
IA258200-DRG-G100	CONTINGENCY MEASURE - GENERAL NOTES
IA258200-DRG-C101	CONTINGENCY MEASURE - SITE PLAN
IA258200-DRG-C102	CONTINGENCY MEASURE - CHEMICAL DOSING SYSTEM - SITE PLAN
IA258200-DRG-C103	CONTINGENCY MEASURE - CHEMICAL DOSING SYSTEM - DETAILS

REFERENCE DRAWINGS

MAK5758D-VA-001	MAK WATER - CONTAINERISED CHEMICAL DOSING TREATMENT PLANT
BPST3300-DWG-POLYMASTER-01	POLYMASTER CHEMICAL STORAGE TANK - GENERAL ARRANGEMENT
BPST3300-DWG-POLYMASTER-02	POLYMASTER CHEMICAL STORAGE TANK - SECTION VIEW

NOT FOR CONSTRUCTION

SCALE 1:50000 (A1) 1000 0 1000 2000 3000 4000 5000m

REFERENCES

DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW	JVP		TF		09/07/21
B	ISSUED FOR APPROVAL	CF		TF		22/07/21

JACOBS
11th Floor, 452 Flinders Street MELBOURNE, VIC 3000 AUSTRALIA
Tel: +61 3 8668 3000 Fax: +61 3 8668 3001 Web: www.jacobs.com

PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

Barwon Water
61-67 RYRIE STREET, GEELONG, VICTORIA 3220
Tel. 1300 656 007 Fax. (03) 5226 2556 www.barwonwater.vic.gov.au

DRG No. IA258200-DRG-C100 DRAWING DISCIPLINE: C SHEET NO. 1 of 1

CONTINGNECY MEASURE
COVER SHEET
LOCALITY PLAN AND DRAWIGN LIST

REVISION B | F.C. | FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	T.FEHRING			PLAN 50 000 SECTION HORIZ. VERT. Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

Plot Date: 22 July 2021 - 8:27 AM Plotted by: Florence, Cris Cad File No: C:\users\florence\appdata\local\projectwise\jacobs_anz_ied0489000\IA258200-DRG-C100.dwg

Note: * indicates signatures on original issue or last revision of drawing

GENERAL:

G1. UNLESS NOTED OTHERWISE ALL DIMENSIONS ARE IN MILLIMETRES. ALL RUNNING DISTANCES ARE IN METRES AND ALL LEVELS ARE TO A.H.D. ALL CO-ORDINATES ARE TO MGA ZONE 54.

G2. ALL PROPRIETARY PRODUCTS SHALL BE INSTALLED STRICTLY IN ACCORDANCE WITH MANUFACTURERS RECOMMENDATIONS.

G3. THE DISTURBANCE OF ACID SULFATE SOILS AND POTENTIALLY ACID SULFATE SOILS SHALL BE MINIMISED. SOILS ARE TO REMAIN INSITU WHEREVER POSSIBLE. CONSTRUCTION TRAFFIC SHALL BE ON APPROVED PATHWAYS TREATED TO PREVENT DISTURBANCE OF THE UNDERLYING SOIL.

G4. CONTRACTOR SHALL NOT REMOVE ANY EXISTING FENCING WITHOUT APPROVAL OF THE CONTRACT ADMINISTRATOR.

G5. CONTRACTOR SHALL KEEP ALL GATES CLOSED OR OPEN AS FOUND ON THE DAY OF WORK.

G6. ALL LOCKED GATES SHALL BE ACCESSED BY THE CONTRACTOR USING APPROVED BARWON WATER PADLOCKS ONLY AND THESE SHALL AT NO TIME REPLACE THE LANDOWNERS LOCKS BUT BE USED "IN SERIES" WITH THESE.

G7. THE CONTRACTOR SHALL ONLY ACCESS PRIVATE LAND USING AGREED AND APPROVED VEHICLE TRACKS AND SHALL NOT MAKE NEW TRACKS WITHOUT THE APPROVAL OF THE CONTRACT ADMINISTRATOR.

G8. THE CONTRACTOR SHALL CONFINE ALL CONSTRUCTION ACTIVITIES TO WITHIN THE CONSTRUCTION CORRIDOR DEFINED BY BARWON WATER. THIS SHALL NOT BE VARIED WITHOUT THE PERMISSION OF THE CONTRACT ADMINISTRATOR.

G9. FOR GEOTECHNICAL CONDITIONS REFER TO THE GEOTECHNICAL FACTUAL REPORTS. GEOTECHNICAL INVESTIGATION LOCATIONS ARE SHOWN ON THE PLANS.

G10. CONTRACTOR SHALL MANAGE WORKS IN ACCORDANCE WITH VICTORIAN ENVIRONMENTAL PROTECTION AUTHORITY (EPA) PUBLICATION 655.1 JULY 2009 FOR ACID SULFATE SOIL AND ROCK.

B

SURVEY AND SET OUT

SV1. THE CONTRACTOR SHALL CONDUCT A FEATURE SURVEY ALONG ALL ALIGNMENTS AND WITHIN 3 M OF ANY PROPOSED CONSTRUCTION; AND ESTABLISH TEMPORARY BENCH MARKS.

SV2. THE CONSTRUCTION CORRIDOR SHALL BE CONFIRMED AND MARKED ON THE FIELD PRIOR TO COMMENCING CONSTRUCTION

SV3. SETTING OUT DIMENSIONS AND ALIGNMENTS SHALL BE CONFIRMED ON THE GROUND BEFORE CONSTRUCTION COMMENCES

SV3. THE CONTRACTOR IS RESPONSIBLE FOR ENSURING THE PROJECT SET OUT AND ANY REVISED ALIGNMENTS ARE CONSISTENT WITH THE DESIGN. SHOULD ACTUAL SITE CONDITIONS CONFLICT WITH THAT DOCUMENTED, THE CONTRACTOR SHALL CONTACT THE SUPERINTENDENT FOR CLARIFICATION BEFORE PROCEEDING.

SV4. CONTRACTOR SHALL PREPARE AS CONSTRUCTED DRAWINGS OF ALL WORKS.

SITE PREPARATION:

SP1. THE CONTRACTOR SHALL NOT UNDERTAKE ANY CLEARING WORK OR ANY TYPE OF DISTURBANCE OUTSIDE THE SPECIFIED LIMITS OF WORK UNLESS APPROVED BY THE SUPERINTENDENT.

SP2. PRIOR TO COMMENCEMENT OF ANY WORK, THE CONTRACTOR AND THE SUPERINTENDENT SHALL CONDUCT A JOINT INSPECTION OF THE SITE TO IDENTIFY AREAS TO BE CLEARED AND VEGETATION TO BE RETAINED AND PROTECTED.

ENVIRONMENTAL MANAGEMENT PLAN:

EMP1. THE CONTRACTOR SHALL CARRY OUT ALL WORKS IN ACCORDANCE WITH THE ENVIRONMENT MANAGEMENT PLAN.

ABBREVIATIONS:

ASS	ACID SULFATE SOIL
PASS	POTENTIAL ACID SULFATE SOIL
DWL	DESIGN WATER LEVEL
NSL	NATURAL SURFACE LEVEL

STAINLESS STEEL:

SS1. STAINLESS STEEL STRUCTURAL COMPONENTS TO BE GRADE 316L.

SS2. STAINLESS STEEL BOLTS AND ANCHORS SHALL BE GRADE 316. NUTS AND WASHERS SHALL BEALL

SS3. STAINLESS STEEL MATING SURFACES AND THREADS SHALL BE COATED WITH 'LOCTITE 567' PRIOR TO ASSEMBLY. GRADE 304 UNLESS STATED OTHERWISE.

NOT FOR CONSTRUCTION

REFERENCES

DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW	JVP		TF		09/07/21
B	ISSUED FOR APPROVAL	CF		TF		22/07/21

JACOBS
11th Floor, 452 Flinders Street, MELBOURNE, VIC 3000, AUSTRALIA
Tel: +61 3 8668 3000 Fax: +61 3 8668 3001 Web: www.jacobs.com

PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

Barwon Water
61-67 RYRIE STREET, GEELONG, VICTORIA 3220
Tel. 1300 656 007 Fax. (03) 5226 2556 www.barwonwater.vic.gov.au

DRG No. IA258200-DRG-G100 DRAWING DISCIPLINE: G SHEET NO. 1 of 1

CONTINGNECY MEASURE
GENERAL NOTES

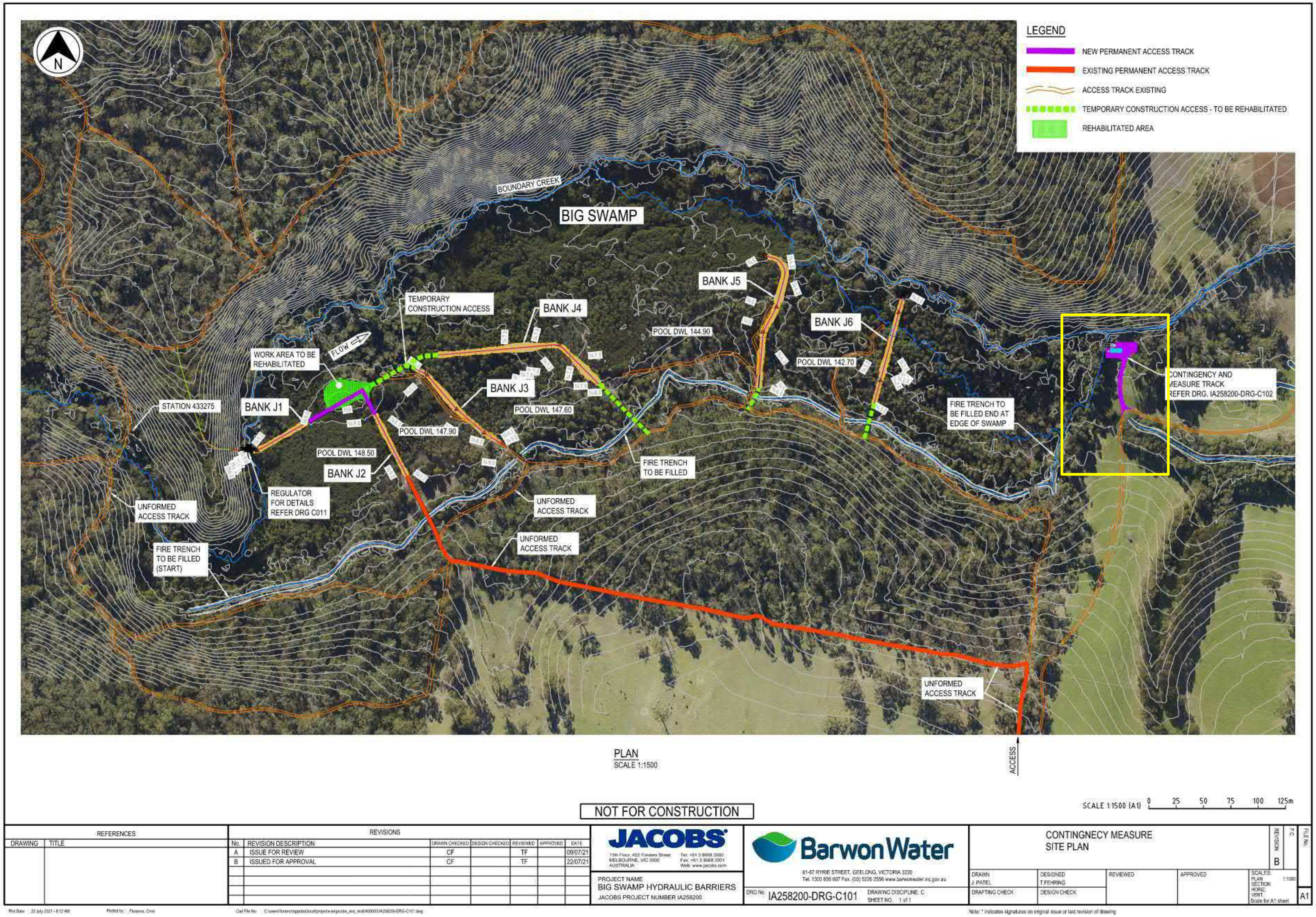
REVISION B F.C. FILE No.

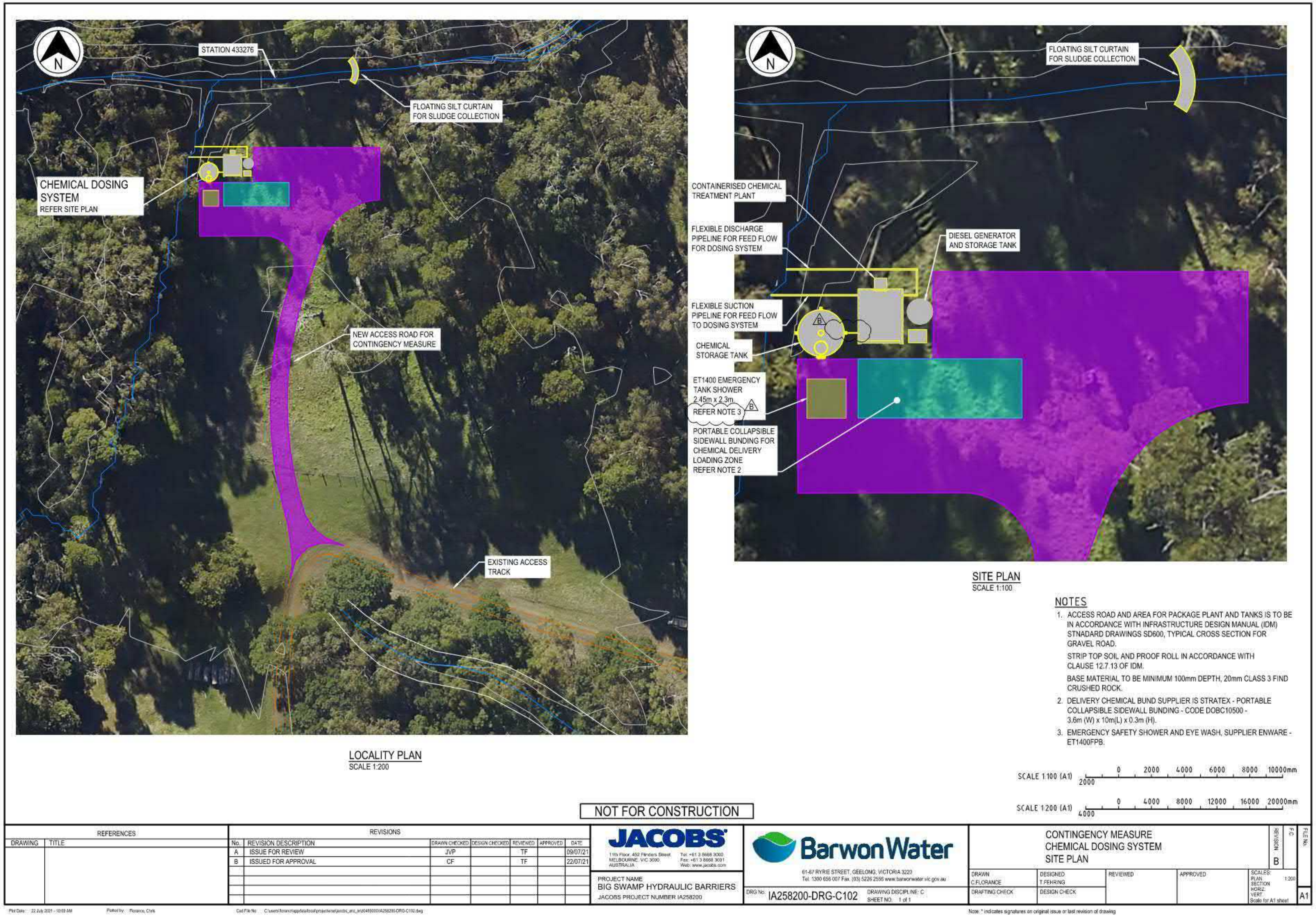
DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
C.FLORANCE	T.FEHRING			PLAN N/A SECTION HORIZ. VERT. Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			

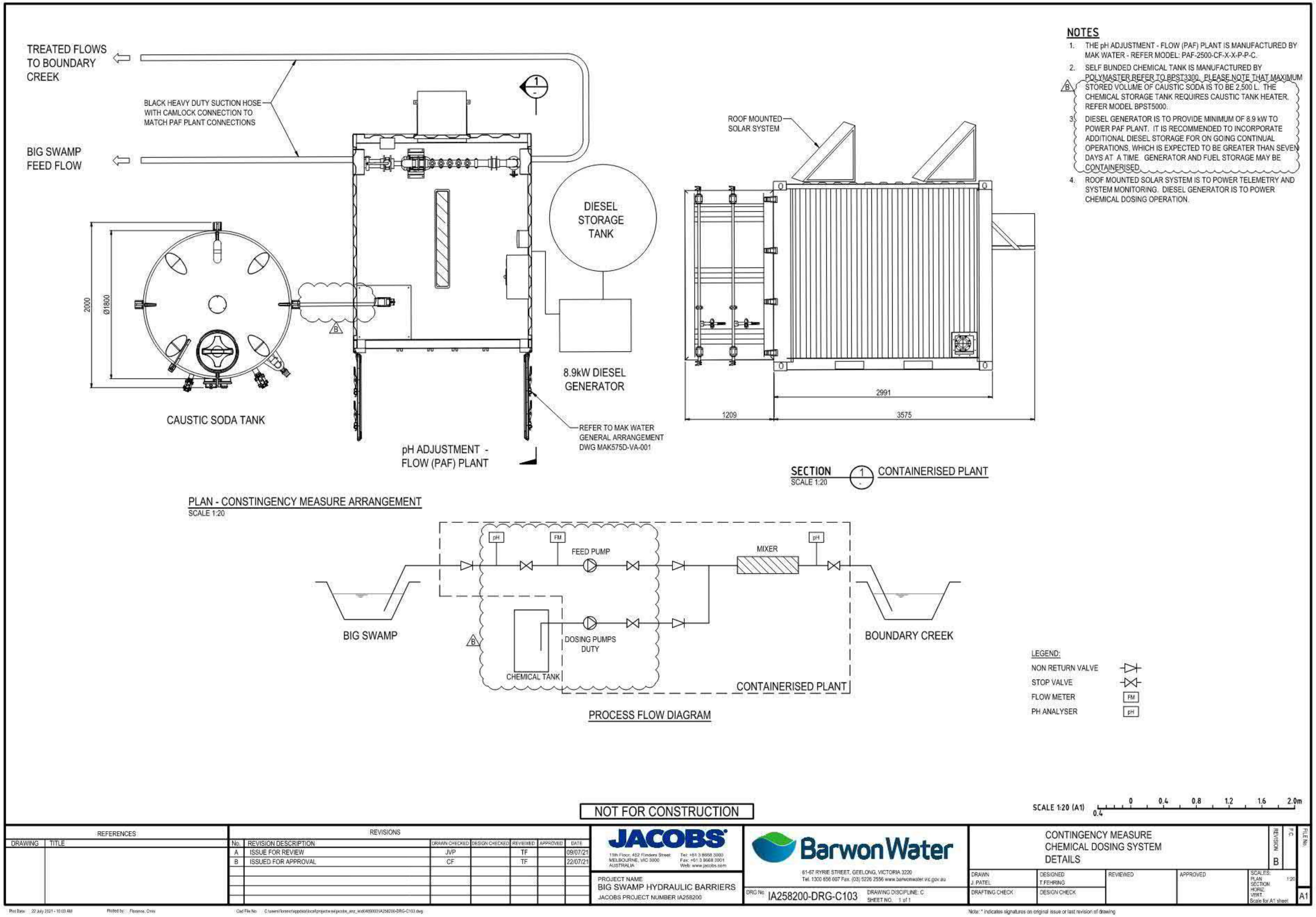
A1

Plot Date: 22 July 2021 - 8:24 AM Plotted by: Florance, Chris Cad File No: C:\users\florancc\appdata\local\projectwise\jacobs_anz_ind\d0469000\IA258200-DRG-G100.dwg

Note: * Indicates signatures on original issue or last revision of drawing


LEGEND
NEW PERMANENT ACCESS TRACK
EXISTING PERMANENT ACCESS TRACK
ACCESS TRACK EXISTING
TEMPORARY CONSTRUCTION ACCESS - TO BE REHABILITATED
REHABILITATED AREA
N
BOUNDARY CREEK
BIG SWAMP
BANK J1
BANK J2
BANK J3
BANK J4
BANK J5
BANK J6
TEMPORARY CONSTRUCTION ACCESS
WORK AREA TO BE REHABILITATED
FLOW
STATION 433275
POOL DWL 148.50
POOL DWL 147.90
POOL DWL 147.60
POOL DWL 144.90
POOL DWL 142.70
REGULATOR FOR DETAILS REFER DRG C011
UNFORMED ACCESS TRACK
FIRE TRENCH TO BE FILLED (START)
FIRE TRENCH TO BE FILLED
FIRE TRENCH TO BE FILLED END AT EDGE OF SWAMP
CONTINGENCY AND MEASURE TRACK REFER DRG. IA258200-DRG-C102
ACCESS
PLAN
SCALE 1:1500
SCALE 1:1500 (A1) 0 25 50 75 100 125m
NOT FOR CONSTRUCTION
REFERENCES
DRAWING
TITLE
REVISIONS
No. REVISION DESCRIPTION
A ISSUE FOR REVIEW CF TF 09/07/21
B ISSUED FOR APPROVAL CF TF 22/07/21
JACOBS
PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200
Barwon Water
CONTINGNECY MEASURE
SITE PLAN
DRAWN J. PATEL
DESIGNED T.FEHRING
REVIEWED
APPROVED
DRAFTING CHECK
DESIGN CHECK
DRG No IA258200-DRG-C101
REVISION B
A1

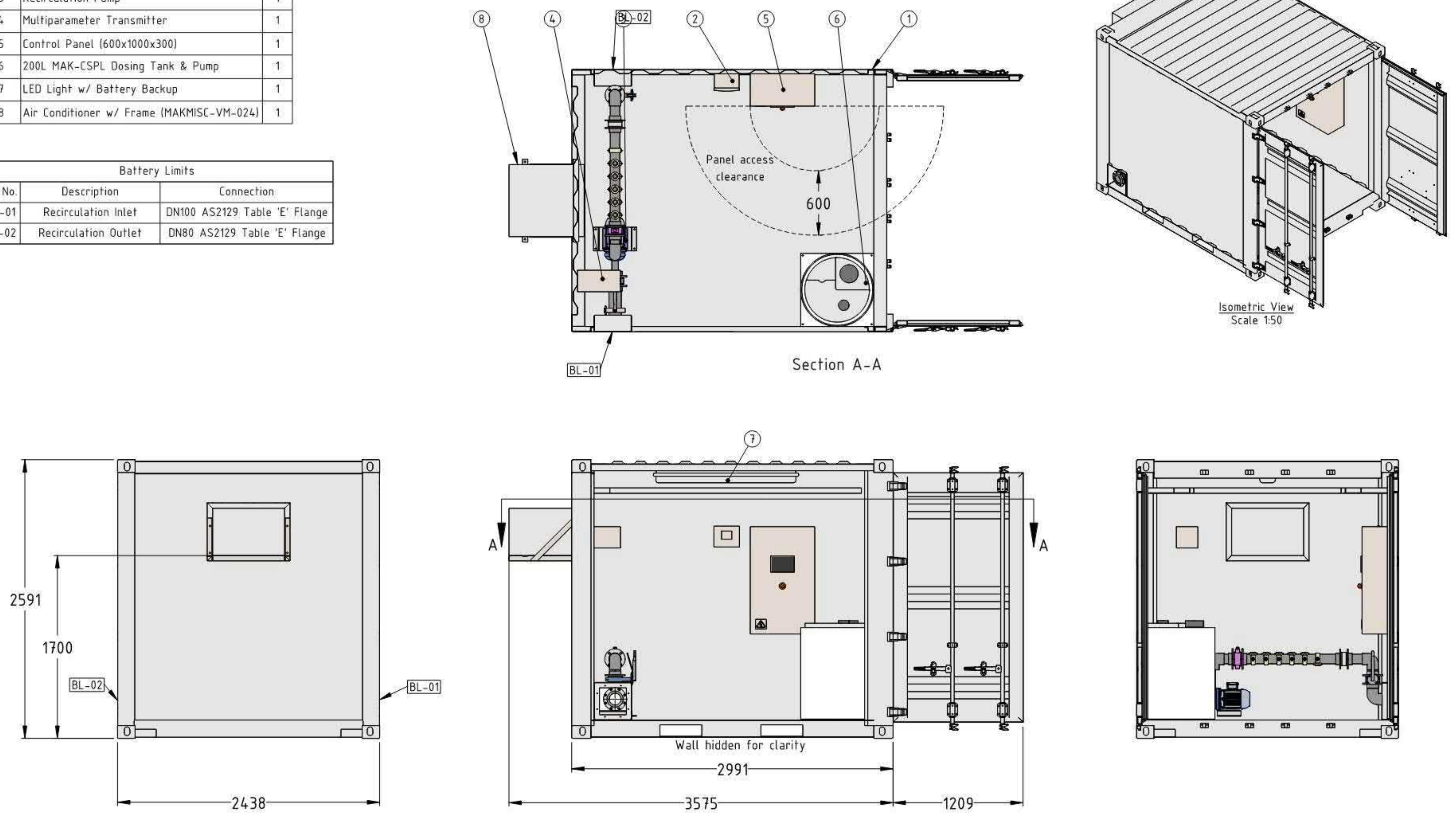

STATION 433276
FLOATING SILT CURTAIN FOR SLUDGE COLLECTION
CHEMICAL DOSING SYSTEM
REFER SITE PLAN
NEW ACCESS ROAD FOR CONTINGENCY MEASURE
EXISTING ACCESS TRACK
LOCALITY PLAN
SCALE 1:200
FLOATING SILT CURTAIN FOR SLUDGE COLLECTION
CONTAINERISED CHEMICAL TREATMENT PLANT
FLEXIBLE DISCHARGE PIPELINE FOR FEED FLOW FOR DOSING SYSTEM
DIESEL GENERATOR AND STORAGE TANK
FLEXIBLE SUCTION PIPELINE FOR FEED FLOW TO DOSING SYSTEM
CHEMICAL STORAGE TANK
ET1400 EMERGENCY TANK SHOWER 2.45m x 2.3m REFER NOTE 3
PORTABLE COLLAPSIBLE SIDEWALL BUNDING FOR CHEMICAL DELIVERY LOADING ZONE REFER NOTE 2
SITE PLAN
SCALE 1:100
NOTES
1. ACCESS ROAD AND AREA FOR PACKAGE PLANT AND TANKS IS TO BE IN ACCORDANCE WITH INFRASTRUCTURE DESIGN MANUAL (IDM) STNADARD DRAWINGS SD600, TYPICAL CROSS SECTION FOR GRAVEL ROAD.
STRIP TOP SOIL AND PROOF ROLL IN ACCORDANCE WITH CLAUSE 12.7.13 OF IDM.
BASE MATERIAL TO BE MINIMUM 100mm DEPTH, 20mm CLASS 3 FIND CRUSHED ROCK.
2. DELIVERY CHEMICAL BUND SUPPLIER IS STRATEX - PORTABLE COLLAPSIBLE SIDEWALL BUNDING - CODE DOBC10500 - 3.6m (W) x 10m(L) x 0.3m (H).
3. EMERGENCY SAFETY SHOWER AND EYE WASH, SUPPLIER ENWARE - ET1400FPB.
SCALE 1:100 (A1) 2000 0 2000 4000 6000 8000 10000mm
SCALE 1:200 (A1) 4000 0 4000 8000 12000 16000 20000mm
NOT FOR CONSTRUCTION
REFERENCES
DRAWING TITLE
REVISIONS
No. REVISION DESCRIPTION DRAWN CHECKED DESIGN CHECKED REVIEWED APPROVED DATE
A ISSUE FOR REVIEW JVP TF 09/07/21
B ISSUED FOR APPROVAL CF TF 22/07/21
JACOBS
11th Floor, 452 Flinders Street MELBOURNE, VIC 3000 AUSTRALIA
Tel: +61 3 8668 3000 Fax: +61 3 8668 3001 Web: www.jacobs.com
PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200
Barwon Water
61-67 RYRIE STREET, GEELONG, VICTORIA 3220
Tel: 1300 656 007 Fax: (03) 5226 2556 www.barwonwater.vic.gov.au
DRG No. IA258200-DRG-C102
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1
CONTINGENCY MEASURE
CHEMICAL DOSING SYSTEM
SITE PLAN
REVISION B
F.C.
FILE No.
DRAWN C.FLORANCE
DESIGNED T.FEHRING
REVIEWED
APPROVED
DRAFTING CHECK
DESIGN CHECK
SCALES: PLAN 1:200 SECTION HORIZ. VERT. Scale for A1 sheet
A1
Plot Date: 22 July 2021 - 10:09 AM
Plotted by: Florance, Chris
Note: * indicates signatures on original issue or last revision of drawing


TREATED FLOWS TO BOUNDARY CREEK
BLACK HEAVY DUTY SUCTION HOSE WITH CAMLOCK CONNECTION TO MATCH PAF PLANT CONNECTIONS
BIG SWAMP FEED FLOW
DIESEL STORAGE TANK
8.9kW DIESEL GENERATOR
CAUSTIC SODA TANK
pH ADJUSTMENT - FLOW (PAF) PLANT
REFER TO MAK WATER GENERAL ARRANGEMENT DWG MAK575D-VA-001
2000
Ø1800
PLAN - CONSTINGENCY MEASURE ARRANGEMENT
SCALE 1:20
ROOF MOUNTED SOLAR SYSTEM
2991
1209
3575
SECTION 1 CONTAINERISED PLANT
SCALE 1:20
NOTES
1. THE pH ADJUSTMENT - FLOW (PAF) PLANT IS MANUFACTURED BY MAK WATER - REFER MODEL: PAF-2500-CF-X-X-P-P-C.
2. SELF BUNDED CHEMICAL TANK IS MANUFACTURED BY POLYMASTER REFER TO BPST3300. PLEASE NOTE THAT MAXIMUM STORED VOLUME OF CAUSTIC SODA IS TO BE 2,500 L. THE CHEMICAL STORAGE TANK REQUIRES CAUSTIC TANK HEATER, REFER MODEL BPST5000.
3. DIESEL GENERATOR IS TO PROVIDE MINIMUM OF 8.9 kW TO POWER PAF PLANT. IT IS RECOMMENDED TO INCORPORATE ADDITIONAL DIESEL STORAGE FOR ON GOING CONTINUAL OPERATIONS, WHICH IS EXPECTED TO BE GREATER THAN SEVEN DAYS AT A TIME. GENERATOR AND FUEL STORAGE MAY BE CONTAINERISED.
4. ROOF MOUNTED SOLAR SYSTEM IS TO POWER TELEMETRY AND SYSTEM MONITORING. DIESEL GENERATOR IS TO POWER CHEMICAL DOSING OPERATION.
pH
FM
FEED PUMP
MIXER
BIG SWAMP
DOSING PUMPS DUTY
CHEMICAL TANK
BOUNDARY CREEK
CONTAINERISED PLANT
PROCESS FLOW DIAGRAM
LEGEND:
NON RETURN VALVE
STOP VALVE
FLOW METER
PH ANALYSER
NOT FOR CONSTRUCTION
SCALE 1:20 (A1)
REFERENCES
DRAWING
TITLE
REVISIONS
No.
REVISION DESCRIPTION
A
ISSUE FOR REVIEW
JVP
TF
09/07/21
B
ISSUED FOR APPROVAL
CF
TF
22/07/21
JACOBS
PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200
Barwon Water
81-87 RYRIE STREET, GEELONG, VICTORIA 3220
CONTINGENCY MEASURE CHEMICAL DOSING SYSTEM DETAILS
DRAWN J. PATEL
DESIGNED T.FEHRING
REVIEWED
APPROVED
DRAFTING CHECK
DESIGN CHECK
DRG No. IA258200-DRG-C103
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1
REVISION B
A1

Item No.	Description	Qty.
1	10 GP Shipping Container	1
2	Distribution Board	1
3	Recirculation Pump	1
4	Multiparameter Transmitter	1
5	Control Panel (600x1000x300)	1
6	200L MAK-CSPL Dosing Tank & Pump	1
7	LED Light w/ Battery Backup	1
8	Air Conditioner w/ Frame (MAKMISC-VM-024)	1

Mass Loading Table	
Dry Loading (kN)	Operating Loading (kN)
30	40

Battery Limits		
BL No.	Description	Connection
BL-01	Recirculation Inlet	DN100 AS2129 Table 'E' Flange
BL-02	Recirculation Outlet	DN80 AS2129 Table 'E' Flange



PO Box 2625 Malaga WA 6944
Telephone: +61 8 9249 8007
Email: info@makwater.com.au
Web: www.makwater.com.au

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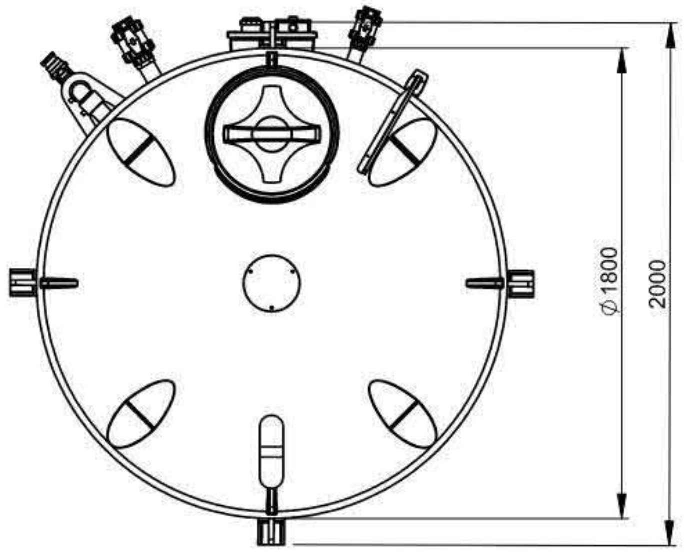
MAK Water
10' Containerised Chemical Dosing Treatment Plant
GA Drawing

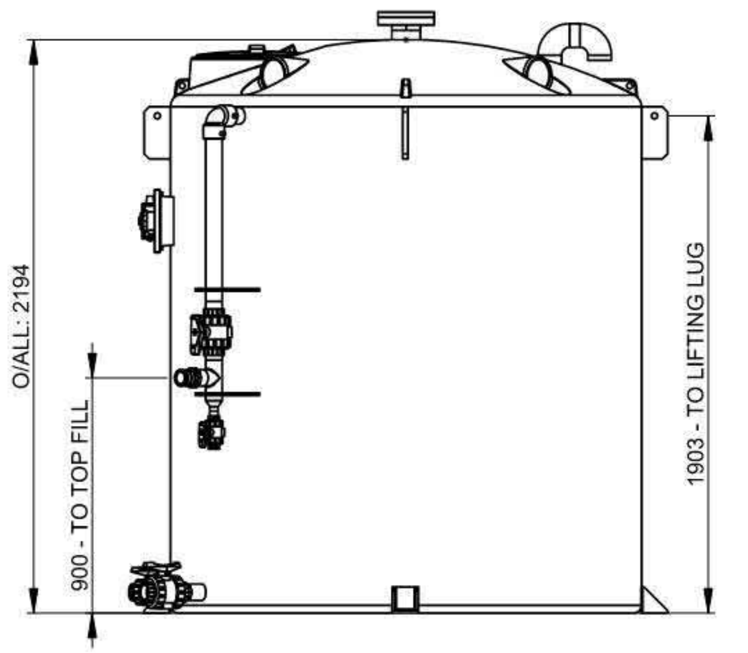
A	12/01/2021	Issued for Information	-	RG	MS	PF
Rev	Date	Description	Notes	DRN	CHK	APP

Reference Drawing No.	Reference Drawing Title

All dimensions in mm | Scale: 1:35 | Sheet 1 of 1
Commercial in Confidence | Paper Size: A3
Client Document No.: -
MAK Document No.: MAK5000-VA-001 | Rev: A

ITEM NO.	Product Code	DESCRIPTION	QTY.
1	BPST3300L	External Tank	1
2	BPST3300L	Internal Tank	1
3	SL8-NV	Screw Lid Assembly 455mm - No Vent	1
4	TFA-50V	Top Fill Assembly	1
5	S-MTA63X50-600-OV	50mm Tank Outlet c/w 2 Inch PVC-U Ball Valve	1
6	S-MTA50X40-BDV	40mm Bund Drain c/w 1.5 Inch PVC-U Ball Valve	1
7	SCV90	Sheperds Crook Vent 90PE	1
8	LQ01	Liquidator - Mechanical Level Indicator	1
9	S-LS110-300	Level Transmitter Mount	1
10	NPP-F	Name Plate Panel	1
11	S-GIZOFA-300	High Level Alarm - Gizmo (Battery)	1
12	S-BA-I	Bund Alarm - (Battery)	1
13	LLUG	Lifting Lug HDPE	4
14	BDL100	Bolt Down Lug 100mm	4





BPST3300-DWG-POLYMASTERS-01

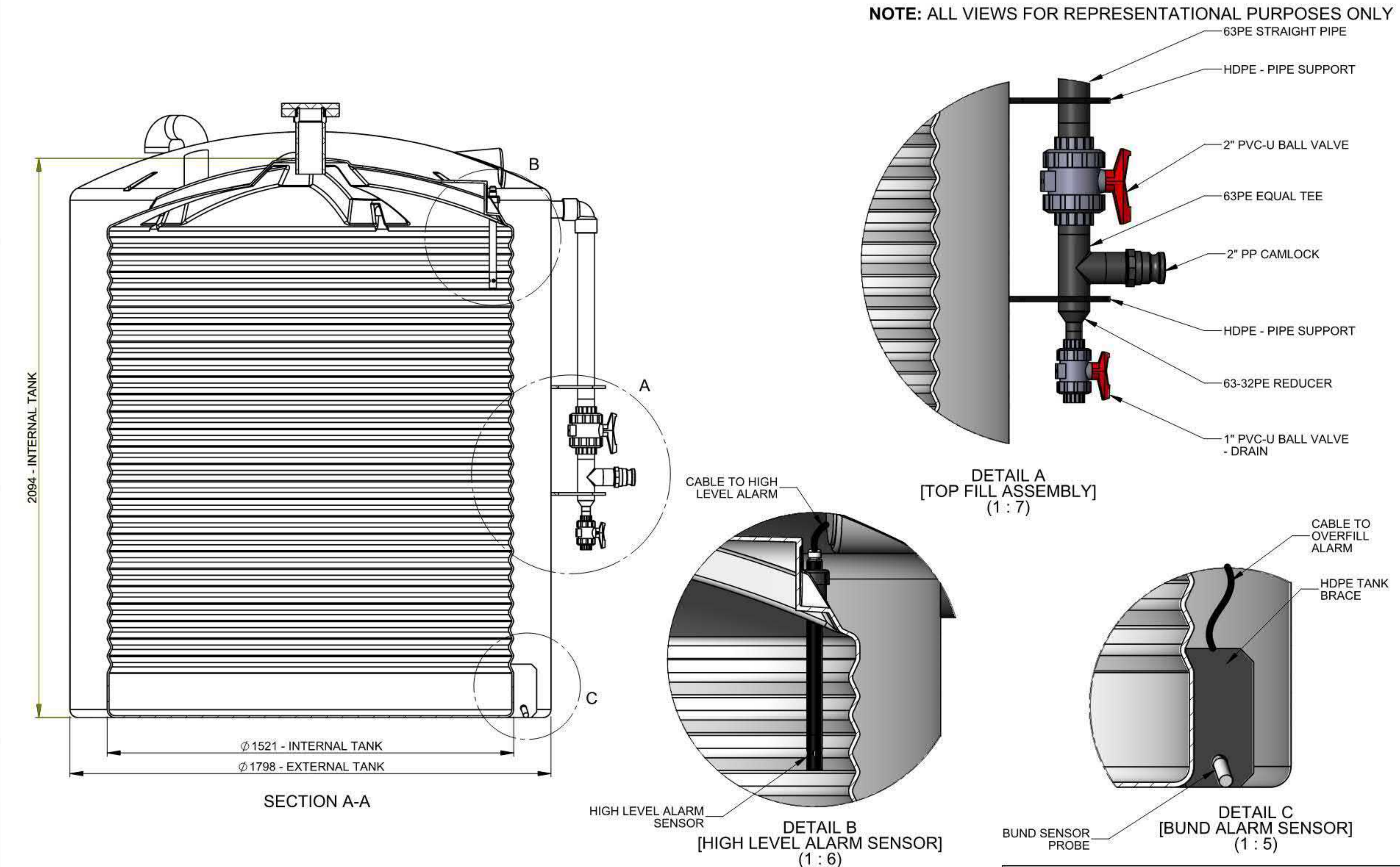
NOTE: ALL TOLERANCES UNLESS OTHERWISE STATED ±10mm / ±1°
DO NOT SCALE, USE DIMENSIONS. ALL DIMENSIONS ARE IN mm

Polymaster

161 KARINIE STREET
SWAN HILL. VIC.
3585
Ph: (03) 5033 9000
Fx: (03) 5033 0224

DESCRIPTION	3,300L Self Bunded Tank	A3 SHEET SIZE	SCALE: NTS
PRODUCT CODE	BPST3300		
MATERIAL	OPTIONAL		
COLOUR	LIGHT GREY		

 DRAWN JT 21-Jun-18 1/2 Rev: B



BPST3300-DWG-POLYMASTERS-02

NOTE: ALL TOLERANCES UNLESS OTHERWISE STATED ±10mm / ±1°
DO NOT SCALE, USE DIMENSIONS. ALL DIMENSIONS ARE IN mm

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Polymaster

161 KARINIE STREET
SWAN HILL. VIC.
3585
Ph: (03) 5033 9000
Fx: (03) 5033 0224

DESCRIPTION	3,300L Self Bunded Tank	A3 SHEET SIZE	SCALE: NTS
PRODUCT CODE	BPST3300		
MATERIAL	OPTIONAL		
COLOUR	LIGHT GREY		
© POLYMASTER GROUP	DRAWN	JT	21-Jun-18 · 2/2 · Rev: B

Appendix B. MAK Water Proposal

PRODUCT DATA SHEET

pH Adjustment - Flow (PAF)

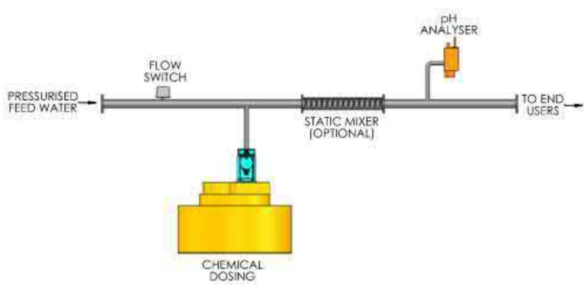
water | wastewater | sewage

mak water

OVERVIEW

MAK Water's pH Adjustment - Flow (PAF) plants are designed to automatically adjust and maintain the pH level of pressurised raw water prior to discharge to sewer/environment or reuse/recycling. The standard treatment process includes an inline pH analyser which monitors the pH level and a dosing pump to automatically dose liquid alkali/acid. Dual chemical dosing pumps (alkali/acid) are available for when the raw water pH varies to allow for correction of both low and high pH raw water.

The system components are sized to suit the raw water flow rate and daily usage. Optional equipment upgrades include; a flow transmitter, a static mixer if required to improve mixing, duty standby dosing pumps, dual chemical dosing pumps (alkali/acid). MAK PAF plants are available as skid mounted or containerised systems for easy deployment to remote locations.



STANDARD SPECIFICATIONS

Parameter	Units	PAF-60	PAF-100	PAF-200	PAF-500	PAF-1000	PAF-2500	PAF-5000
Chemical Storage Tank Size	L	60	100	200	500	1,000	2,500	5,000
pH Level (target)	pH	6 ~ 8 (pH neutral) or as required						
Raw Water Temperature	°C	15 ~ 35						
Ambient Design Temperature	°C	5 ~ 45 (-5 ~ 50 for insulated containerised system)						
Raw Water Flow Rate (max)	m³/hr	1,000 (higher flow available on request)						
Raw Water Pressure (max)	kPa	600 (higher pressure available on request)						
Power Supply	-	AC 240V, 1 phase, 50Hz						
Power Consumption (approx.)	kW	0.5						
Container Size (optional)	ft	10	10	10	10	10	20	20
Slid Size	mm	1,300 x 600 x 1,500				2,000 x 1,500 x 1,500		

makwater.com.au 1300 669 032 Clearmake a mak water company

STANDARD INCLUSIONS + OPTIONS

✓ = Standard Supply o = Optional Supply - = Not Applicable

Equipment	PAF-60	PAF-100	PAF-200	PAF-500	PAF-1000	PAF-2500	PAF-5000
Skid Mounted Plant	✓	✓	✓	✓	✓	✓	✓
Chemical Dosing Pump	✓	✓	✓	✓	✓	✓	✓
Bunded Chemical Storage Tank	✓	✓	✓	✓	✓	✓	✓
pH Analyser	✓	✓	✓	✓	✓	✓	✓
Control System with Local Indicator (standard)	✓	✓	✓	✓	✓	✓	✓
Containerised System c/w A/C & Lights	o	o	o	o	o	o	o
Container Non-slip Floor Coating	-	-	-	-	-	o	o
Container Insulation (walls & ceiling)	o	o	o	o	o	o	o
Container Side Access Door	-	-	-	-	-	o	o
Duty Standby Dosing Pumps	o	o	o	o	o	o	o
Static Mixer	o	o	o	o	o	o	o
Dual Chemical Dosing (acid & alkali)	o	o	o	o	o	o	o
Safety Shower & Eyewash Station	o	o	o	o	o	o	o
PLC Control System with HMI	o	o	o	o	o	o	o
Alarm Signal Output for Client Interface	o	o	o	o	o	o	o
Premium Instrumentation Package	o	o	o	o	o	o	o

Instrumentation	Standard Package	Premium Package
Flow Switch	✓	✓
Float Switch (chemical storage tank)	✓	✓
Level Transmitter (4-20 mA, chemical storage tank)	-	✓
pH Analyser (4-20mA)	✓	✓
Flow Transmitter	o	o
Temperature Sensor & Alarm	o	o
Data Logger (pH level)	-	✓
Remote Monitoring & Control Capabilities	-	✓

MODEL SELECTION

0060 60 L - Chemical storage tank size
0100 100 L - Chemical storage tank size
0200 200 L - Chemical storage tank size
0500 500 L - Chemical storage tank size
1000 1,000 L - Chemical storage tank size
2500 2,500 L - Chemical storage tank size
5000 5,000 L - Chemical storage tank size
XXXX Custom tank (please nominate size)

XX Skid mounted
CX Containerised - standard
CF Containerised - with floor coatings
CP Containerised - with floor coatings & insulation

X Dosing pump - standard, single duty
O Dosing pump - duty standby

X Chemical dosing - standard, single
O Chemical dosing - dual, acid & alkali

X Standard control system
P PLC control system with HMI
C Custom control system

X Standard instrument package
P Premium instrument package, c/w remote monitoring
C Custom instrument package

PAF _ _ _ _ _ _ _ _ _ _

NEED A QUOTE?

COMPLETE THIS TABLE AND EMAIL TO...

sales@makwater.com.au

Disclaimer: MAK Water is continuously updating and improving its products and services, so please contact us for more detailed information or to confirm specifications. MAK Water takes no responsibility for any errors resulting from the use of information contained within this document.

mak water

PRODUCT OVERVIEW PAF

water | wastewater | treatment | recycling

Clearmake a mak water company

makwater.com.au WA Perth +61 8 9249 8007 Karratha +61 8 9159 0068 SA +61 8 8395 6122 VIC +61 3 4367 7055 QLD +61 7 5455 6822

Overview

MAK Water's pH Adjustment – Flow (PAF) plants are designed to automatically adjust and maintain the pH level of pressurised raw water, prior to discharge to sewer/environment or reuse/recycling.

Dual chemical dosing pumps (alkali/acid) are available for when the raw water pH varies to allow for correction of both low and high pH raw water.

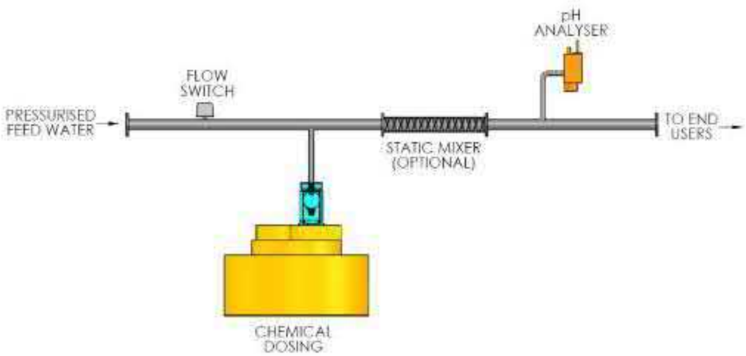
The MAK Advantage:

- High quality Australian designed and built systems
- Experienced team with >4,000 systems operating throughout Australia and internationally
- Nationwide service & maintenance capabilities
- Remote monitoring for expert process support
- Fully automated systems minimise operator attendance
- MAK standard designs for fast lead times
- Optimised designs to suit client's objectives
- Fully customisable to accommodate client specific engineering standards, vendor data requirements and site preferred electrical equipment
- Extensive hire fleet available for rapid deployment

MAK skid mounted pH Adjustment plant

Clearmake
a mak water company

Overview



The standard treatment process includes an inline pH analyser which monitors the pH level and a dosing pump to automatically dose liquid alkali/acid.

The system components are sized to suit the raw water flow rate and daily usage. Chemical storage tank(s) are provided with 110% bunding in compliance with AS1940-2004 (The storage and handling of flammable and combustible liquids).

Optional equipment upgrades include; a flow transmitter, a static mixer if required to improve mixing, duty standby dosing pumps, dual chemical dosing pumps (alkali/acid).

MAK PAF plants are available as skid mounted or containerised systems for easy deployment to remote locations.

Overview

The following table summarises typical raw water and treated water values:

Parameter	Unit	Raw Water (typical)	Treated Water (typical)
pH Level	pH	1 ~ 14	6 ~ 8 (pH neutral) or as required
Pressure	kPa	0 ~ 800 (pressurised feed)	-
Flow Rate	m^3/hr	0 ~ 1,000	-
Temperature	°C	15 to 35	-

NOTE: MAK Water recommends a water analysis be carried out prior to detailed design.

Process Steps

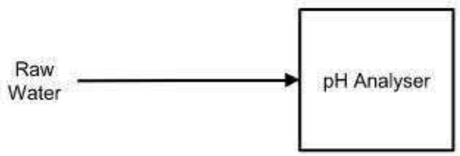
Pressurised Feed Water

Raw water enters the pipeline and treated water is discharged to sewer/environment or reuse/recycling.

The pipeline is fitted with a pressure switch; dosing is turned on/off depending on pressure. An option is provided for a flow transmitter which provides raw water flow measurement and flow paced dosing.

If required, MAK Water can provide a distribution pump and control system for distribution of treated water to end users.

Process Steps

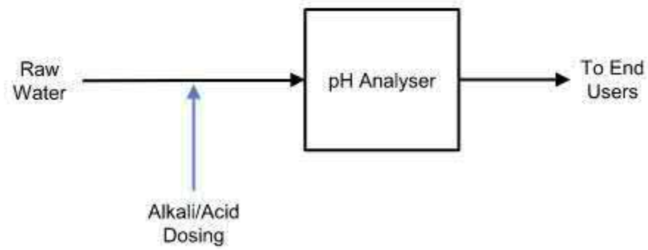


pH Monitoring

The inline pH analyser monitors the pH level and provides a feedback signal to the control system.

Where ClearAccess™ remote monitoring is installed, pH level data is continuously logged.

Process Steps



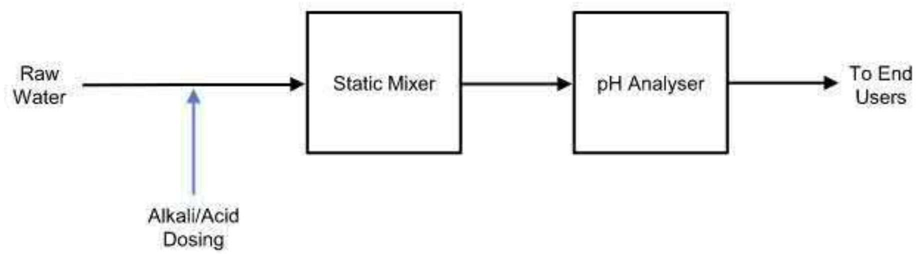
pH Adjustment

To adjust pH level up/down as required, liquid alkali/acid is dosed into the pipeline. The requirement for dosing is based on pH level, using the feedback signal from the pH analyser. The system will dose alkali/acid when the measured pH level is outside the programmed high/low set point and continue for as long as required to establish and maintain the pH level within the target range. A signal can be provided to prevent distribution of treated water when the pH level is out of range.

The chemical storage tank(s) are fitted with a low level switch for auto-shutdown & to alert the operator of a low level condition: the tank level should be checked regularly and topped up as required.

Where ClearAccess™ remote monitoring is installed, a level transmitter continuously monitors tank levels.

Options – Static Mixer



Static Mixer

Additional mixing of raw water and alkali/acid may be required in the treatment process. If required, an inline static mixer is installed in the pipeline after the dosing point to improve mixing.

Options - ClearAccess™

Optional ClearAccess™ Remote Monitoring enables personnel to view and operate the plant remotely. This saves time in response to emergencies and assists local operators to diagnose problems. It prevents unnecessary service call-outs and improves reliability and plant uptime.

Key Functionality:

- Remotely view and operate the plant on your PC, smart phone or tablet
- Automatic alerts (email or SMS) on alarm conditions
- Automatic report generated daily and emailed to your inbox
- Real time monitoring of process data, such as flow rates, pressure and alarm conditions/status messages
- Password protected system with two login security levels

Inclusions:

- Additional electrical instrumentation (premium package)
- Additional PLC hardware and programming
- Programming of email alert system

NOTE: Remote monitoring requires an internet connection or mobile network coverage (client to provide SIM card).

Process Support via ClearAccess™

ClearAccess™ from your Smart Phone or Tablet

Clearmake
a mak water company

Options – Containerised Plant

MAK SHS plants can be installed in ISO sea container for safe, fast deployment by sea, road and rail. Installing the plant inside a sea container is an ideal way to protect the plant and equipment from harsh operating conditions in remote sites. The durable construction assures the plant is able to be transported through rough terrain and perform to the design requirements on arrival at remote sites (plug and play operation).

Standard 20' Container

Premium Fit Out (insulation, floor coating and access door)

Standard Inclusions:

- As new, freshly painted inside and out (high gloss enamel)
- Distribution board with separate circuits for lights & aircon
- Overhead internal lighting & reverse cycle air conditioning
- GPO's for maintenance work

Containerised WTP with access door, window and safety shower & eyewash station

Premium Container Fit Out Options:

- Chemically resistant, non-slip floor coverings
- Wall and ceiling insulation
- Personal access doors & windows
- Smoke detectors and alarming
- Safety shower & eyewash station with flow switch & lighting
- Winterisation for extreme climates (-40ºC/-40ºF)
- High spec/high build two-pack epoxy container painting

Clearmake
a mak water company

Project Experience

Project	Brisbane Airport Corporation (BAC) Custom pH Adjustment Plant
Location	Brisbane, QLD
Scope	D&C, commissioning & operator training
Capacity	1,000 L/hr
Raw Water	Wastewater from laboratory
Treated Water	Discharge to sewer
Features	pH neutralisation via alkali dosing pH and temperature monitoring Environmental and trade waste compliance Custom Fiberglass batching tank Containerised system for quick and easy site installation Fully automated PLC control system

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Project Experience

Project	Newcrest Mining Custom pH Adjustment Plant
Location	Orange, NSW
Scope	D&C, commissioning & operator training
Capacity	800 L/hr
Raw Water	Wastewater from laboratory sinks
Treated Water	Discharge to sewer
Features	pH neutralisation via alkali dosing pH and temperature monitoring Feed and recirculation pumps Environmental and trade waste compliance Lowest total operating cost – on site treatment rather than trucking waste off site for disposal Custom 1000L neutralisation tank Skid mounted system for quick and easy installation Fully automated PLC control system

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a mak water company

Project Experience

Project	CS Energy – Callide Oxyfuel Project Custom pH Adjustment Plant
Location	Callide A Power Station Biloela, QLD
Scope	D&C, commissioning & operator training
Capacity	2,500 L/hr
Raw Water	Wastewater from pre cooling scrubber
Treated Water	Discharge to ash pit
Features	pH neutralisation via alkali dosing pH and temperature monitoring Environmental compliance Skid mounted system for quick and easy installation Fully automated PLC control system

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Project Experience

Project	Genalysis Laboratory Services Custom pH Adjustment Plant
Location	Townsville, QLD
Scope	D&C, commissioning & operator training
Capacity	1,000 L/hr
Raw Water	Wastewater from laboratory sinks
Treated Water	Discharge to sewer
Features	pH neutralisation via alkali dosing pH and temperature monitoring Environmental and trade waste compliance Custom 1000L neutralisation tank and 80L acid discharge tank Skid mounted system for quick and easy installation Fully automated PLC control system

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Appendix C. Supplier Information

Polymaster Tanks

Polymaster's self bunded tanks. The ultimate storage solution for chemicals and dangerous liquids.

Custom engineered solutions can be developed for specific applications. Certified to Australian standards, these tanks will save time, space and money over traditional bunding methods. Specially formulated Polymaster PE material options are available to safely contain extra aggressive chemicals such as sodium hypochlorite and sulphuric acid.

70%
cost reduction on installation costs

6 Weeks
reduced construction time

66%
less footprint

CERTIFIED DESIGN
AS/NZS4766

UV resistance
suitable for outdoor application

Removes need
for traditional concrete bund

110%
bund capacity to comply with AS3780

1,965
chemicals can be stored

- Engineered up to 2SG for heavy liquids
- Tanks can be easily relocated from site to site
- Save time: testing and fit out completed before delivered to site

Visit our website for more
→ polymaster.com.au


Self Bunded Tank with Cabinet
Polymaster
Level transmitter mount
Weather proof vent
Mechanical level indicator
Store over 1,965 chemicals - Multiple grades of PE available
Outer tank exceeds 110% capacity of storage tank
- AS Regulations
Bund alarm float switch
Bund drain
Inspection hatches
Weatherproof rebate seal
Lifting lugs
High level alarm float switch
Lockable cabinet
Bolt down lug
* Standard configuration shown. Custom configurations available on request.
Cabinet Details
Bund alarm
- visual display
(Chemical unloading panels available, see pg.5)
High level alarm
- visual / audible
Top fill assembly with camlock & drain
Rain resistant door seal
Stainless steel mounting plate (HDPE available)
Anti - theft locking mechanism
Tank outlet & valve
3

Self Bunded Tank without cabinet

* Standard configuration shown. Custom configurations available on request.

TESTIMONIAL

"I highly recommend Polymaster Industrial for all chemical storage projects. I had enormous confidence from the start with their design and material compatibility assessment. It's reassuring to work with a team that asks questions about how the tanks were intended to operate on site.

I was impressed with how we were able to customise each tank with different fittings and positions to suit both engineering and aesthetic requirements.

Our project was delivered on time and on budget. Well done guys."

Mark L - Project Engineer

4

Options

CHEMICAL UNLOADING PANEL

- Single and 3-phase options
- All-in-one Tank Management System
  - Safe, easy operation of tank

- Tank overfill protection
  - Alarm
  - Inloading high level safety cut-off
  - Radar & Ultrasonic Level Transmitters available

JOINING MULTIPLE TANKS

- Join multiple tanks for unlimited capacity
- Double containment (bunded) connection between tanks

- Connections at base allow tanks to operate as 'one tank'
- Safe & secure

MULTIPLE CABINETS

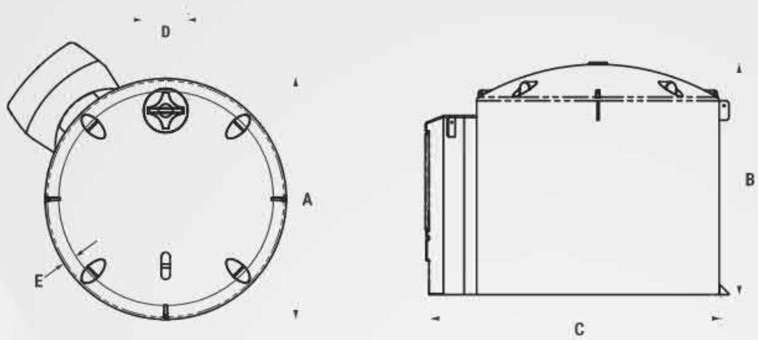
- Segregation of equipment
- Increased capacity for housing multiple dosing systems

- Ensures all equipment is protected

5

Specifications

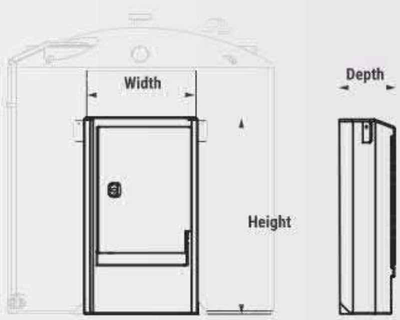
TANK



CODE	CAPACITY (LTRS)	A (MM)	B (MM)	C (MM)	D (MM)	E (MM)
BPST1500	1500	1169	2250	1910	350	85
BPST2300	2300	1600	2200	2410	350	150
BPST3300	3300	1800	2200	2630	455	140
BPST5000	5000	2200	2200	3050	455	130
BPST7000	7000	2500	2380	3370	455	180
BPST10000	10,000	2500	2700	3360	455	50
BPST13000	13,000	3050	2900	3930	455	120
BPST21000	21,000	3570	3570	4460	455	260
BPST30000	30,000	3800	3690	4700	600	110

Technical drawings available

CABINET



WIDTH (MM)	HEIGHT (MM)	DEPTH (MM)
1070	1850	950

6

7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Together we
hold the future.
Polymaster

POLYMASTER SELF BUNDED TANKS
COMPLIANCE WITH AS3780-2008, SECTION 5

AS3780-2008: The storage and handling of corrosive substances
It is important to note Polymaster compliance to Section 5 for our Self Bunded Tank range. Below is further explanation around some key clauses to provide clarity around specific requirements:

Clause 5.3.2.2

Polymaster Self Bunded Tanks do not have an FRL of 240/240/240 and therefore the standard separation distances apply

Clause 5.4.2

The standard recommends that the compound (bund) capacity is 110% of the storage tank. All Polymaster Self Bunded Tanks have a secondary containment compound that is at least 110% of the SFL of the internal storage tank.

Clause 5.4.3

(c) provides exemption for the distance between storage tank and bund for double skinned tanks and therefore the 1 metre distance between the edge of storage tank and compound does not apply.

(f) requests that 'any pipe which passes through the wall of a bund should be sealed to prevent leakage from the compound'. All fittings that pass through the outer tank on a Polymaster Self Bunded Tank are welded and sealed as standard.

Clause 5.5.6

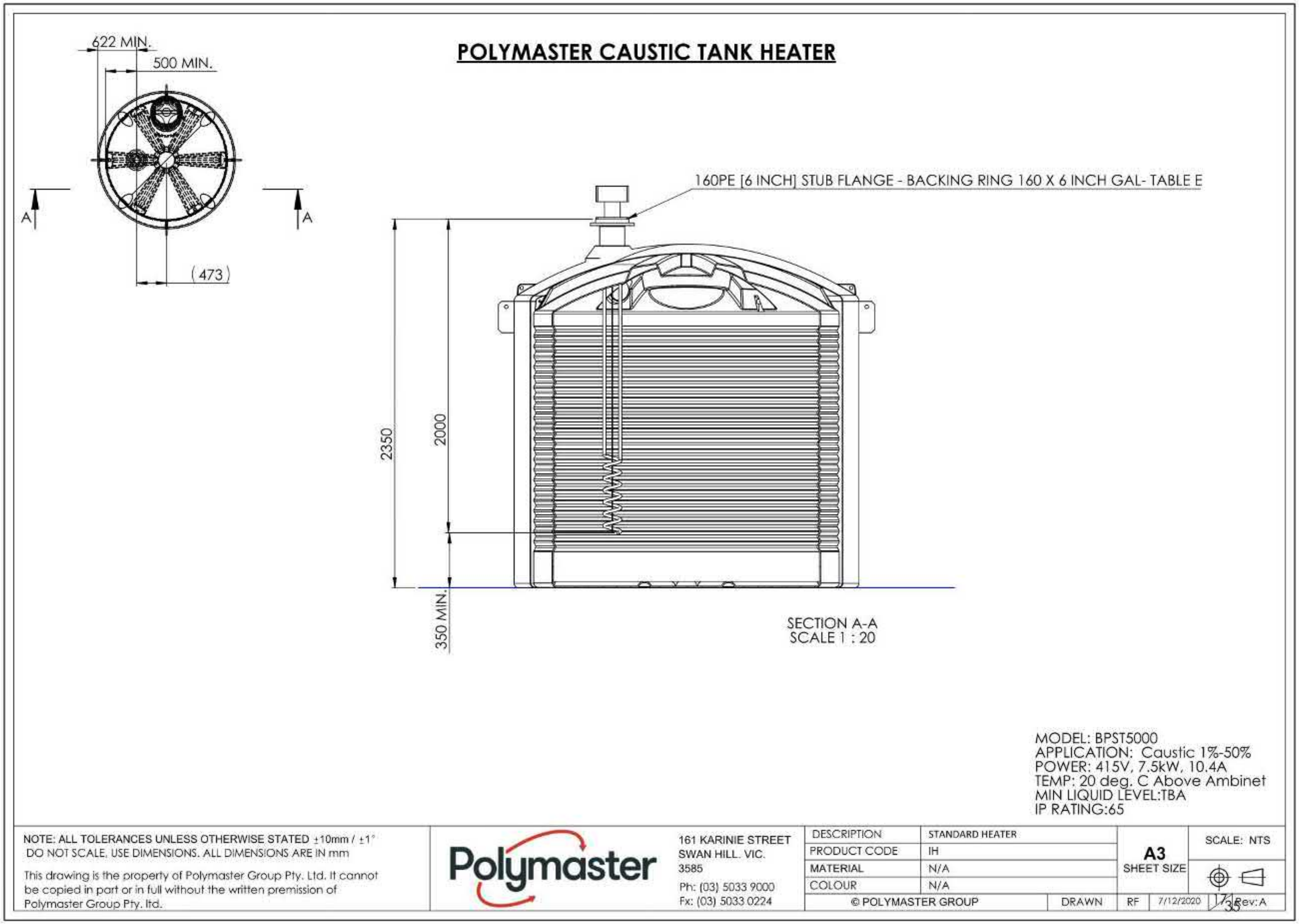
(c) if an internal DIP pipe is requested for the filling line, a minimum 15mm hole needs to be inserted into the filling line above the overflow level to prevent siphoning.

Clause 5.7.3

Polymaster Self Bunded Tanks are roto-moulded and are therefore classified to be as per point (d). All tanks used for manufacturing the Self Bunded Tanks are tested and certified to AS/NZS 4766 which is in accordance with ASTM D1998 as per authorisation from SAI Global.

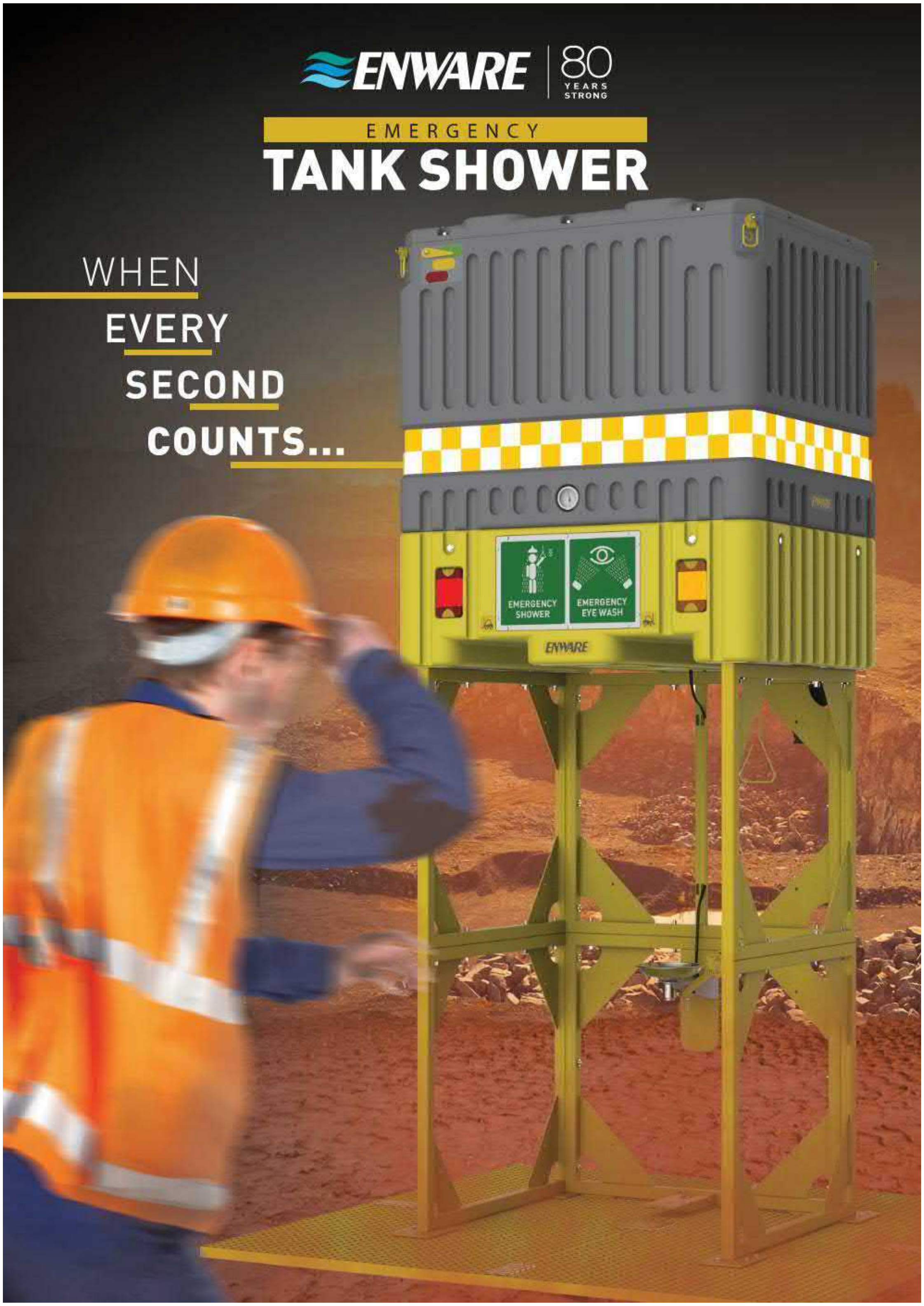
Clause 5.7.7

The overflow line on a Polymaster Self Bunded Tank does not 'terminate in full view of the person filling the tank' because the outer tank completely covers the internal tank. As a standard feature, Polymaster installs a High-Level Alarm to satisfy the requirements of point (a)(i). However, to satisfy the requirements of (a)(ii) a 'extra-high-level cut-off device' is required – Polymaster can provide a Power Control Panel which has functionality to stop power supply to the in-loading pump to satisfy this requirement. Alternatively, clients can fit their own system onsite.



POLYMASTER CAUSTIC TANK HEATER
622 MIN.
500 MIN.
(473)
A
A
160PE [6 INCH] STUB FLANGE - BACKING RING 160 X 6 INCH GAL- TABLE E
2350
2000
350 MIN.
SECTION A-A
SCALE 1 : 20
MODEL: BPST5000
APPLICATION: Caustic 1%-50%
POWER: 415V, 7.5kW, 10.4A
TEMP: 20 deg. C Above Ambinet
MIN LIQUID LEVEL:TBA
IP RATING:65
NOTE: ALL TOLERANCES UNLESS OTHERWISE STATED ±10mm / ±1°
DO NOT SCALE, USE DIMENSIONS. ALL DIMENSIONS ARE IN mm
This drawing is the property of Polymaster Group Pty. Ltd. It cannot be copied in part or in full without the written premission of Polymaster Group Pty. ltd.
Polymaster
161 KARINIE STREET
SWAN HILL. VIC.
3585
Ph: (03) 5033 9000
Fx: (03) 5033 0224
DESCRIPTION
STANDARD HEATER
PRODUCT CODE
IH
MATERIAL
N/A
COLOUR
N/A
© POLYMASTER GROUP
DRAWN
RF
7/12/2020
A3
SHEET SIZE
SCALE: NTS
Rev:A

Safety Shower



WORKFORCE SAFETY
IS AT THE HEART OF OUR DESIGN

Mining sites, like many remote location industries, present unique challenges when it comes to providing safe working environments.

These sites are dynamic, with ever changing progressive operations and evolving productivity requirements. In these challenging and complex environments, the provision of agile and customisable solutions are essential in ensuring work environments remain safe.

The ET1400 has been designed to provide remote workers with an easily deployed permanent or semi-permanent emergency safety shower in locations where suitable infrastructure such as power and water may not yet be established. The result is a robust, reliable and highly visible first response emergency shower and eye wash station, providing your workforce with confidence that help is right by their side... any site, any day, any time.

GOOD DESIGN AWARD® GOLD WINNER

"AN INSPIRED DESIGN, BRILLIANTLY EXECUTED ..."

In an emergency situation, every second counts... and this thought became the inspiration for the design thinking approach behind the Award winning ET1400 Emergency Tank Shower. Without complex technology it will operate simply and reliably in some of the harshest work place environments in the world. The ET1400 Emergency Tank Shower has been designed and built for the mining industry where Safety of the workforce is paramount.

In recognition of excellence in design and innovation, the ET1400 Emergency Tank Shower has just been awarded the prestigious Gold Award - Product Design Commercial and Industrial Category... at the 2018 Good Design Awards®. We are proud that our design thinking approach delivering operational simplicity and smart design features has been rewarded with this prestigious accolade.

"Thoughtful design... a no nonsense safety product that has been brilliantly executed" and "Great example of a company that knows its product category, and has thought of everything..."
Judges comments

Enware's 80 year history brings a breadth of experience in the design and development of emergency showers and eye washes - and the ability to offer innovative solutions based on an understanding of the needs specific to the Mining Industry and other work sites.

Minimising the impact of workplace injuries to people, their families, business and community remains at the heart of Enware design... now, and into the future.

Quality Management ISO 9001 Global-Mark.com.au®

Certified Product Australian Standard

Certified Product

DESIGNED TO WORK, SIMPLY AND RELIABLY
IN SOME OF THE HARSHEST WORK PLACE ENVIRONMENTS IN THE WORLD.


SMART IN USE
SMART IN DESIGN
The ET1400 Emergency Tank Shower
Robust construction and highly visible design aesthetic gives your workforce confidence that help is near by.
With a 1400 L capacity, the tank includes a unique gravity fed flow control system to supply a constant flow of flushing fluid for up to 15 minutes.
DESIGNED TO COMPLY:
AS4775
ANSI – Z358.1
COMPACT DESIGN
Mobilise your workforce with ease and speed
Easy to install and pack down
Minimises storage footprint
RELOCATABLE FOOT BASE
Easily relocated
Easy to assemble and disassemble
No cement base required
LIFTING POINTS
Easy to relocate
Crane lifting points
Designed to be forklifted (when tank is empty)
WATER GAUGE
Water level can be viewed from the ground
LINEAR LOW DENSITY POLYETHYLENE
Tank: 60 mm foam core
Impact resistant
UV resistant
WATER TEMPERATURE GAUGE
Temperature can be viewed from the ground
SOFT FLOW, LOW VELOCITY SHOWER HEAD
Even and soft distribution of flushing fluid to the body
FILL POINT OPTIONS
40 mm infill
Option to connect to mains plumbing
Inspection hatches
EYE WASH STATION
Hand or foot options to activate eye wash
INTEGRATED CHILLER AND HEATER
Fits neatly into the tank pallet for convenience and protection.
Keeps water temperature within the range guideline (AS4775 and ANSI Z358.1).
ROBUST STRUCTURAL FRAME
Flat pack:
• Ease of assembly
• Transportable within tank
• Category B Rated
• 316 Stainless steel
• Powder coated option available
Single piece frame:
• Category D Rated
• 316 Stainless steel
• Powder coated option available
EMERGENCY SHOWER
EMERGENCY EYE WASH

SMART IN USE
SMART IN DESIGN

FEATURE	ET1400	ET1400F	ET1400FB	ET1400FP	ET1400FPB	ET1400S
Material:						
LLDPE foam core - Tank	✓	✓	✓	✓	✓	✓
LLDPE - Lid and Pallet	✓	✓	✓	✓	✓	✓
Shower - pull hand activation	✓	✓	✓	✓	✓	✓
Eye Wash - hand and foot activation	-	✓	✓	✓	✓	✓
Flat Pack Frame - Stainless Steel (316): Wind Rating*	-	B*	✓	✓	✓	-
Single Piece Frame - Stainless Steel (316): Wind Rating*	-	-	-	-	-	D*
Foot Base - Fibre Glass Reinforced Plastic (FRP)	-	-	✓	-	✓	Opt.
Privacy Panels: Stainless Steel (316) - set of 6	-	-	-	✓	✓	-
Dimensions:						
Height (mm)	1659	3769	3807	3769	3807	3769
Width (mm)	1500	1500	2450	1500	2450	1500
Depth (mm)	1150	1150	2298	1150	2298	1150
Weight (total) - kg	391	576	656	618	698	591
Weight - Frame Only - kg	-	185	185	185	185	200
Weight - Foot Base - kg	-	-	80	-	80	-
Weight - Privacy Panels - kg	-	-	-	42	42	-
Optional Extras:	**Optional extras must be specified at the time of order.**					
Alarm - Non Hazardous - Back to Base	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Alarm - Non Hazardous - Audio Visual & Back to Base	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Low Level Water Alarm	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Integrated Chiller	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Heater	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Back Lit Emergency Signage	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.
Downlights - green LED	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.

*Frame Ratings: Frames are not rated when installed onto the relocatable foot base and/or privacy panels are installed.
Note: Tank shower must be installed as per manufacturer's drawings and installation instructions.

ENWARE 80 YEARS STRONG

1300 369 273 (AUS) | www.enware.com.au | info@enware.com.au

Portable Chemical Bund

fabric solutions
Australia pty ltd

Portable Spill Bunds

"Portable Spill Bunds are environmentally friendly, reusable, chemical & UV resistant."

Portable Spill Bunds are used for both permanent and temporary containment of liquids and potentially hazardous substances. Portable spill bunds are an environmentally friendly option to prevent contamination or pollution. Spill bunds can help you comply with EPA and OH&S regulations.

FEATURES

- Reusable and relocatable
- Designed for quick and easy deployment
- Lightweight and easily stored when not in use
- Easy to clean
- Can be manufactured to any size
- Manufactured from a range of materials that are chemical, fuel and UV resistant
- Drive over models available
- Portable Spill bunds can have either foam filled sides or collapsible sides depending on application.
- Can be fitted with drain points and/or collection sumps
- Protective groundsheets, floor inserts or wheel tracks available

APPLICATIONS

- Plant and equipment (generators, pumps, compressors etc)
- Wash down applications
  Servicing or storing plant and equipment
- Drive-on drive-off fuel transfers
- Storage of drums and containers

Free Call: 1800 039 996
Email: info@fabricsolutions.com.au
Website: www.fabricsolutions.com.au/portable-spill-bunds/

"Innovative Solutions"

stratex
PROTECTING OUR GREATEST ASSETS

• Spill Kits • Absorbents • Storage & Bunding • Safety Wear

Portable Collapsible Sidewall Bunding

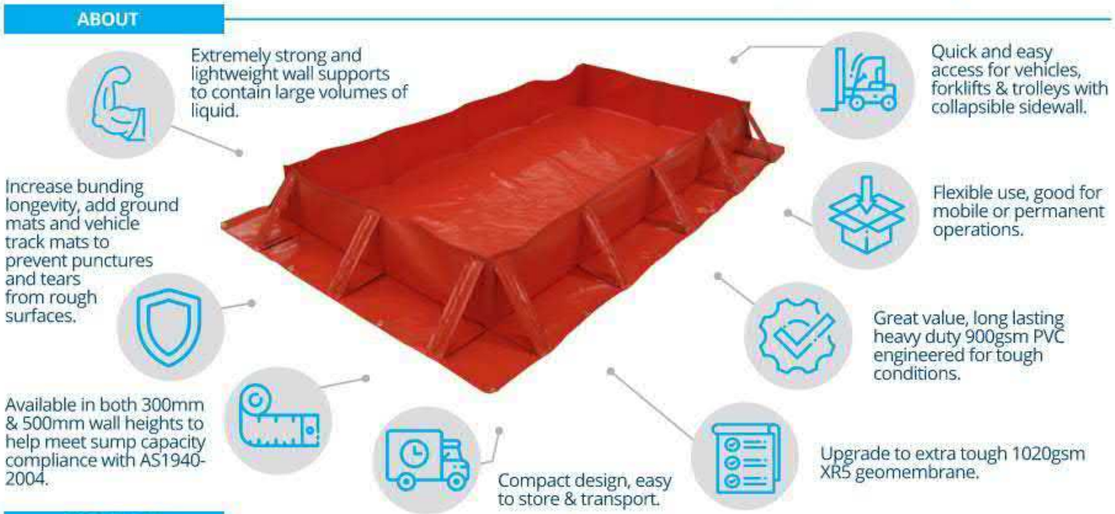
STORAGE & BUNDING

Description:
Storage of drums, plant & equipment while containing any hazardous liquid leaks and spills

Use:
• Generators • Fuel Storage • Drums
• IBC's • Drill Rigs • Heavy Machinery

Application:
• Servicing heavy vehicles & machinery
• Storage of drums and IBC's
• Spill containment for plant & equipment • Wash bays

ABOUT



TO ORDER

Code	Description
DOBC400	Portable Collapsible Bunding, Collapsible Sidewall (1200W x 1200L x 300H mm) - 400L
DOBC600	Portable Collapsible Bunding, Collapsible Sidewall (1200W x 1800L x 300H mm) - 600L
DOBC800	Portable Collapsible Bunding, Collapsible Sidewall (1200W x 2400L x 300H mm) - 800L
DOBC950	Portable Collapsible Bunding, Collapsible Sidewall (1800W x 1800L x 300H mm) - 950L
DOBC1700	Portable Collapsible Bunding, Collapsible Sidewall (2400W x 2400L x 300H mm) - 1700L
DOBC2500	Portable Collapsible Bunding, Collapsible Sidewall (2400W x 600L x 300H mm) - 2500L
DOBC10500	Portable Collapsible Bunding, Collapsible Sidewall (3600W x 10000L x 300H mm) - 10500L

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Floating Silt Curtain

SILT CURTAIN
For Coastal and
Water Applications

GEOFABRICS®

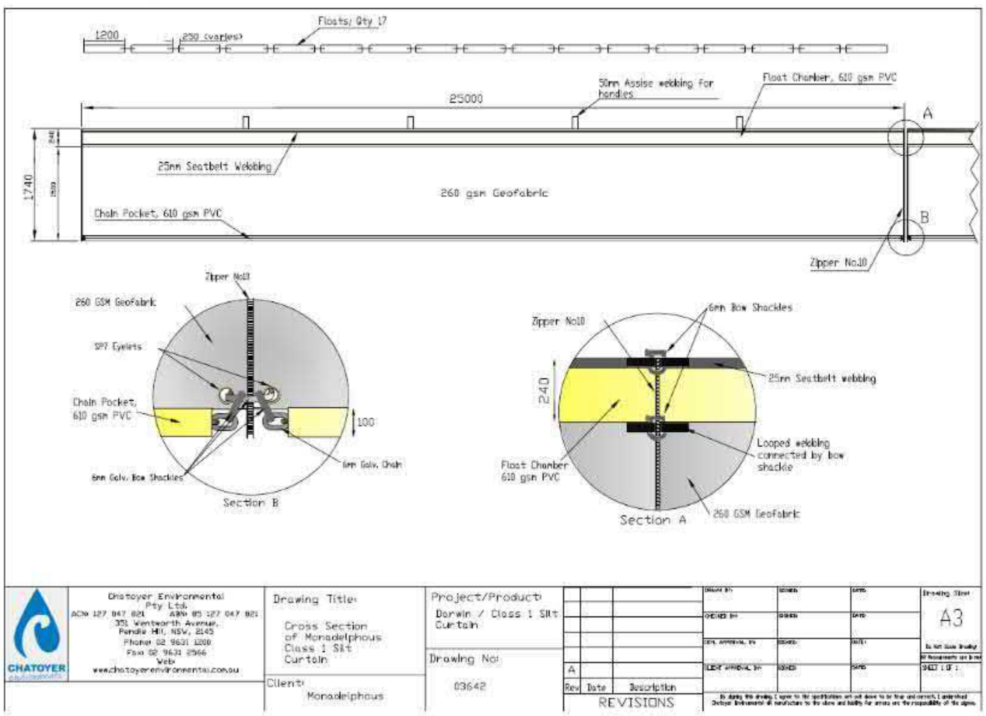
Introduction

A silt curtain is either a permeable or impervious structure that sits suspended in the water column to control migrating water bourne sediment. Also known as a *turbidity curtain* or *silt screen*, the silt curtain's function is to contain disturbed sediment about one to two metres from the surface. This allows suspended sediment to settle and drop within the water column by controlling dispersion. A silt curtain provides the necessary environment and time for the suspended sediment to settle to the bottom.

DRAWINGS AND INSTRUCTIONS

Drawings of the intended curtain can be submitted by Chatoyer Environmental, if required, for approval prior to manufacture. Complete specifications and material descriptions of all components can be supplied. Due to the degree of technicality, drawing sign-off by the client is a requirement for all of our customised and heavy duty permanent curtain designs.

Sample drawing:



Silt Curtain Components

FREEBOARD
The portion of the silt curtain that sits above the water line.

DRAFT
The submerged portion of the silt curtain.

FLOTATION
Flotation consists of high density closed cell, polyethylene foam. These floats are crumble resistant and oil resistant, ensuring continued flotation. We offer various sizes and configurations.

SKIRT
The material used will depend on the conditions in which the curtain will be installed. Our most commonly used option is a 270gsm non woven geotextile fabric that stops anything larger than 90 microns.

BALLAST
The curtain is maintained in position by applying a ballast of galvanised chain sewn into a chain pocket at the base of the curtain. This ballast extends consistently for the full length of the curtain allowing for continuous tension.

STRENGTH WEBBING
Seat belt webbing will be installed along each section of curtain. One on top of the float, one directly below the float and, for large curtains, one between the ballast and skirt. The webbing will assist in supporting horizontal forces placed on the curtain.

CONNECTORS
The curtains shall be connected using specially moulded ASTM 962 connectors to attach the freeboard section of the curtain. These connectors provide strength and durability in the water. For offshore conditions opt for heavy duty moulded connectors.

Heavy duty marine zipper is utilised to connect the lengths of skirt which allows for identical sections of curtain to be replaced if necessary. Further, a selection of bow shackles will be used to ensure the connection of the curtains.

ANCHOR POINTS
Attachment points are present on all ASTM 962 connectors via stainless steel eye nuts and furnished with a galvanised steel chain, attached with a bow shackle on one side of the skirt and floating buoys.

How to Choose Your Curtain

Silt curtain effectiveness is considered as the degree of turbidity reduction achieved within the controlled area relative to the turbidity levels outside of the area. Factors which affect this effectiveness are:

- The quantity and type of material in suspension
- The characteristics, design and construction of the silt curtain
- The mooring and square metre area of the silt curtain deployed
- The hydrodynamic conditions experienced such as tidal movement, wind velocity and wave height.

In the instance of typical construction projects and pipeline disposals where suspended solid concentrations are high, a vast majority of the silt will drop to the bottom while only about 5% of the sediment remains suspended in the water column.

The silt curtain is not designed to dam the turbid water but instead provides a control for the dispersion of the sediment laden water and allowing it to settle.

CONSIDERATIONS

1. Is the curtain to be deployed in open water or stable (enclosed) waterways?

OPEN WATER – ensure the curtain is robust enough to handle all sea states, tidal flow and wind conditions. You may require external (foam filled LDPE) floats and/or heavier duty geotextile to ensure appropriate buoyancy and longevity.

ENCLOSED WATER - internal floats will generally suffice however you should understand the tidal influences on variable water depths, currents and winds. Internal floats are available in sizes 100mm x 100mm, 150mm x 150mm or 200mm x 200mm. The degree of currents and winds within the water column will also affect the weight of ballast required and connector types.

2. Is the curtain to be deployed for a time period greater than 12 months?

SHORT TERM DEPLOYMENT – standard PVC construction will generally have sufficient UV stabilisation for short term deployment (<12 months in water).

LONG TERM DEPLOYMENT – the construction material may need to be of a higher grade than standard PVC. We generally recommend polypropylene coated fabric which provides greater intrinsic strength than a standard PVC.

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3. Is there vessel traffic in the area of deployment?

YES – you may need to gain approval from waterways authorities and consider options to facilitate night time visibility, navigation markers, exclusion zones and more.

NO – a standard curtain with standard installation should be approved.

4. How deep should the curtain be?

As a rule of thumb, turbidity is most active in the top two metres of the water column. Since the purpose of a silt curtain is to disrupt the water flow and allow the suspended solids to settle, your curtain should be deep enough to:

- Provide sufficient disruption to the water flow (current),
- Remain clear from the sea bed (or river bed) at low tide, and
- Take into consideration any EPA or other environmental requirements.

Unless required by regulatory or project requirements, a silt curtain does not need to go down to the sea or river bed to be effective. Allow a minimum half metre gap between the curtain and the sea bed at low tide. If the silt curtain is too deep, slack can be generated in the curtain skirt at low tide. This can create issues during periods of high wind as the curtain slack will billow and cause considerable forces against the curtain and mooring systems. Examples of airborne silt curtains have been cited due to incorrect skirt depths in wind prone areas. Some other issues arising with silt curtains that incorporate full depth skirts are:

- In calm water, sediment could build up over the ballast chain and start to drag the curtain down. This is also known as 'making sand' as the curtain moves back and forth over the bottom.
- In moving water, the curtain needs to be able to move freely allowing the forces of the water to pass through and under the curtain.
- A totally contained area through total depth silt curtains may have an adverse affect on marine fauna.

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Design Summary – Configuration Matrix

The below table indicates recommended fabrication aspects for different curtain depths (internal floats) in Class 2 and Class 3 designs. Consultation with a technical expert is recommended.

Curtain Depth	Class 2 Enclosed Water		Class 3 Open Water	
	Float Size (mm)	Ballast Chain (mm)	Float Size (mm)	Ballast Chain (mm)
1 metre	100	6	150	8
2 metre	100	6	150	8
3 metre	100	6	150	8
4 metre	100	6	150	8
5 metre	150	8	150	10
6 metre	150	8	150	10
7 metre	150	8	150	10
8 metre	150	10	200	13
9 metre	150	10	200	13
10 metre	150	10	200	13

This is a guide only and alternative configurations may be required for the hydrodynamic conditions.

	Low Risk – calm water with little or no current, tidal flow, wave or wind action
	Medium Risk – consider current, tidal flow, wave and wind action on curtain
	High Risk – take care to fully understand natural forces on curtain

GEOFABRICS

Design Summary – Class 2

Medium Risk Applications

Moderate wind and/or water forces.

Example: river, calm harbour

Most Popular Design

Application of Project	Medium term projects in sheltered water
Float Chamber Material	610gsm PVC
Float Size	100mm x 100mm or 150mm x 150mm
High Tensile Webbing Strips 50mm	1 above float chamber 1 below float chamber
Skirt (270gsm non woven geotextile)	Up to 8m depth
Galvanised Chain Ballast Thickness	6mm - 8mm
Connectors	Marine grade #10 zipper on skirt supported by lacing Standard ASTM 962 extruded aluminium connectors on float chamber
Triangle Patch Stitching (for tensile strengthing)	2 patches
Other	Handles Shackles Anchoring points <u>Optional</u> Toggle pins Reflective bouys

Options & Accessories

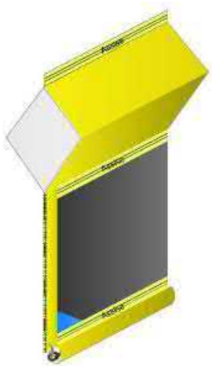
- External Floats
- Hi-Vis (solar lights, reflective floats)
- Woven Geotextile
- Reinforce With Added Webbing
- Heavy Duty Moulded Connectors
- Anchor Set
- Tidal Riser
- Towing Bridle
- Installation / Removal

Design Summary – Class 3

High Risk Applications

Strong wind and water forces.

Example: open ocean, harbour, river mouth



Application of Project	Long term projects in open water
Float Chamber Material	900gsm PVC
Float Size	150mm x 150mm or 200mm x 200mm
High Tensile Webbing Strips 50mm	1 above float chamber 1 below float chamber 1 above chain pocket (uses updgraded load strap)
Skirt (270gsm non woven geotextile)	Up to 20m depth
Galvanised Chain Ballast Thickness	8mm -13mm
Connectors	Marine grade #10 zipper on skirt supported by lacing Heavy duty ASTM 962 extruded aluminium connectors on float chamber
Triangle Patch Stitching (for tensile strengthing)	2 patches
Other	Handles Shackles Anchoring points Optional External floats Toggle pins Reflective bouys

Options & Accessories

- External Floats
- Hi-Vis (solar lights, reflective floats)
- Woven Geotextile
- Reinforce With Added Webbing
- Anchor Set
- Tidal Riser
- Towing Bridle
- Installation / Removal

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- Heavy Duty Moulded Connectors

The Chatoyer Advantage

CHATOYER
environmental

- ✓ Over 50,000 metres of silt curtain manufactured in the last five years for the Australian, New Zealand and Pacific environments.
- ✓ Our technical experience translates to exceptional design and technical support.
- ✓ We ensure quality construction from our purpose built factory.
- ✓ Our materials and components are reliable and durable.
- ✓ Our curtains are delivered fully assembled and ready for immediate deployment.

Deployment

Silt curtains supplied by Chatoyer Environmental are packed with the skirt furled and multiple sections connected and packed on pallets. This allows the silt curtain to be immediately deployed on site.

In projects that require a large length of silt curtain and hence numerous pallets, each pallet will be clearly identified and numbered. Pallet sections will be joined in consecutive fashion and pallets should be laid down as near as possible to the deployment zone.

Once the desired length of silt curtain is connected, the furled curtains can be towed to site at a maximum two to three knot speed. Ensure the curtain remains furled and is only unfurled once the silt curtain is secured to the anchoring system and in the desired position.

After the furled curtain has been anchored, the curtain should be checked to confirm the skirt is not twisted around the floatation chamber. Once the furled and untwisted curtain is anchored in the right location, remove the ties furling the curtain and allow the silt curtain system to drop into place. In the instance where the curtain needs to be manoeuvred back to its correct deployment position, refurl the curtain before dragging the silt curtain through the water. The movement of a silt curtain with its skirt deployed through water places undue pressure on the system.

Maintenance

If the silt curtain system is to be deployed for an extended period (greater than 12 months), it is recommended that a maintenance schedule be implemented to maximise the effectiveness and longevity of the silt curtain.

Typical maintenance activities include:

- Monitoring the curtain skirt against the sea bed to ensure it is free moving and not anchored under sand or dispersed mud.
- Replacing worn or broken anchor lines.
- Reviewing the integrity of the PVC floatation chamber and connection points such as ASTM connectors and zips.
- Removal of marine growth from the curtain.
- Hardware is often placed under pressure, especially at anchoring points and the wear and tear on these parts should also be considered.

Recovery

To recover the silt curtain, refurl the curtain skirt and remove the mooring systems. Tow the system back to the launching site for removal from the waterway and disposal.

If the curtain is to be reused, it can be cleaned down with a high pressure washer to remove silt and sediment from the filter media. Once dry, the curtain can be packed on a pallet and stored. If serviced and stored properly, a high quality silt curtain system can be reused numerous times.

Custom Heavy Duty Silt Curtain
Being Deployed
Barangaroo, Sydney, NSW

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NEW ZEALAND	AUCKLAND (64) 9 634 6495	HAMILTON (64) 21 732 178	NAPIER (64) 21 916 736	CHRISTCHURCH (64) 3 349 5600		
AUSTRALIA	MELBOURNE (61) 3 8586 9111	SYDNEY (61) 2 8785 8800	NEWCASTLE (61) 2 4951 2688	COFFS HARBOUR (61) 2 6653 5706	PERTH (61) 8 6305 0561	ADELAIDE (61) 8 8162 5855
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0800 60 60 20
(Freephone NZ only)
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