Section 78 Scope of works (revised)

31 July 2019

Executive Summary

In mid-September, 2018, Barwon Water received a Section 78 Ministerial Notice pursuant to Section 78 of the Water Act 1989, directing the corporation to develop and implement a Remediation Plan for the Boundary Creek and Big Swamp environments.

In accordance with that Notice, Barwon Water submitted its scope of works to Southern Rural Water by December 20.

The scope of works outlines the area that will be covered by the Remediation Plan, the environmental values to be included and the necessary environmental assessments and methodology proposed to develop the Remediation Plan.

The environmental assessments require a description of the current environmental conditions including hydrogeological conditions, hydrology, ecological assessment, LIDAR topographic mapping, results of soil sampling program.

In developing the scope of works, Barwon Water has:

- Identified all appropriate hydrogeological, hydrological and geochemical assessments to support the development of the Remediation Plan.
- Incorporated ideas and feedback gathered from the community via Barwon Water's Boundary Creek and Big Swamp remediation working group (including the Corangamite Catchment Management Authority).
- Shared a draft scope of works with Southern Rural Water's independent technical review panel for feedback.
- Considered the State Environmental Protection Policy (Victorian Waters).

In addition, the Boundary Creek and Big Swamp remediation working group has also benefitted from the advice of three independent technical experts who they nominated to support them in their discussions. The scope of works document also incorporates input from these technical experts.

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

Addendum

0n 31 July 2019, Barwon Water resubmitted a revised scope of works to address feedback received from Southern Rural Water and their independent technical review panel.

Feedback was received on the revised scope of works from the remediation working group and their nominated expert panel. This was incorporated into the resubmission.

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1 How to navigate this document

Barwon Water submitted a scope of works as per clause 2.4 of the section 78 Ministerial Notice on 20 December 2018.

This document focused on the environmental assessments required to address information gaps to develop a remediation plan for areas of confirmed impact, namely Boundary Creek and Big Swamp.

Feedback from Southern Rural Water and their Independent Technical Reference Panel received in February 2019, suggested that the scope of works could be improved by assessing a broader geographical extent of the area and expanding the breadth of environmental values that may have been impacted from historic groundwater pumping from the Barwon Downs borefield.

This aligned with feedback from the Boundary Creek and Big Swamp remediation working group and their nominated expert panel.

This revised scope of works incorporates feedback from all stakeholders and will be resubmitted to Southern Rural Water on 31 July 2019 for approval.

Figure 1 outlines the journey of the development of the scope of works, how the scope of works was developed and key content with reference to relevant chapters and how the scope of works will inform the remediation plan.

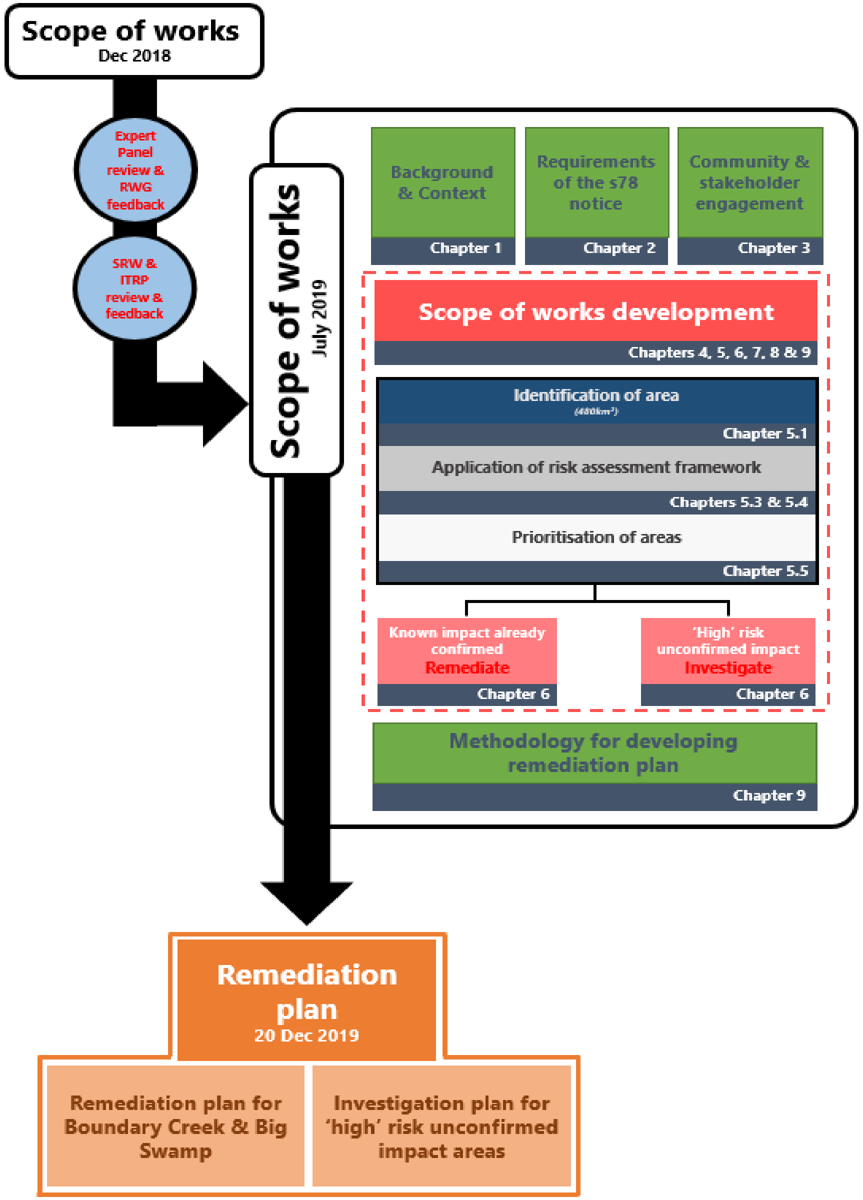

Figure 1: Roadmap to navigate scope of works

2 Background and context

The Boundary Creek catchment has undergone significant modification over the last century, including:

- Land clearing and channelisation of some sections of Boundary Creek for agriculture and farming;
- Installation of a 160ML on-stream water storage known as 'McDonalds Dam';
- Groundwater extraction by Barwon Water;
- Peat fires that may have altered the soil chemistry and the excavation of fire trenches that likely lowered the groundwater table, and
- Significant shifts in the long term climatic conditions across Victoria and the local Boundary Creek catchment.

Recent technical work[1] confirmed that Barwon Water's pumping from the Barwon Downs borefield over the past 30 years is the main cause of a reduction in baseflow (groundwater contribution to streamflow) in the lower reaches of Boundary Creek, increasing the frequency and duration of no flow periods.

The dry climate experienced in the same period and failures in the effectiveness of some existing licence conditions under Groundwater Extraction Licence No. BEE032496 were also contributing factors.

Lack of flow, especially during the summer months, in some sections of the Creek have caused acid sulfate soils in the swamp to dry out and oxidise, leading to the release of acidic water downstream of the swamp.

This conclusion has been shared with the community and our stakeholders.

Throughout our consultation process for the renewal of the Barwon Downs licence, the community made it clear that they placed a high value on rehabilitating Boundary Creek and Big Swamp to improve stream flow and water quality, with the ultimate goal of returning the creek to a healthy, thriving ecosystem.

Remediation efforts were already underway and committed to as part of the Barwon Downs licence application. This has now been given legal force through an issuing of a Ministerial Notice under section 78 of the *Water Act 1989*.

[1] Jacobs (2018) Yeodene Swamp Study, Jacobs (2018) Numerical Model Calibration Report

2.1 Section 78 Ministerial Notice

The purpose of the Notice is to ensure that Barwon Water successfully remediate impacts caused by historic groundwater extraction. The section 78 Notice directs Barwon Water to undertake the following requirements:

- Discontinue extraction, other than for maintenance and emergency response purposes, while the assessment is being completed and until all remediation work required under the remediation plan has been completed.
- Prepare and implement a remediation and environmental protection plan for Boundary Creek, Big Swamp and the surrounding environment.

3 Requirements of the Notice

As per clause 2.4 of the Notice, Barwon Water must submit a scope of works by 20 December 2018 for approval by Southern Rural Water (SRW).

The scope of works should include the:

- Identification of the area covered by the Plan (chapter 5);
- Environmental values to be included (chapter 5);
- Necessary environmental assessments (chapter 8), and
- Methodology (see chapter 9) for how it proposes to develop the Plan.

Barwon Water must also undertake - as a component of the Plan to be submitted by 20 December 2019 - as per sub-clause 2.5a, a description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment; this will include:

- Hydrogeological conditions (groundwater levels and quality)
- Hydrology (surface water quality and flow monitoring)
- Ecological assessment
- LIDAR topographic mapping
- Results of soil sampling program (soil chemistry, peat profile, incubation tests)
- Additional matter arising from the scope contemplated in clause 2.4

This requirement will be delivered through the scope of works by inclusion of the necessary environmental assessments which can be found under the chapter titled Areas prioritised for remediation - Environmental Assessments.

As outlined in clause 2.6 of the Notice, in preparing both the scope of works and the Plan, Barwon Water must:

a) Identify all appropriate hydrogeological, hydrological and geochemical assessments to support the development of the Plan (during the scope of works process);

b) Carry out appropriate hydrogeological, hydrological and geochemical assessments to support the assumptions, controls, actions and targets described in the scope of works (during the development of the Plan);

c) Provide quarterly updates on progress to SRW;

d) Consult with the Corangamite Catchment Management Authority;

e) Consult with the SRW appointed Expert Reviewer;

f) Engage with the local community to seek their ideas and feedback;

g) Ensure the State Environmental Protection Policy (Victorian Waters) are considered and;

h) Present each of the points in 2.5 under separate headings (in the Plan).

The requirements for meeting these obligations are outlined under the chapters titled What does success look like for remediation?, Area covered by the Plan and environmental values, Areas prioritised for remediation - Environmental Assessments and Methodology.

This section details Barwon Water's process in engaging with the local community and key stakeholders as required by the relevant conditions under clause 2.6 of the section 78 Notice.

3.1 Preliminary concept development for remediation

In 2017 – well ahead of the issuing of the section 78 Notice – Barwon Water engaged specialist consultants and Latrobe University to improve the understanding of the swamp and investigate possible management options for remediation.

The resulting study – Jacobs (2018) Yeodene Swamp Study - built on previous technical studies and a field program – characterised the chemical and physical processes occurring in and around Big Swamp to improve the understanding of the swamp's behaviour and how that affects the quantity and quality of water downstream.

Analysis of the data and field program concluded that:

- The decline in pH (acidic water) appears to be correlated to reduced flow and in particular, periods when Boundary Creek has recorded cease to flow (no flow) at the Yeodene stream gauge.
- It can be asserted that the processes contributing to flow reductions in Boundary Creek during1990-1992 and since 1999 are the key factors driving pH change at those times. Those factors are known to be primarily groundwater extraction and contribution from a drier climate.

- Cease to flow events have caused (refer to Figure 2):
    - Soils in the swamp to dry and oxidise,
    - Potential Acid Sulfate Soils to turn into Actual Acid Sulfate Soils, and
    - The release of acidic water with high concentrations of dissolved metals downstream of the swamp.
- The drying of the swamp and subsequent acidic water being released has been further exacerbated by the 2 ML/day supplementary flow not reaching the swamp, as the entirety of flows have not been passed through 'McDonalds Dam' over the summer months.

A review of possible management options to remediate the swamp considered six options, with a recommendation that inundating the swamp was the most technically feasible option.

Key features of this management option are:

- Increasing the supplementary flow initially from 2 ML/day to 3 ML/day downstream of 'McDonalds Dam' to account for the losses in Reach 2 and to meet the recommended low flow requirement of 0.5 ML/day at the Yeodene stream gauge.
- Installation of a hydraulic barrier to close off the fire trenches and agricultural drains at the eastern end the swamp to minimise water flow exiting the swamp, thereby helping to keep areas saturated.

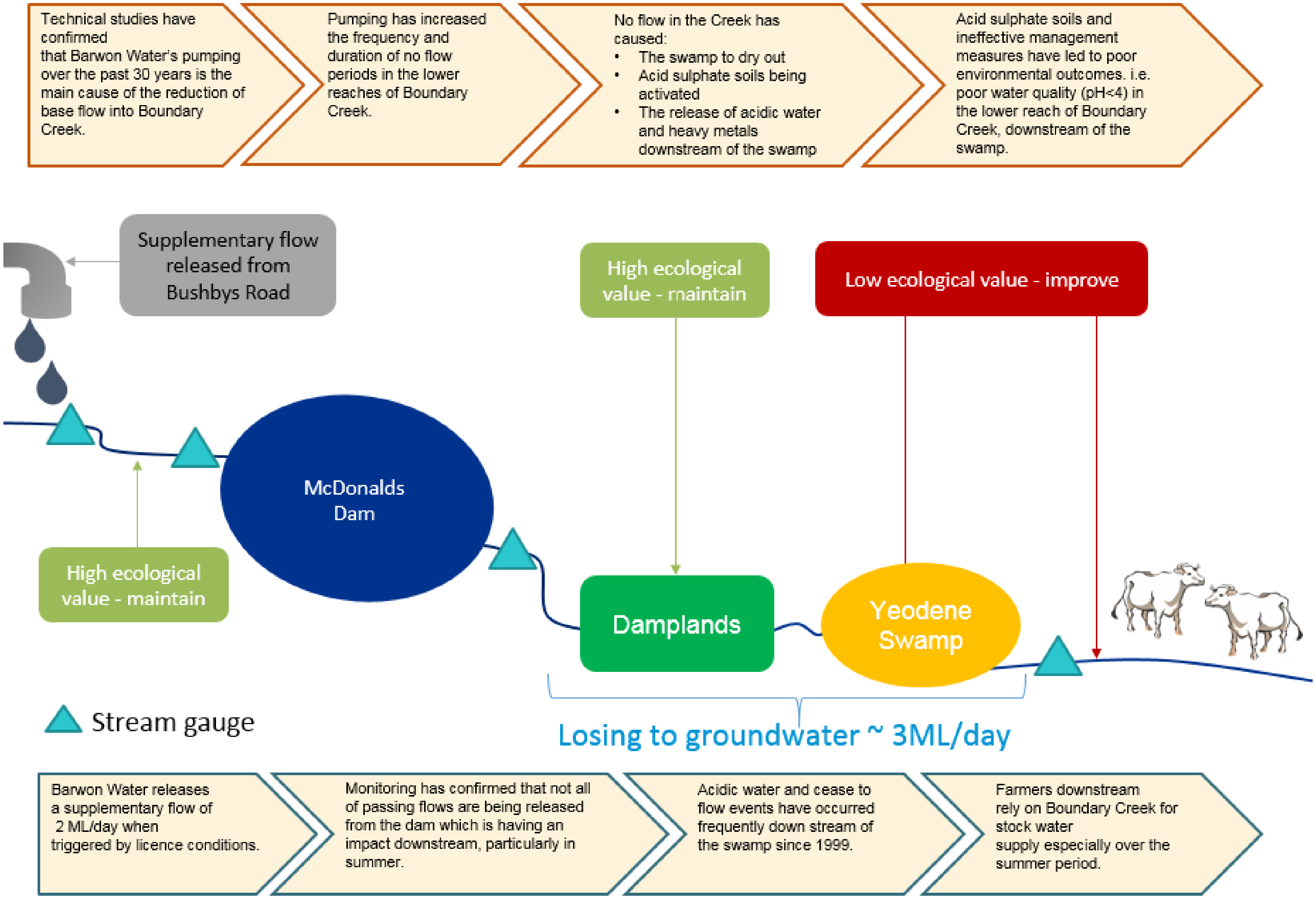

Figure 2: Boundary Creek historic impact

3.2 Formation of the Boundary Creek and Big Swamp remediation working group

In May 2018, the Boundary Creek and Big Swamp remediation working group was established via an advertised expressions of interest process inviting interested stakeholders to actively engage with Barwon Water in the design of a remediation plan for Boundary Creek and Big Swamp.

The role of the group as per their Terms of Reference is to:

- Provide valuable community/local knowledge to help inform and develop a remediation plan;
- Actively engage and provide constructive advice throughout the consultation process;
- Represent community and stakeholder views and provide feedback in relation to the existing concept design by Jacobs and Latrobe University;
- Suggest alternate options where appropriate accounting for safety, financial, environmental, operational and social considerations, and
- Foster greater community awareness of the remediation plan by being 'information stewards' and disseminating information to the broader community.

The working group is made up of representatives from the Corangamite Catchment Management Authority (CCMA), Colac Otway Shire Council, Land and Water Resources Otway Catchment (LAWROC), Environment Victoria, Upper Barwon Landcare Group, Boundary Creek landowners, Traditional Owners and other interested community members[2].

3.3 Remediation working group workshop one

The workshop objectives for the first session in May, 2018 were to:

- Establish the group guidelines,
- Hear the features of the catchment and the history,
- Provide an overview of the preliminary concept design, and
- Agree on key information gaps and nominate technical experts who can respond to the group's concerns at the following session.

Information gaps raised by the working group were grouped according to the following questions and key themes:

- Will increased flows drive rewetting through upstream areas of the swamp (answering this will raise confidence in the preliminary concept design)?

[2] The Boundary Creek and Big Swamp remediation working group forms part of how Barwon Water is engaging and consulting with the local community and Corangamite Catchment Management Authority pursuant to clause 2.6d and clause 2.6f of the Notice.

- Success criteria on reversal of the chemical reaction (answering this will determine how successful inundation of the swamp will be)
- Design of barrier / dam wall (to determine if this is the best solution and whether it will decrease downstream impacts)
- A site visit
- Options assessment (better understanding of the relative merits of each remediation option)
- Location of Lower Tertiary Aquifer (to improve understanding of the risk of contamination and improve the accuracy of how much surface water flow is needed to achieve rewetting and maintain downstream flow)
- Performance Evaluation Review Technique (to enable transparency about management choices during the concept design process)
- Peer review on reversal (independent source of expertise to provide direction on the remediation concept on behalf of the working group)
- Approvals and permits (are there legal / statutory / regulatory approvals to be aware of)
- Core samples (to determine if previous soil samples could be useful)

Information gaps were tabulated with the agreement that a review of the concept design would be undertaken by the nominated technical experts.

Refer to Appendix A for the key information gaps table.

3.4 Working group nominated expert panel

The three experts nominated by the working group were:

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

The role of the expert panel is to provide independent advice on various aspects of the remediation concept as needed by the working group.

3.5 Expert panel review of the preliminary concept design

The expert panel were tasked with reviewing the preliminary concept design as outlined in the Jacobs (2018) Yeodene Swamp Study and where possible, address the information gaps raised by the working group.

Each expert produced a review paper that was shared in workshop two with the working group, and included:

- Critical review of the Jacobs (2018) Yeodene Swamp Study including the methodology of the field program and the field program results to identify any assumptions, key knowledge gaps or other issues;
- Commentary on the six management strategies presented for remediation and suggested alternatives or hybrid options;
- Responses, where appropriate, to the information gaps raised by the working group in workshop one, and
- Any additional technical information gaps that if addressed would improve the confidence and success of the remediation concept.

Recommendations that the expert panel put forward were the need for:

- A more accurate assessment of the current store of acid in the swamp;
- Improved understanding of the water balance and water quality entering and exiting the swamp;
- Further field and research activities to confirm geochemical reactions and the rate at which these processes occur;
- Further work to determine the ecological and environmental outcomes that remediation is seeking to achieve;
- Confirmation of engineering design of the hydraulic barrier and what depth it extends below the swamp, and
- Improving the understanding of the effects of fire on the physical, chemical and biological characteristics of Big Swamp.

The review completed by the expert panel raised further technical information gaps but all agreed the fundamentals of the proposed concept gives Barwon Water the best chance of successful remediation.

Review papers can be found in Appendix B.

3.6 Remediation working group workshop two

The workshop objectives for the second session in July, 2018 were for the working group to:

- Listen to the expert panel's review of the preliminary concept design and any technical information gaps arising from the review, and

- Address the information gaps, where possible, that were tabled in workshop one by the working group.

The main themes of their findings focused on the need for additional monitoring and soil sampling in the swamp before a solution is implemented, exploring other options for remediation such as closing the system and that regardless of the solution, ensuring adequate risk mitigation strategies be put in place to reduce the risks of any unintended further environmental impacts.

3.7 Working group site visit to Big Swamp

The working group requested a site visit to provide an ''on the ground experience' of the issues facing the catchment, understanding the existing infrastructure and visualising the proposed remediation concept for the swamp and creek.

This site visit occurred in July, 2018 with most working group members attending (refer to Figure 3).

Figure 3: Remediation working group site visit

3.8 What does success look like for remediation?

To inform the design of the remediation plan, the working group were asked to identify and prioritise success measures to understand what they valued and why.

This was the objective of workshop three in August, 2018.

Success measures put forward by the working group (note that the list below are collectively individual contributions, not a consensual unanimous list) included:

- A fully informed and involved public presence in all future decisions about the swamp and creek – local community representation, no repeats!!;
- Boundary Creek flowing 12 months of the year with water of a quality suitable for stock and domestic use;
- Adaptive management of remediation;
- Big Swamp and Boundary Creek have healthy and sustained ecological systems;
- Impact to Barwon River monitored and fixed where required;
- Ensuring solution mitigates fire risk / threat;
- Intention to do no harm;
- Groundwater levels to recover;
- Make Big Swamp a closed system;
- Underlying problems must be found;
- Decommission borefield, and
- High quality data and documentation.

The expert panel nominated by the working group, consultants Jacobs and Latrobe University (hereafter the 'technical experts') also provided a consolidated list of success measures which included:

- Improve surface water quality in reach 3 of Boundary Creek;
- Acidification events in Boundary Creek returning to a frequency / intensity of the mid-1990s;
- Return the natural wetting and drying cycles of the swamp and the creek including minimum flow requirements in reach 3 of Boundary Creek;
- Reduce soil acidity so it does not pose a significant risk of harm to aquatic and terrestrial ecosystems, and
- Reduce fire risk in Yeodene Swamp.

The agreed next steps from workshop three were to:

- Consolidate both streams of information gaps raised by the working group and the technical experts;
- The technical experts to prioritise the importance of the information gaps;

- Scope a field program activities taking into consideration the requirements of the section 78 Notice, constraints and timeframes;
- Inform the working group of the field program based on the prioritised information gaps;
- Implement the field program as soon as practicable, pending the review by the Southern Rural Water appointed expert reviewer, and
- Consider any immediate actions to prevent or minimise low pH events in Boundary Creek and the Barwon River.

3.9 Expert panel discussion paper

The working group's nominated expert panel produced a discussion paper titled 'Listing and prioritising research questions and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek.'

The purpose of the discussion paper was to:

- Identify relevant information which may help inform the understanding of the hydrology, hydrogeology and biogeochemistry of Boundary Creek and Big Swamp;
- To consolidate all information gaps raised to date and prioritise them based on their relevance and importance in developing a remediation plan;
- Broadly outline potential research activities (scoping of a field program) that could address the information gaps with indicative costs; and
- Identify any risks associated with the research activities that could preclude them from being achieved.

A desktop review was completed on available scientific studies for Boundary Creek and Big Swamp. Scientific reports were critically reviewed - examining methodology, results and conclusions.

Potential approaches to address information gaps were explored and consideration was given to feasibility and indicative costs.

The following information gaps were given priority status:

- Is 'McDonalds Dam' a net sink for surface water from late spring to early autumn?
- Is reach 2 net losing?
- Can surface water alone sustain the ecological condition of the damplands?
- Are there preferential surface or sub-surface flow paths in Big Swamp?
- How much actual and potential acidity is currently stored in Big Swamp?
- How much sulfate remains in the sediment profile of Big Swamp?

- How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
- Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in the swamp?
- Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?
- Is it necessary to directly introduce alkalinity (in the form of lime or other ameliorants) directly into the swamp?
- How extensive is the fire damage to the peat in Big Swamp?
- How has drying and fire affected the overall geomorphology of the swamp?
- Have inflows from Boundary Creek negatively impacted on sediment quality in the Barwon River?
- Have inflows from Boundary Creek impacted on the ecological condition of the Barwon River?

This discussion paper can be found in Appendix C.

Corresponding activities have been proposed to help answer these and are detailed in the environmental assessments section below.

3.10 Technical workshop to develop field program and provide expert advice on s78 scope of works requirement

A workshop was held in November 2018 with the technical experts (the nominated expert panel as well as other specialist consultants) to review and prioritise information gaps as well as broadly outline the activities that would need to be undertaken through a field program to address these gaps.

The technical experts also provided direction and input into the requirement to submit a scope of works under the section 78 Notice. This informed the:

- Definition of impact and thereby, defining the geographic area to be covered by the remediation Plan;
- High level beneficial uses and environmental values to be considered;
- Necessary environmental assessments via addressing the prioritised information gaps through a field program, and a
- Methodology outlining key deliverables and timeframes to develop the Plan.

The activities described in this section are illustrated in Figure 4 below.

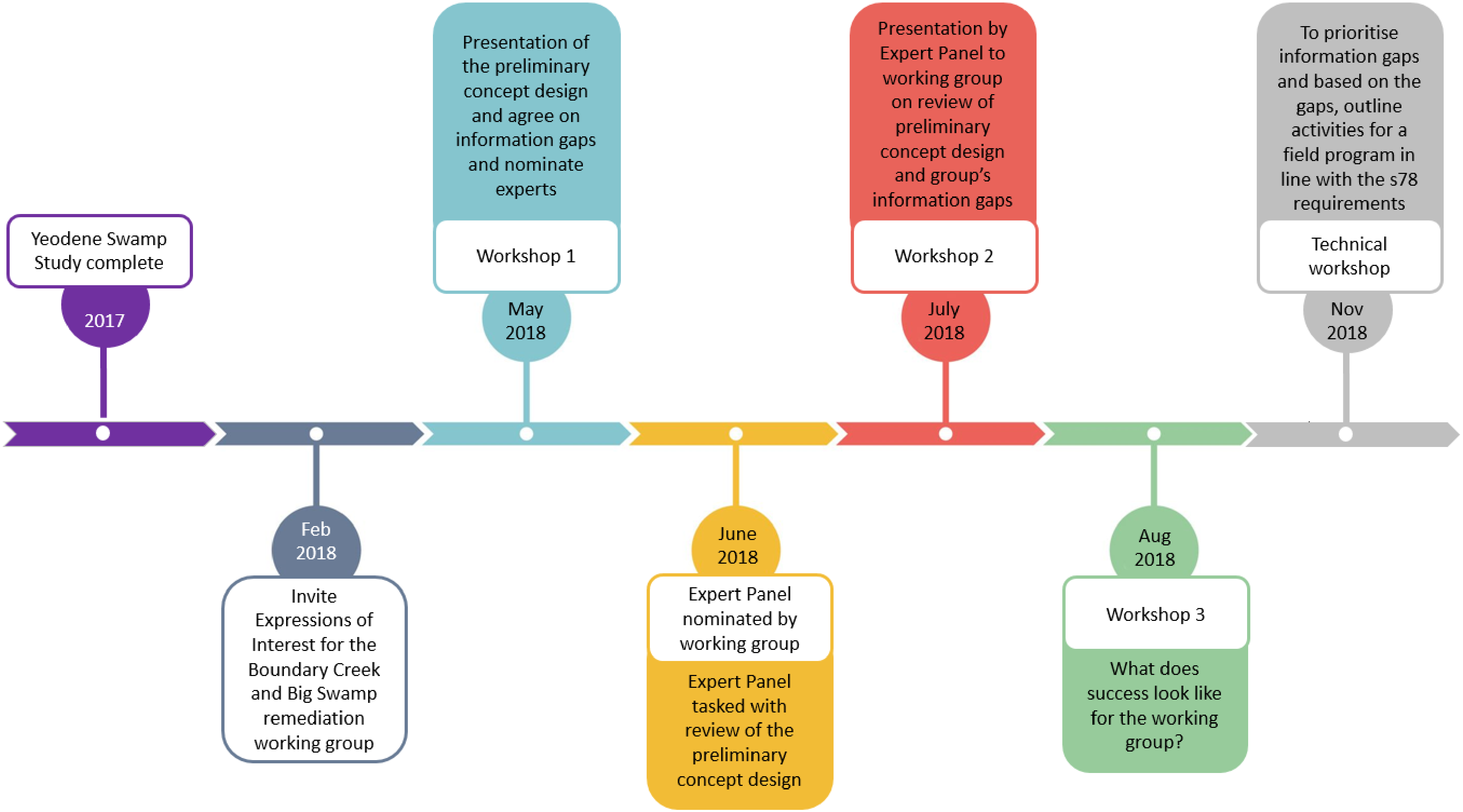

Figure 4: Consultation and engagement process that informed the development of the scope of works

4 Development of the scope of works

The following section provides Barwon Water's responses to clause 2.4 pursuant to the section 78 Ministerial Notice which requires that by 20 December 2018 Barwon Water must submit a scope of works for approval by SRW.

The scope of works is to include the identification of the area covered by the Plan, the environmental values to be included, the necessary environmental assessments and methodology for how it proposes to develop the Plan.

The development of the scope of works is based on three streams of input (refer to Figure 5):

- Existing technical studies;
- Outcomes of the workshop series with the remediation working group, and
- The expert panel nominated by the remediation working group.

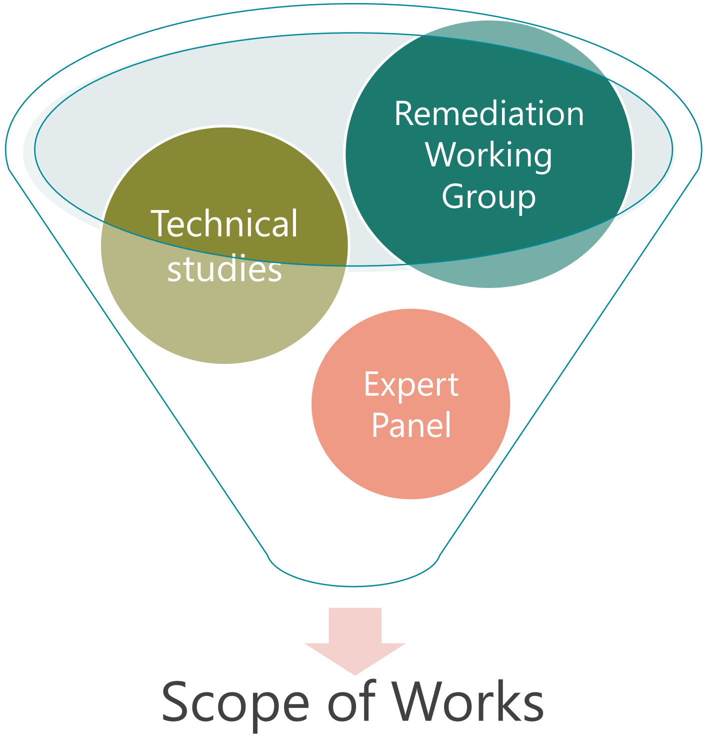

Figure 5: Inputs to the scope of works

5 Area covered by the Plan and environmental values

5.1 Identification of areas for remediation

Identification of the area to be covered by the remediation plan has been based on a systematic, risk based approach.

The scope of works considers the whole extent of the Lower Tertiary Aquifer (LTA) regional groundwater system as a starting point (refer to Figure 6) which covers an area of approximately 480 km^2.

Within the whole area, only some identified areas will transition into the remediation plan. The following chapters outline the risk-based process undertaken to determine which areas within the whole regional groundwater system will be included in the remediation plan, either as areas of confirmed impact or areas that require confirmation of impact.

To narrow down on the identified areas, a risk assessment approach was used to meet the requirements of the notice.

Using a risk assessment is a well-defined and accepted approach and has been widely adopted for groundwater resource assessment and allocation planning.

Taking a risk assessment approach for groundwater is recommended in the DELWP "Resource Share Guidance" (DELWP, 2015).

The concepts of "dependency", "value" and "stress" that are covered in the guidance are incorporated in our approach which is described in more detail in the following sections.

Extent of LTA

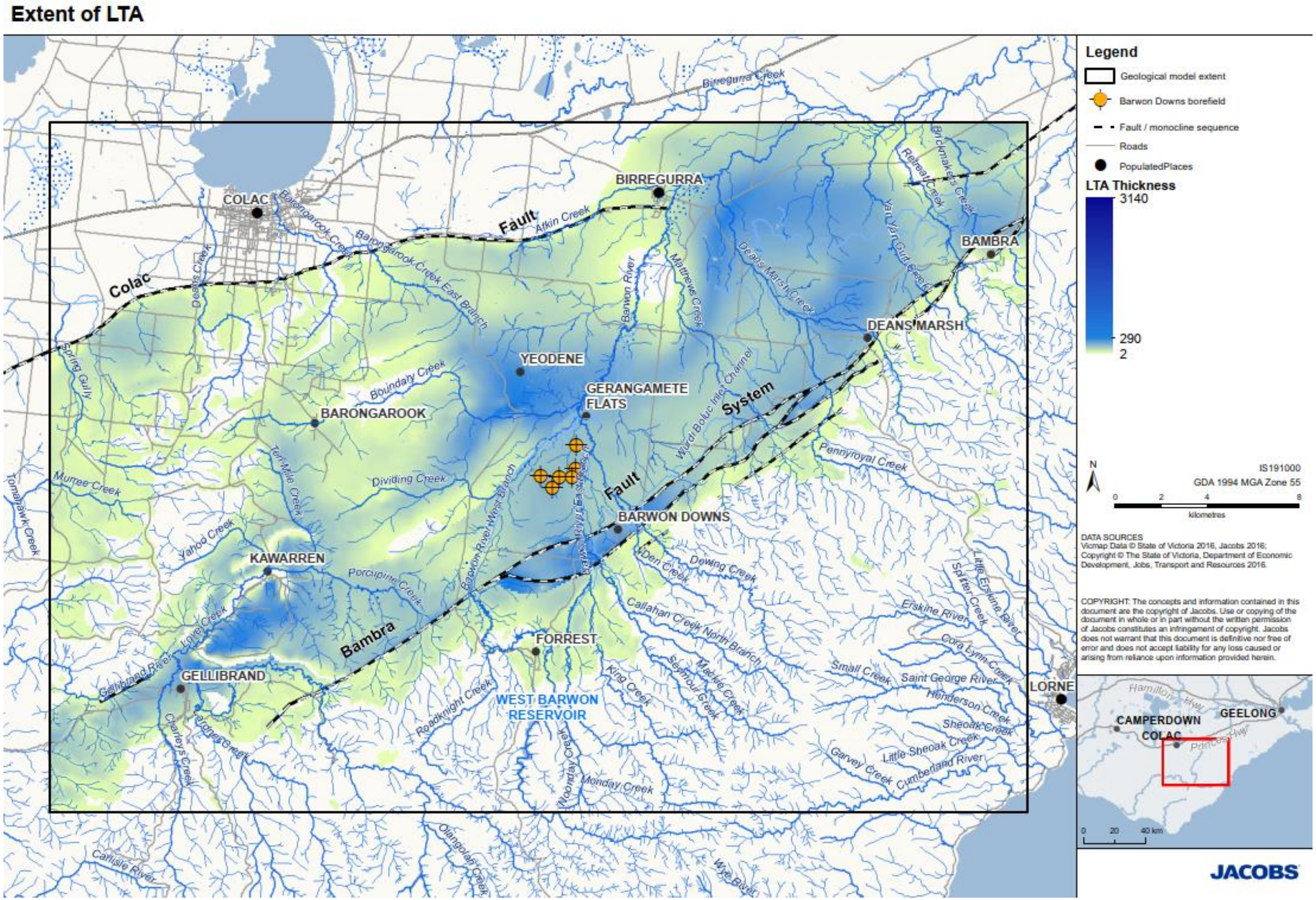

Figure 6: Extent and thickness of Lower Tertiary Aquifer (LTA)

5.1.1 Groundwater model

Groundwater modelling for Barwon Downs has occurred since the 1990s (Witebsky et al, 1995; Teng, 1996). Progressive improvements of the groundwater model have been made since – an approach consistent with the Australian Groundwater

Modelling Guidelines (Barnett et al, 2012). The last significant update to the model occurred in 2016-17 where it was expanded, re-built and re-calibrated.

The focus of the current model was to confirm potential impacts of pumping. This is a shift from previous models which had concentrated primarily on undertaking a resource assessment to determine the availability of groundwater.

The updated model was run over the period 1980 to 2016 with and without the Barwon Downs borefield operating to determine the historical impact.

The model can accurately differentiate historical pumping impacts from impacts associated with climate variability and identify areas where environmental receptors have been potentially impacted from historical operation of the Barwon Downs borefield.

However, the model is conservative, as it over predicts drawdown in some areas, particularly where there are alluvial aquifers present that have not been included in the model and where there are regional aquitards.

There is limited site-specific monitoring data along many of creeks and rivers in terms of both streamflow and groundwater monitoring of both alluvial and regional aquifers. In addition to this, site specific studies completed as part of the Barwon Downs borefield Technical Works Monitoring Program have highlighted there are physical attributes, such as the presence of a local alluvial aquifer and the regional aquitard, that essentially mitigate the risk the drawdown. These physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) are not well represented or include significant levels of predictive uncertainty in the model.

The Technical Works Monitoring Program confirmed that alluvial aquifers are present in many areas and most have not been influenced by drawdown, even in areas where the model may predict a decline in the watertable aquifer. In addition to this, drawdown in the regional aquitard near the surface is often less than predicted by the model. Drawdown takes time to propagate through the aquitard to the surface. However, the model calculates drawdown at the centre of each formation. As such, the model over predicts water table drawdown where the aquitard outcrops.

The conservative nature of the groundwater model means that areas identified as high or moderate risk need to be confirmed with site specific studies to understand the local interaction between groundwater and surface water and identify high value groundwater dependent ecosystem and their associated values.

5.1.2 Hydrogeology

The surficial geology together with the extent of groundwater model is shown in Figure 7. The key hydrogeological units are:

- Quaternary Alluvium
- Mid Tertiary Aquifer (MTA)
    - Clifton Formation
- Mid Tertiary Aquitard (MTD)
    - Gellibrand Marl
    - Narrawaturk Aquitard
- Lower Tertiary Aquifer (LTA)
    - Mepunga and Dilwyn Formations
    - Pember Mudstone
    - Pebble Point Formation
- Basement (a mix of pre-Tertiary rocks that vary across the groundwater catchment)

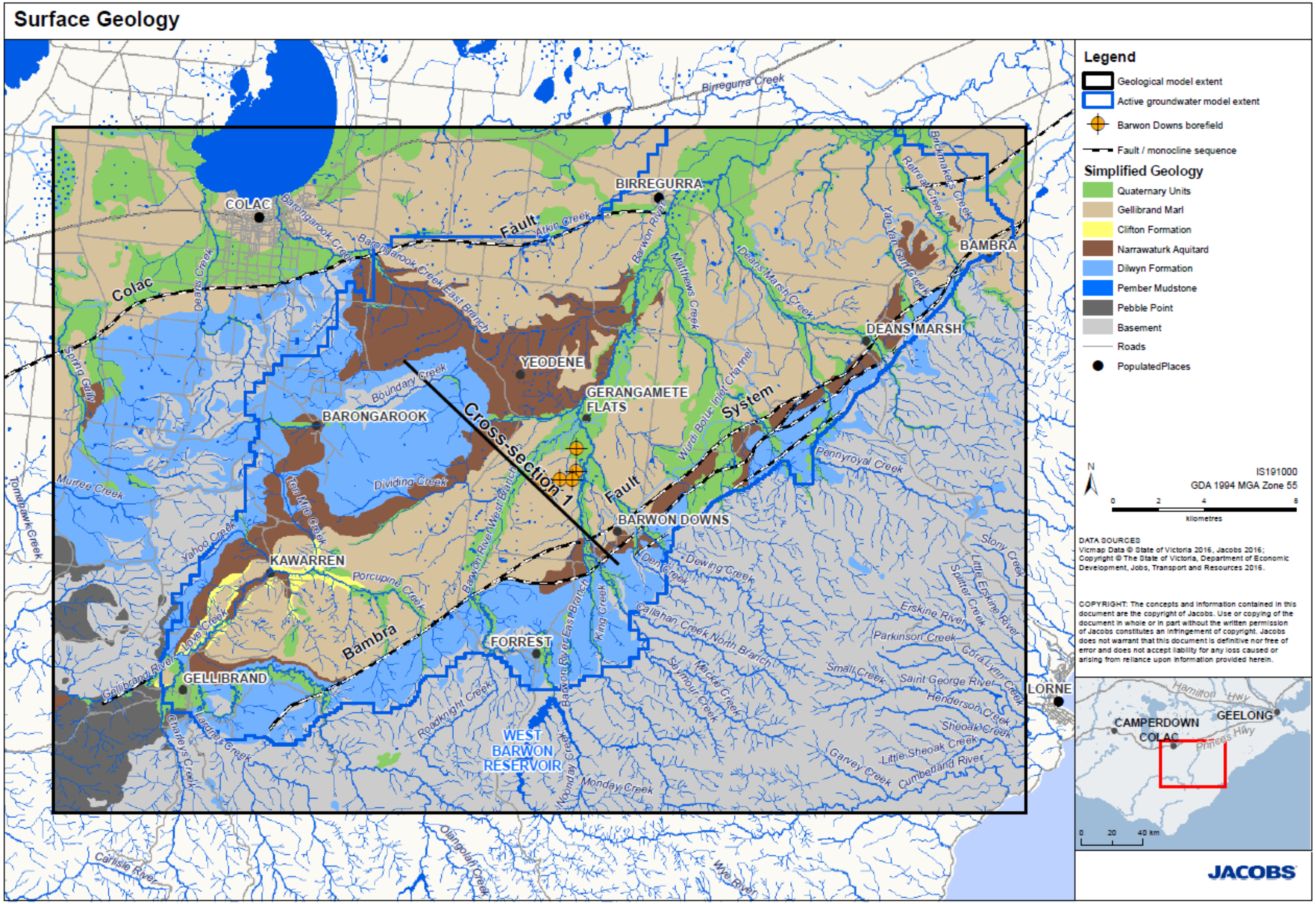

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Figure 7: Surface geology of the Barwon Downs graben and the extent of the groundwater model

The extent of the Barwon Downs groundwater model is largely defined by the extent of the Lower Tertiary Aquifer (LTA). The LTA extends to the north of the groundwater model; however, groundwater monitoring and previous studies have confirmed that drawdown does not extend to this part of the graben. Also, units of the same age as the LTA extend to the east of the groundwater model extent, but in this area the sediments are fine grained and are not considered to be a significant groundwater resource and are only present at depth and are well beyond the conceived area of impact of Barwon Downs borefield.

Groundwater Management Areas (GMAs)

The groundwater catchment that includes the LTA is covered by two Groundwater Management Areas (GMAs) – the Gerangamete and Gellibrand GMAs. The boundaries of these GMAs, together with the extent of the LTA in the groundwater model is shown in Figure 8.

The Barwon Downs borefield is in the Gerangamete GMA. The Gerangamete GMA includes all Middle and Lower Tertiary aquifers. The Clifton Formation aquifer (LMTA) exists in the centre of the graben and is a minor aquifer which lies between two thick aquitards. The LMTA outcrops in the valleys around Kawarren (see Figure 7). The Mepunga, Dilwyn and Pebble Point Formations together form the LTA which is the major aquifer in the graben. The LTA outcrops on the Barongarook High on the north western side of the graben and in the Bambra Fault zone on the south east side of the graben.

Surface water catchments

The LTA covers an area of approximately 480 km^2 below the surface and extends beneath two surface water catchments, the Barwon River catchment and the Otway Coast catchment (see Figure 8).

Most of the Barwon River's tributaries rise in the Otway Ranges to the south east of the borefield and flow north towards Birregurra. The remaining tributaries, including Boundary Creek, rise in the west of the catchment and flow across the Barongarook High before joining the Barwon River at the Gerangamete Flats.

Barongarook High is the main recharge area of the aquifer.

The Otway Coast catchment is a large catchment with many rivers that flow towards the coast. The Gellibrand River is in the largest of these rivers and is located to the south west of the borefield with tributaries rising in the Otway Ranges and the Barongarook High. This includes Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren. Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

All major rivers and creeks were included in the groundwater model including:

- Barwon River Catchment:
    - Dividing Creek
    - Boundary Creek
    - East Barwon River
    - West Barwon River
    - Barwon River downstream of the confluence between East and West Barwon Rivers.

- Gellibrand River Catchment:
    - Porcupine Creek
    - Ten Mile Creek
    - Yahoo Creek
    - Loves Creek

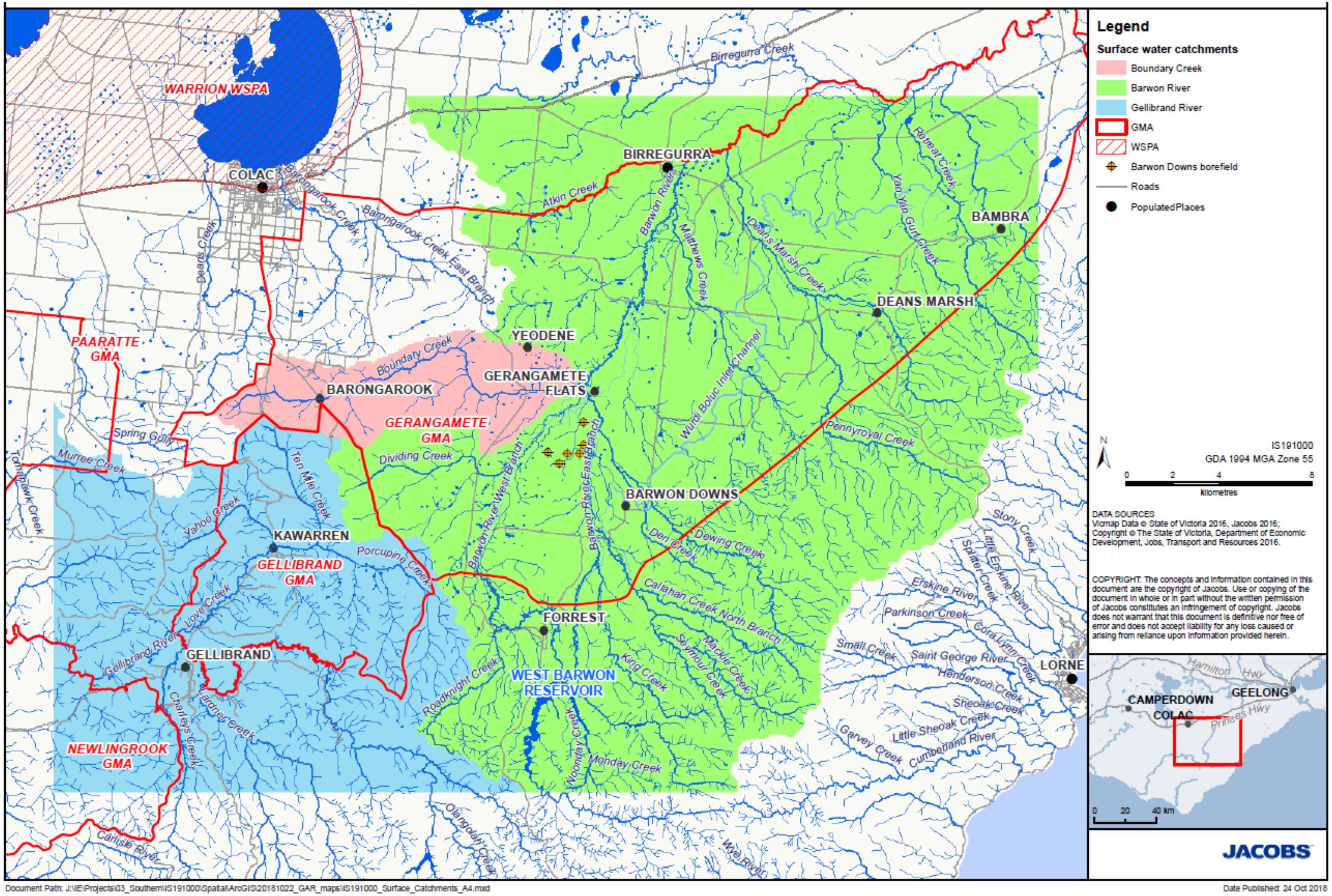

Figure 8: Location of the groundwater model extent, surface water catchments and Groundwater Management Areas (GMA)

5.2 Beneficial uses and environmental values

5.2.1 Consideration of the State Environmental Protection Policy (Victorian Waters)

Under clause 2.6g of the section 78 Notice, in preparing the scope of works, Barwon Water must ensure that the State Environmental Protection Policy (Victorian Waters) are considered.

The State Environment Protection Policy (Victorian Waters), also referred to as SEPP (Waters), provides a framework for the protection and management of water quality in Victoria, covering surface waters, estuarine and marine waters and groundwaters across the State. SEPP (Waters) commenced on 19 October 2018.

One of the ways in which the SEPP Waters seeks to achieve this objective is through identification of beneficial uses for waters and provision of environmental quality objectives to ensure beneficial uses can be realised (Victorian Government, 2018). SEPP Waters also identify the rules for decision makers and obligations on industry in order to protect our water environments.

Beneficial uses of all waters are described in this Policy and include water quality for the protection of ecosystems and species, human consumption, agriculture and industry, recreation, spiritual values and several other uses.

The beneficial uses of groundwater and surface water to be protected in accordance with the SEPP Waters vary depending upon the segment of the environment. For groundwater, segments of the environment are defined by the background level of Total Dissolved Solids (TDS is adopted as a proxy for salinity) in groundwater, as shown in Table 1, below.

Table 1: Segments of the groundwater environment

Segments	A1	A2	B	C	D	E	F
TDS range (mg/L)	0 - 600	601 – 1,200	1,201 – 3,100	3,101 – 5,400	5,401 – 7,100	7,101 – 10,000	>10,001

The groundwater salinity in the LTA is typically less than 500 mg/L TDS, which means that groundwater falls into Segment A1. Under Segment A1, the beneficial uses of groundwater requiring protection beneath the site and surrounding region include:

- Water dependent ecosystems and species (including surface water receptors)
- Potable water supply (desirable)
- Agriculture and irrigation (irrigation)
- Agriculture and irrigation (stock watering)
- Industrial and commercial
- Water based recreation (primary contact recreation)
- Traditional Owner cultural values
- Cultural and spiritual values, and
- Buildings and structures.

The SEPP Waters sets out the environmental quality indicators and objectives required to ensure protection of the beneficial uses of water. These criteria vary depending upon the beneficial use and are outlined in Table 2, below.

Table 2: Beneficial Uses of Water to be protected and assessment criteria

Beneficial Use	Intent of beneficial use and relevant guidelines
Water dependent ecosystems and species (largely unmodified)	Water quality that is suitable to protect the integrity and biodiversity of water dependent ecosystems including surface water, groundwater dependent ecosystems (wetlands, rivers and terrestrial vegetation) and maintenance of fish passage.

Beneficial Use	Intent of beneficial use and relevant guidelines
	Values for toxicants are specified in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, referred to as the ANZG. The SEPP Waters refers to the 2000 "ANZECC guidelines" however these have been superseded by the 2018 ANZG.
Potable Water Supply	Water quality is suitable for potable purposes. *The SEPP Waters indicates that potable water supply and/or human consumption after appropriate treatment requires water quality to be within guidance outlined in the Australian Drinking Water Guidelines (ADWG; NHMRC, 2011).*
Agriculture and irrigation: Irrigation	Water quality is suitable for agricultural activities such as irrigation of domestic gardens, commercial agriculture, parks and golf courses. *The SEPP Waters specifies that water quality meets the level of that indicator specified in the ANZECC guidelines for irrigation. The 2018 water quality guidelines refer to guidance from the 2000 ANZECC guidelines for this beneficial use.*
Agriculture and irrigation: Stock Watering	Water quality is suitable for stock watering *The SEPP Waters specifies that water quality meets the level of that indicator specified in the ANZECC guidelines for stock watering. The 2018 water quality guidelines refer to guidance from the 2000 ANZECC guidelines for this beneficial use.*
Industrial and commercial	The SEPP Waters states that groundwater must not be affected to the extent that industrial or commercial water quality is impacted however provides no specific guidance for this beneficial use.
Water based recreation (primary contact)	Water quality that is suitable for primary contact recreation (e.g. swimming, diving, water skiing, caving and spas), secondary contact recreation (e.g. boating and fishing) and for aesthetic enjoyment. For the purpose of water-based recreation (primary contact) the SEPP Waters states "…water quality indicators must not be greater than the level specified for water-based recreation." For chemical and aesthetic quality objectives, the SEPP Water refers to the Guidelines for Managing Risks in Recreational Water (National Health and Medical Research Council (NHMRC), 2008) which in turn, refers to the 2004 version of the ADWG (superseded by the 2018 update, as above).

Beneficial Use	Intent of beneficial use and relevant guidelines
	It is noted in the Guidelines for Managing Risks in Recreational Water that ADWG are based upon consumption of 2 L of water per day whereas consumption through recreation is approximately 200 mL. As such, the guidelines state that a substance occurring in recreational water at a concentration of 10 times that stipulated in the drinking water guidelines may merit further consideration. This factor of 10 should only be applied to non-volatile parameters where the only exposure pathway is ingestion.
Traditional Owner cultural values	Water quality that protects the cultural values of Traditional Owners, having recognised primary responsibility for protecting the values of water for cultural needs, to ensure that Traditional Owner cultural practices can continue. Values may include traditional aquaculture, fishing, harvesting, and cultivation of freshwater and marine foods, fish, grasses, medicines and filtration of water holes. No specific objectives or indicators are provided in the SEPP Waters for the beneficial uses of Traditional Owner cultural values. In the absence of specific objectives for these beneficial uses, criteria for the protection of water dependent ecosystems become the criteria.
Cultural and spiritual values	Water quality that is suitable for cultural and spiritual needs and that will ensure that cultural, spiritual and ceremonial practices can continue. These include the cultural values held by communities (e.g. baptisms, water-based festivals and cultural celebrations). No specific objectives or indicators are provided in the SEPP Waters for the beneficial uses of cultural and spiritual values. In the absence of specific objectives for these beneficial uses, criteria for the protection of water dependent ecosystems become the criteria.
Buildings and structures	For the purposes of Buildings and structures, the SEPP Waters states that introduced contaminants must not cause groundwater to become corrosive to structures of building materials. Contaminants with potential corrosive action include, but are not limited to, pH, sulfate, chloride, redox potential and salinity. No specific objectives or indicators are provided in the SEPP Waters for the beneficial use of Buildings and structures, however it is recommended that best practice guidelines and standards be used. These best practice measures vary based upon the construction of the building or structure, e.g. depth of piles or foundations and type of material used.

5.2.2 Environmental values

In addition to the beneficial uses defined in the SEPP Waters, there are other environmental values that will be considered in the scope of works.

The Resource Sharing Guidance (DELWP, 2015), describes the range of features and values that may depend on groundwater. Features include any physical feature that interacts with groundwater (e.g. aquifer, springs, rivers, wetlands) and includes environmental, social, cultural and economic values associated with those features.

This highlights that groundwater dependent features can support many different values. Examples provided by DELWP (2015) include:

- Groundwater can support terrestrial vegetation, which in turn can support other environmental or social values.
- Groundwater can contribute baseflow to a river, which in turn may support environmental values within or adjacent to the river, such as aquatic ecosystems and riparian vegetation. It may also support other social, cultural or economic values such as diversions from the waterway for agricultural production or consumptive use as well as recreational, aesthetic and aboriginal cultural values.

5.2.3 Community values

Values specific to Boundary Creek were identified by the Boundary Creek Remediation Working Group. These include:

- Physical structure (rehabilitation manual for streams, bank and stream bed erosion, peat)
- Soils and sediment quality
- Riparian zone
- Aquatic organisms
- Water quality
- Water flow
- Amenity / cultural / livelihood (stock and domestic)
- Fire protection

5.2.4 Informing of values

Technical investigations described later in this section have focused on assessing the potential impact of borefield operation on groundwater levels, streamflow, terrestrial vegetation and acid sulfate soils.

By focusing on these features, investigations and monitoring can be systematically targeted to ensure that the values listed in Table 2 are protected. In other words, the approach firstly assesses the magnitude of drawdown and potential impacts on groundwater dependent features, such that risks to linked values can be protected.

5.3 Risk assessment framework

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

The guidelines have been used to assess the potential risk to vegetation and rivers and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The guidelines outline a risk assessment process for High Value GDE's involving seven steps that have been adapted for the requirements of the section 78 notice:

1. Determine the area and identify high value ecosystems. Determine that the aquifer is unconfined and identify any features within that area, such as river, springs, soaks or terrestrial vegetation containing high value ecosystems. If the aquifer if unconfined and high value ecosystems are identified, go to step 2, otherwise assess the risk as low.

2. Determine the likelihood that the proposed groundwater extraction will interact with the feature.

3. Determine the consequence of groundwater extraction on the features.

4. Determine the risk to the high value ecosystems dependent on groundwater.

5. Determine how risk will be managed high value groundwater dependent ecosystems where initial risk is ranked as medium or high.

6. Consult with relevant Catchment Management Authority

7. Make a final decision.

This scope of work is limited to steps 1 through to 6. It is envisaged that Step 7 will be undertaken by Southern Rural Water.

The ministerial guidelines are specifically intended to be applied for high value GDEs. The guidelines have been adopted to provide an assessment framework for all areas across the study area, to identify areas that are potentially at risk.

In the assessment approach we have adopted, there is an over-strict application of the guidelines in that the test for high value has not been applied in the assessment. High Value GDEs are defined in the ministerial guidelines as follows:

"***high value ecosystems***" *means those ecosystems that are recognised by State and National Governments as being significant for their environmental values; including but not limited to:*

a) Ramsar listed wetlands as identified In the Australian Wetlands database of the Commonwealth Government wetlands listed in the Directory of Important Wetlands in Australia of the Commonwealth Government

b) Heritage river areas under Schedule 1 of the Heritage Rivers Act 1992

c) *species and communities listed under the Flora and Fauna Guarantee Act 1988 of the Victorian Government or the Environment Protection and Biodiversity Act 1999 of the Commonwealth Government*

d) *priority environmental values set by waterway managers, including those identified in Regional Waterway Strategies (or previously, Regional River Health Strategies) or their relevant sub-strategies.*

During Step 1, all features within the study area were assessed, regardless of whether they were situated where the regional aquifer is unconfined or identified as high value. The reason for this is that the location of all high value GDEs across the whole study area is not known.

Consequently, the guidelines were adapted to understand the potential areas at high risk and allow for a more targeted assessment to confirm impacts and identify potential high value GDEs.

In addition to this, drawdown from the regional aquifer has the potential to propagate through the overlying hydrogeological units, especially where the overlying aquitard is thin, therefore areas where the aquitard is present were also considered in the first instance.

The Guidelines state that:

- If the **risk is low**, the groundwater extraction licence application can be approved.
- If the **risk is moderate**, risk treatment options would be developed to manage risk and the groundwater licence can be approved with conditions.
- If the **risk is high**, risk treatment options to reduce the risk to medium or decide to accept the risk and fully document the reason, or the groundwater licence application many be refused.

5.3.1 Risk assessment framework for rivers

The risk posed to rivers because of groundwater extraction from the Barwon Downs borefield was assessed using the risk assessment framework outlined in the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).

The risk assessment framework as outlined in the Ministerial Guidelines is:

- **Likelihood** of groundwater-surface water interaction defined by either:
  - The depth to watertable in the regional aquifer OR
  - The time lag until 60% of extraction comes from the river.
- **Consequence** of the proposed groundwater extraction on the river defined by either:
  - The drawdown in the regional aquifer OR
  - The percentage reduction in low flow.
- **Risk** is considered in terms of low, medium, high risk using the following equation:
  - Likelihood x Consequence = Risk

Likelihood

The likelihood was defined based on a qualitative assessment of the time lag for a potential impact to reach the river or creek. The likelihood of connection to the regional aquifer and aquitard was defined as (see Table 3):

- Unlikely – rivers and creeks known to be disconnected (e.g. Dividing Creek)
- Possible – rivers and creeks where they flow over the regional aquitard, on the basis that the aquitard is a low permeability which increases the time lag for impact of groundwater extraction.
- Certain – rivers and creeks where they flow over the regional aquifer, on the basis that the permeability of the aquifer is high so the time lag for potential impact of groundwater extraction will be less.

Table 3: Likelihood of rivers being dependent of groundwater (surface flow)

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

Consequence

The consequence of pumping has been considered using both measures outlined in Table 4:

1. Percentage reduction in low flows (10th percentile low flow, or low) defined by the change in river flux. The change in river flux represents the difference in river flux between no pumping (Scenario 0) and the pumping scenarios (Scenarios 2 and 3).
2. Drawdown in the aquifer where the aquifer outcrops near the river.

Two consequence measures have been used because there is limited flow data available for many of the creeks, which introduces uncertainty when comparing the reduction in baseflow predicted by the model. Therefore, drawdown in the regional aquifer was used as another measure. The drawdown in the aquifer, where the aquifer outcrops is provided in Figure 9.

Table 4: Consequence classifications for streams (drawdown and reduction of baseflow to river)

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

Risk matrix

Connection between receptor class and groundwater		Reduction in streamflow / Drawdown: Minor	Moderate	Significant
	Unlikely	**Low**	**Low**	**Medium**
	Possible	**Low**	**Medium**	**High**
	Certain	**Medium**	**High**	**High**

5.3.2 Risk assessment framework for vegetation and PASS

The Ministerial Guidelines have been adopted to assess the potential risk to groundwater dependent vegetation and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The risk assessment framework is based on the following:

- **Likelihood** that groundwater will interact with the high value GDE defined by the depth to watertable in the regional aquifer (see Table 5)
- **Consequence** of the proposed groundwater extraction on the feature defined by the drawdown in the regional aquifer (see Table 6)
- **Risk** is considered in terms of low, medium, high risk using the following equation
    - Likelihood x Consequence = Risk

Table 5: Likelihood of terrestrial vegetation being dependent of groundwater (depth to watertable)

Likelihood	Description	Measure
Unlikely	A disconnected ecosystem	Depth to watertable > 6 m from surface
Possible	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface
Certain	A well-connected ecosystem	Depth to watertable < 2 m from surface

Table 6: Consequence (drawdown in watertable level)

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

Risk matrix

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

Groundwater Drawdown

5.4 Risk assessment results

The risk associated with historical pumping has been assessed using the drawdown results predicted by the groundwater model. The model can differentiate historical pumping impacts from impacts associated with climate variability and identify areas where environmental receptors have been potentially impacted from historical operation of the Barwon Downs borefield. The risk to groundwater dependent features is presented in regard to the following:

- Change in baseflow to rivers to inform potential risk to rivers
- Change in groundwater levels in watertable aquifer (i.e. drawdown) to inform potential risk to rivers where there are no flow gauges, vegetation, wetlands, springs and PASS

5.4.1 Rivers

Rivers across the study area are shown in Figure 9, which illustrates the spatial representation of the potential risk to rivers from groundwater pumping based on drawdown and likelihood of connection (Table 6). This illustrates the reaches most at risk of baseflow reduction due to borefield operation. However, it is also recognised that flow reductions to these reaches may propagate further downstream, placing longer portions of rivers at risk of impact.

To assess this, an overview of the risk to rivers based on flow reduction is tabulated in Table 7. This highlights river reaches that are classified as potential high, medium and low risk based on the likelihood of connection and the flow reduction predicted by the model. The risk is described as potential given the conservative nature of the groundwater model. For more detail, refer to Table 8.

Areas identified as high risk need to be confirmed with site specific studies to understand the local interaction between groundwater and surface water and identify high value groundwater dependent ecosystems and their associated values.

Table 7: Overview of potential risk to rivers

High risk	Medium risk	Low risk
Barwon Downstream confluence	Barwon River West Branch	Boundary Creek Reach 1
Barwon River East Branch	Boundary Creek Reach 3	
Boundary Creek – Reach 2	Porcupine Creek	
Gellibrand River	Loves Creek	
Ten Mile Creek	Dividing Creek	
Yahoo Creek		

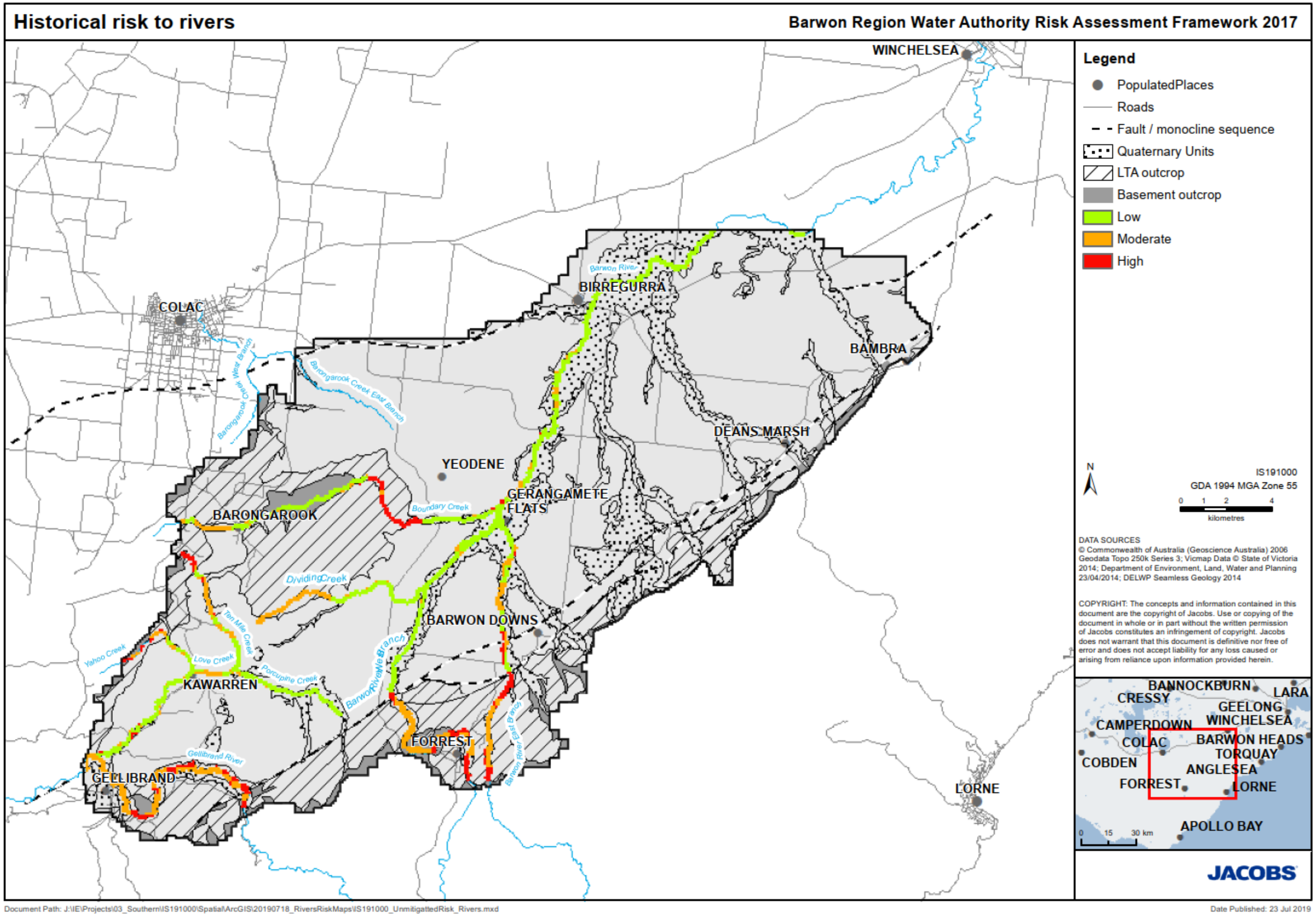

Figure 9: Historical potential risk to rivers according to modelled drawdown (consequence) and modelled likelihood

Table 8: Risk assessment results for rivers and creeks in the Barwon River catchment based on modelled flow reduction as a proportion of flow (consequence) and potential connection to LTA (likelihood)

River Reach	Low Flow (Q90)	Likelihood of connection to regional groundwater	Max impact historic			Potential maximum risk
			ML/day	% low flow	Consequence	
Barwon River (total)	**4.9**[1]		**4.1**			
West Branch aquifer		High	<0.01	<1%	Low	**Medium**
West Branch aquitard		Moderate	0.1	2%	Med	**Medium**
Downstream confluence		Moderate	0.7	14%	High	**High**
East Branch aquifer		High	1.6	33%	High	**High**
East Branch aquitard		Moderate	1.7	35%	High	**High**
Boundary Creek	**1.0**[2]		**3.1**			
Reach 1		Moderate	<0.01	<1%	Low	**Low**
Reach 2		High	2.9	>100%	High	**High**
Reach 3		Moderate	0.3	30%	High	**Medium**
Dividing Creek	**NA**	Low	0.4	NA	NA	**NA**
Gellibrand River	12.24	High	0.3	2%	Moderate	**High**
Porcupine Creek	0.35	Moderate	0.008	2%	Moderate	**Medium**
Ten Mile Creek	1.33	Mod – High	0.2	15%	High	**High**
Yahoo Creek	1.02	Mod – High	0.08	8%	Moderate	**High**
Loves Creek	1.67	Moderate	0.02	1%	Moderate	**Medium**

1.Based on Ricketts March gauge

2.Based on Yeodene gauge

Table 9: Risk assessment results for rivers and creeks in the Barwon River catchment based on drawdown (where there are no flow gauges)

River Reach	Likelihood of connection to regional aquifer	Consequence		Potential Risk
		Drawdown	Consequence	
Dividing Creek	Low	>2m	High	**Medium**

5.4.2 Vegetation and potential acid sulfate soils

The risk to other groundwater dependent features (vegetation, wetlands, springs and PASS) across the model area and based on model results, is shown in Figure 10.

An overview of the risk to rivers vegetation is tabulated in Table 10, which highlights areas classified as potential high, medium and low risk based on the likelihood of connection to the regional aquifer and drawdown predicted by the model. The risk is described as potential given the conservative nature of the groundwater model. For more detail, refer to Table 11 and Table 12.

It should be noted that there are some discrepancy between the risks illustrated in and that tabulated in Table 11. Namely, the figure illustrates a low potential risk at TB5, TB6 and TB7 while Table 11 indicates a medium risk. This is due to the discrepancy between the depth to water table predicted by the model and that observed in field.

It should also be noted that while monitoring of groundwater levels, vegetation condition and PASS has been focused on the sites listed in Table 11 below, these represent a set of monitoring locations that have been narrowed from preceding investigations. For example, broader areas of potential impact to vegetation were assessed via remoted sensing and NDVI analysis across 36 sites, with no evidence found to suggest that groundwater extraction from the Barwon Downs borefield has had a negative impact on vegetation activity or condition (Jacobs 2016).

It is noted however, that the majority of these investigations were focused in the west of the Barwon Downs Graben. The focus was on the Otway Ranges State Forest which was identified as a potential GDE where the LTA outcrops and hence, at risk of drawdown impact. Some isolated areas to the north and east of this area were assessed, but due to being dominated by pastureland, were not considered as directly related to borefield impacts. It is not known if high value GDEs exist in these areas.

Similarly, monitoring at the four current PASS sites has been rationalized based on a preliminary assessment of 14 locations throughout the graben and subsequent sampling at six locations.

The results from these investigations will be reviewed in light of areas identified as potential '**high**' risk and if necessary, confirmed with site specified studies to understand the local interaction between groundwater and surface water to identify high value groundwater dependent ecosystems and their associated values. In particular, this includes areas to the south of the Graben near the Gellibrand River, those to the East of the Barwon River between Barwon Downs and Deans Marsh and those to the north of Yeodene.

Table 10: Overview of confirmed potential risk to vegetation and PASS monitoring sites

High risk	Medium risk		Low risk
T1	T4	T12	T3
T2	T5	PASS1	T9
	T6	PASS2	T11
	T7	PASS4	T13
	T8		T14
	T10		PASS3

Table 11: Risk Assessment results for vegetation monitoring sites based on modelled drawdown (consequence) and likelihood of connection to LTA derived from field investigations (likelihood)

Region of graben	Vegetation monitoring site	Impact/ Reference site	Local Hydrogeology	Vegetation dependent on regional aquifer	Likelihood of connection to regional aquifer	Consequence (drawdown predicted in regional aquitard/aquifer)	Potential Risk
West	T1/TB1c	Impact	Alluvial / aquitard	No	Low	29.3	**High**
	T2	Impact	Alluvial / aquifer	Yes	High	16.1	**High**
	T3	Impact	Perched / aquifer	No	Low	0.6	**Low**
	T4	Impact	Perched / aquifer	No	Low	16.4	**Medium**
	T5	Reference	Alluvial / aquifer	Yes	High	0	**Medium**
	T6	Reference	Alluvial / aquifer	Yes	High	0	**Medium**
	T7	Reference	Alluvial / aquifer	Yes	High	0	**Medium**
	T8	Impact	Alluvial / aquitard	No	Low	9.4	**Medium**
	T9	Impact	Alluvial / aquitard	No	Low	0.1	**Low**
	T10	Impact	Alluvial / aquitard	No	Low	15.5	**Medium**
	T11	Reference	Alluvial / aquitard	No	Low	0	**Low**
	T12	Reference	Alluvial / aquitard	No	Low	5.0	**Medium**
	T13	Reference	Alluvial / aquitard	No	Low	0.4	**Low**
	T14	Reference	Alluvial / aquitard	No	Low	0.2	**Low**

Table 12: Risk Assessment results for PASS monitoring sites based on modelled drawdown (consequence) and connection to regional aquifer derived from site investigations (likelihood)

Region of graben	PASS monitoring site	Local Hydrogeology	Vegetation dependent on regional aquifer	Likelihood of connection to regional aquifer	Consequence (drawdown predicted in regional aquitard/aquifer)		Potential Risk
West	PASS1	Alluvial / aquitard	No	Low	5.0	High	**Medium**
East	PASS2	Alluvial / aquifer	No	Low	5.9	High	**Medium**
West	PASS3	Alluvial / aquitard	No	Low	0.4	Moderate	**Low**
East	PASS4	Alluvial / aquitard	No	Low	2.5	High	**Medium**

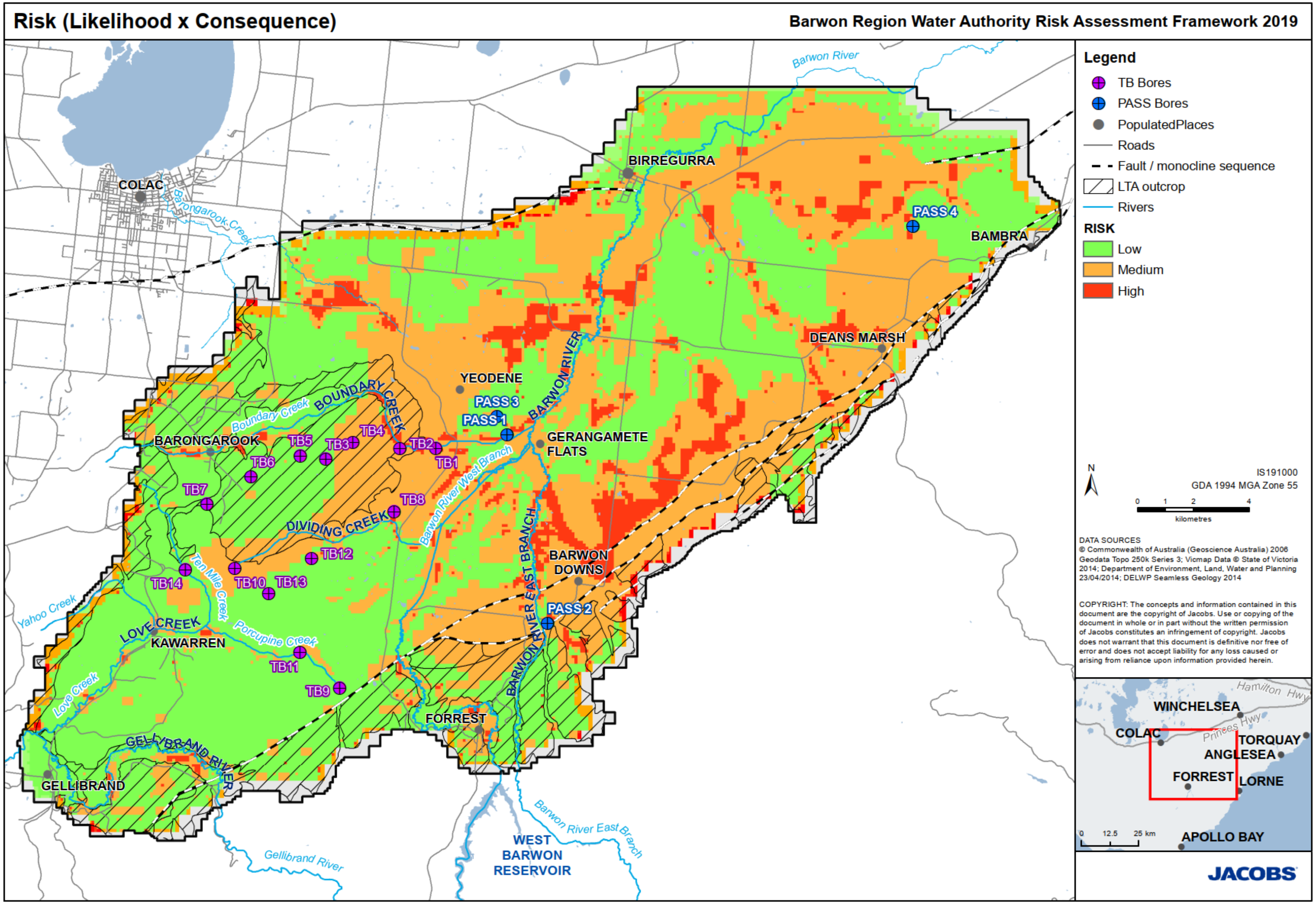

Figure 10: Historical risk to vegetation and potential acid sulfate soils based on modelled drawdown (consequence) and modelled likelihood

6 Prioritisation for at risk areas

The groundwater model predicts drawdown in all hydrogeological layers for the whole extent of the Lower Tertiary Aquifer regional groundwater system which covers an area of approximately 480 km^2.

The remediation plan will focus on areas of potential high risk where impacts have been confirmed with monitoring and high value GDEs are known to exist.

The remediation plan will also include investigation of areas of potential high risk where there is insufficient monitoring to confirm if the risk is high. These areas will be the focus for further work to confirm the risk and presence of high value GDEs or associated beneficial uses or environmental values.

The model was used to inform the **potential risk** to beneficial uses and environmental values at the surface.

While the model was able to narrow down sites at risk from historic groundwater pumping and give them a ranking of high, medium or low, it should be noted that these risk ratings are outputs of a model based on conservative assumptions.

Areas will require further site specific investigations to 'ground-truth' and improve the understanding of the local hydrogeological conceptual model and to validate the model's predictions of potential risk with observable monitoring data.

Barwon Water proposes that any **potential risk rated as high** as an outcome of the risk assessment process be prioritised to confirm if historic groundwater pumping has had a measurable negative impact to any beneficial uses or environmental values.

Barwon Water also proposes to review the risk assessment following completion of investigations of the high risk rated areas before proceeding with any investigations for medium risk areas. This will consider the additional data collected for the high risk areas to determine if there is need to confirm impacts for risks rated medium for any beneficial uses or environmental values.

This approach is shown in Figure 11.

Currently, the only site known to be an area of confirmed impact is Boundary Creek and Big Swamp. Observable data on groundwater levels, water quality and surface water have confirmed the risk is high for this area.

The approach to focus on remediating Boundary Creek and Big Swamp while investigating the broader catchment to confirm potential risk was agreed to and supported by the remediation working group (meeting held on 21 March, 2019).

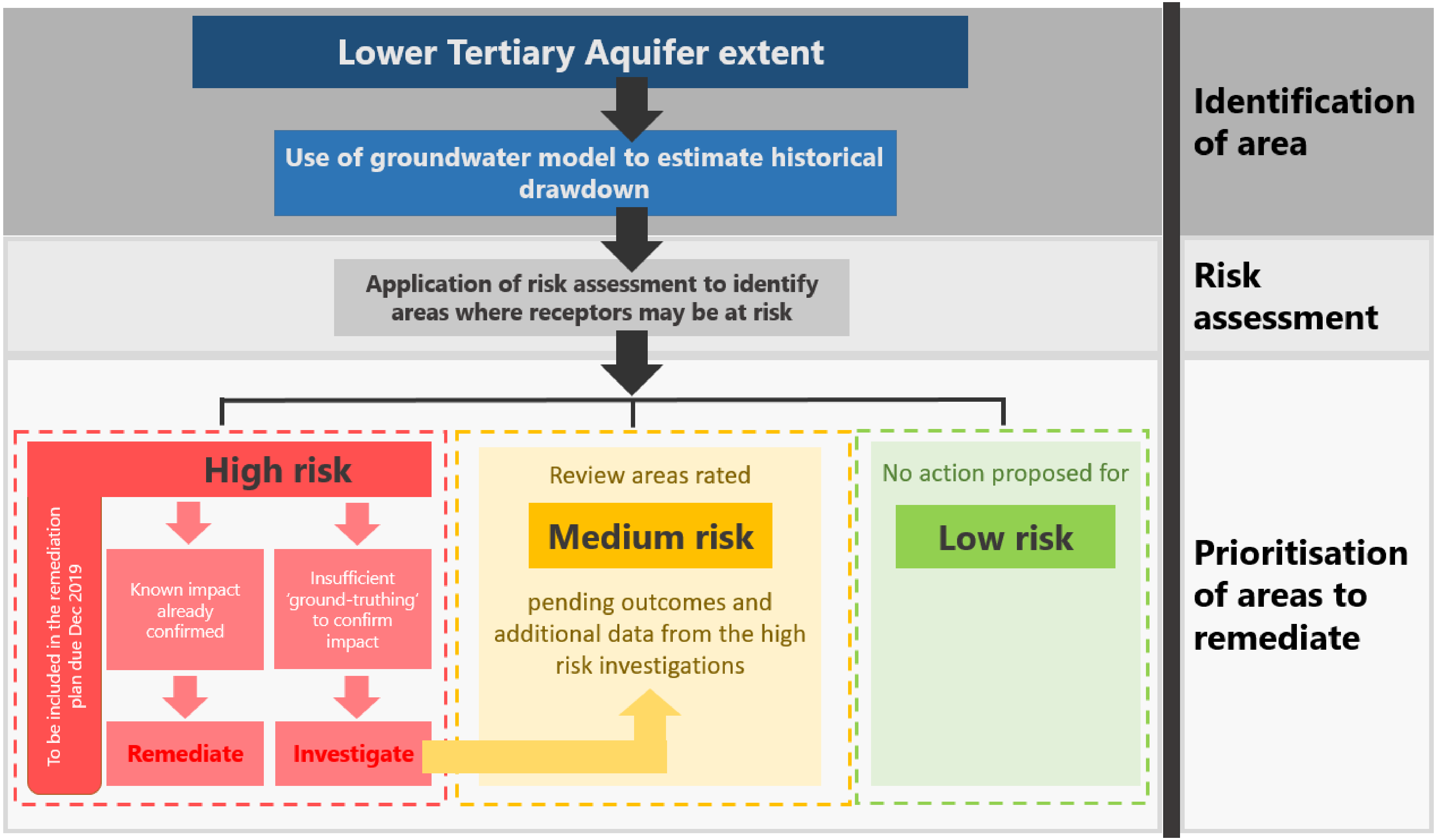

Figure 11: Approach taken to prioritise areas for remediation

6.1.1 Boundary Creek catchment

A report commissioned by Barwon Water titled "Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts" (Jacobs June, 2017) found that, operation of the borefield over the past 30 years is responsible for two thirds of the reduction of groundwater base flow into Boundary Creek, the dry climate experienced during the same period accounts for the remaining one third and operation of the borefield has increased the frequency and duration of no flow periods in lower reaches of Boundary Creek.

The report also highlighted that the main driver of reduced baseflow in Boundary Creek was related to the lowering of groundwater levels in the Lower Tertiary Aquifer which outcrops along much of Boundary Creek.

Boundary Creek was identified as a receptor that could be adversely impacted by groundwater pumping in the 1990s and has been an area of community concern for many decades. Consequently, the catchment is heavily monitored with several gauges monitoring flow and water quality and numerous groundwater bores.

Monitoring data has enabled the potential impacts to be confirmed for Boundary Creek.

6.1.2 Broader catchment area

Across most of the study area, there is insufficient monitoring to confirm predicted drawdown at the surface and thus, potential risk to receptors.

The monitoring program is typically lacking in one or more of the following:

- Recent surface water flow
- Recent surface water quality monitoring
- Shallow groundwater bores monitoring the alluvial aquifer or the shallow regional aquifer
- Groundwater bores monitoring the (deeper) regional aquifer.

The existing monitoring data has been reviewed for all rivers, vegetation and PASS to confirm if potential risk can be confirmed.

Where there is sufficient monitoring to confirm an adverse impact from groundwater pumping and the presence of high value groundwater dependent feature, a recommended scope of works for remediation is outlined.

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

6.1.3 Rivers – key findings from review of monitoring data

The existing monitoring data has been reviewed for all rivers with potential high risk and Boundary Creek is the only surface water feature that has sufficient monitoring to confirm an impact from pumping (refer to Table 13).

Further work is required to investigate the potential impact from pumping for the remaining rivers including Barwon River downstream of the confluence, Gellibrand River, Yahoo Creek and Ten Mile Creek which have all been classified as high potential risk

Table 13: Summary of potential risks, available monitoring data and ability to confirm historical impacts

Receptor	Potential risk	Available surface water monitoring data	Available GW monitoring data	Confirmed / unconfirmed impact	Action
Boundary Creek R1	**Low**	✓	✓	Confirmed	No action
Boundary Creek R2	**High**	✓	✓	Confirmed	**Remediate**
Boundary Creek R3	**Medium**[3]	✓	✓	Confirmed	**Remediate**
Barwon River West Branch (LTA)	**Medium**	×	×	Unconfirmed	Review in future
Barwon River West Branch (MTD)	**Medium**	×	×	Unconfirmed	Review in future
Barwon River East (LTA)	**High**	×	×	Unconfirmed	Investigate
Barwon River East (MTD)	**High**	×	×	Unconfirmed	Investigate
Barwon River (downstream of the confluence)	**High**	✓	×	Unconfirmed	Investigate
Dividing Creek	**Medium**	×	✓	Unconfirmed	Review in future
Gellibrand River	**High**	✓	×	Unconfirmed	Investigate
Porcupine Creek	**Medium**	×	✓	Unconfirmed	Review in future
Ten Mile Creek	**High**	×	✓	Unconfirmed	Investigate
Yahoo Creek	**High**	✓	×	Unconfirmed	Investigate
Loves Creek	**Medium**	×	×	Unconfirmed	Review in future

[3] Although rated as medium risk, there are flow-on effects that impact both water flows and water quality from Boundary Creek reach 2.

6.1.4 Boundary Creek key findings

- Sufficient information to confirm that the potential high risk predicted by the groundwater model and risk assessment framework has confirmed that Boundary Creek has been impacted by groundwater pumping.
- Groundwater level monitoring at UBCk1 and UBCK2 have confirmed that Reach 1 remains gaining.
- Surface water monitoring at Barongarook (233273) and upstream of McDonalds Dam (233231) confirm that Reach 1 remains perennial.
- Groundwater level monitoring at bores 109130 and 109128 have confirmed that Reach 2 has switched from a gaining reach to a losing reach.
- Surface water flow gauging downstream of McDonalds Dam (233229) and Yeodene (233228) confirm that Reach 2 of Boundary Creek has shifted from a perennial creek to an ephemeral creek.
- Groundwater level monitoring at bores LBC01 and LBC02 confirm that Reach 3 remains a gaining reach.

6.1.5 Barwon River

- Insufficient monitoring data along the Barwon River East where the river flows over outcropping LTA:
  - Groundwater monitoring at bore 48249 and PASS2 could be used to assess groundwater-surface water interaction, however the elevation of the East Branch needs to be surveyed.
  - While flow accretion monitoring has been undertaken on the East Branch, surface water flow gauging at gauges 233204, 233268 and 233253 are insufficient to confirm impacts. Gauge 233268 is the only gauge that is currently monitored, and subsequently additional downstream gauges are required.
- Insufficient monitoring data along the Barwon River East where river flows over the regional aquitard:
  - Groundwater monitoring at bores 48250, 82848, 82850, 82851 and 82852 is insufficient to confirm impacts as bores are not currently monitored and are screened too deep.
  - There are no surface water gauges in this area.

- Insufficient monitoring data along the Barwon River downstream of the confluence between the East and West Branches:
  - No shallow groundwater monitoring bores are present to confirm groundwater levels in the shallow regional aquifer and the alluvial aquifer.
  - Surface water gauging at Rickets Marsh (233224) exists, however additional gauge downstream of the confluence is required.

6.1.6 Gellibrand River

- Sufficient surface water gauges, however insufficient groundwater monitoring data along Gellibrand River.
  - Shallow groundwater bores are present but are not currently monitored (e.g. 108916, 108917, 108918 and 108920). Deep groundwater monitoring bores are also present but are not monitored (e.g. 108898 and 10899).
  - Two active surface water gauges 235227 (Bunkers Hill) and 235202 (Gellibrand 235227 and 235202 are currently monitored. Gauge 235228 (Gellibrand) is not currently monitored.

6.1.7 Ten Mile Creek

- Insufficient surface water monitoring data along Ten Mile Creek:
  - There are several groundwater monitoring bores that have been monitored since 1993 to present (Bores 114169, 113705, 113706) and more recently TB14 has been installed.
  - Surface water gauge 235239 was reinstated in 2018 and is currently monitored.

6.1.8 Yahoo Creek

- Insufficient monitoring data along Yahoo Creek:
  - There are no active monitoring bores in this area.
  - Surface water gauge 235240 was reinstated in 2018 and is currently monitored.

6.2 Vegetation – key findings from review of monitoring data

The existing monitoring data has been reviewed for all vegetation monitoring sites.

Table 14 provides an overview of the assessment of the monitoring data.

T1 and T2 vegetation monitoring sites, located in the Boundary Creek catchment, are the only areas where there is sufficient monitoring to confirm that vegetation has been impacted by groundwater pumping.

While the risk assessment indicates that there is a moderate potential risk at T4, T5, T6, T7, T8, T10 and T12, investigations undertaken at these sites indicates that either drawdown has not propagated to these sites, or that an alluvial aquifer is present that buffers the impact from groundwater pumping.

At the remaining T3, T9, T11, T13 and T14 sites, investigations and monitoring have confirmed that there has been no impact to the vegetation at these locations.

The groundwater model indicates that there are other areas in the study area (particularly to in the south east of the graben) where drawdown is predicted to have occurred and the potential risk is moderate and high. The monitoring data in these areas will be reviewed to understand if there is sufficient information to confirm if impacts have occurred.

Table 14: Summary of potential risks to receptors, available monitoring data and ability to confirm historical impacts

Region of graben	Receptor	Potential risk	Available GW monitoring data	Confirmed / unconfirmed impact	Action
West	T1	**High**	✓	Confirmed impact	**Remediate**
	T2	**High**	✓	Confirmed impact	**Remediate**
	T3	**Low**	✓	Confirmed no impact	No action
	T4	**Medium**	✓	Confirmed no impact	No action
	T5	**Medium**	✓	Confirmed no impact	No action
	T6	**Medium**	✓	Confirmed no impact	No action
	T7	**Medium**	✓	Confirmed no impact	No action
	T8	**Medium**	✓	Confirmed no impact	No action
	T9	**Low**	✓	Confirmed no impact	No action
	T10	**Medium**	✓	Confirmed no impact	No action
	T11	**Low**	✓	Confirmed no impact	No action
	T12	**Medium**	✓	Confirmed no impact	No action
	T13	**Low**	✓	Confirmed no impact	No action
	T14	**Low**	✓	Confirmed no impact	No action
	North of Yeodene	**High**	TBA	Unconfirmed	Investigate
East	Barwon Downs to Deans Marsh	**High**	TBA	Unconfirmed	Investigate
South	Along Gellibrand River	**High**	TBA	Unconfirmed	Investigate

6.3 Potential acid sulfate soils – key findings from review of monitoring data

The existing monitoring data has been reviewed for Yeodene Swamp and the PASS monitoring sites. Table 15 provides an overview of the assessment of the monitoring data.

There is sufficient information to confirm that Big Swamp has been impacted by pumping from Barwon Downs. Big Swamp is located in the Boundary Creek catchment.

There is also sufficient information for the PASS monitoring sites to confirm that there has been no impact to the PASS at these locations. This is primarily because either drawdown has not propagated to these sites, or there is an alluvial aquifer present that buffers the impact from groundwater pumping.

The PASS monitoring sites were selected as these are considered to be the most sensitive to impact from pumping from Barwon Downs. No other PASS sites are recommended for further investigation.

Table 15: Summary of potential risks to receptors, available monitoring data and ability to confirm historical impacts

Region of graben	Receptor	Potential risk	Available SW monitoring data	Available GW monitoring data	Confirmed / unconfirmed impact	Action
West	**Big Swamp**	**High**	✓	✓	**Confirmed impact**	**Remediate**
West	PASS1	**Medium**	✓	✓	Confirmed no impact	No action
East	PASS2	**Medium**	✓	✓	Confirmed no impact	No action
West	PASS3	**Low**	✓	✓	Confirmed no impact	No action
East	PASS4	**Medium**	✓	✓	Confirmed no impact	No action

6.3.1 Yeodene (Big) Swamp

- Sufficient monitoring data to confirm that Big Swamp has been influenced by pumping:
  - Although groundwater level monitoring at TB1a, TB1b and TB1c indicate an upward hydraulic gradient between the aquitard and alluvium, and groundwater levels ranging between 1 and 2 m bgl towards the downstream end of Big Swamp, drawdown impacts upstream of the swamp have caused reduced inflows to the swamp.
  - Surface water monitoring in Boundary Creek at Yeodene (233228) indicates that flow cessation in the creek is related to borefield operation. Surface water pH monitoring indicates a decline in the median pH from 6.5 to 3.8 due to flow cessation. This confirms that borefield operation has resulted in surface water acidification through Big Swamp.

7 Prioritisation Summary

Areas prioritised for remediation with impact confirmed include:

- Boundary Creek reaches 2 and 3
- Vegetation in Boundary Creek in reaches 2 and 3
- Big Swamp

Areas prioritised for further investigation based on potential '**high**' risk ranking:

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

Figure 12 below illustrates the outcomes of Table 13 and Figure 11, which is colour coded according to:

1. No action in areas of confirmed low risk
2. Unconfirmed medium risk (Review areas pending outcomes of the high risk investigations)
3. Unconfirmed areas of high risk (Investigate)
4. Confirmed areas of high risk (Remediate)

Note that Figure 12 focuses on rivers only.

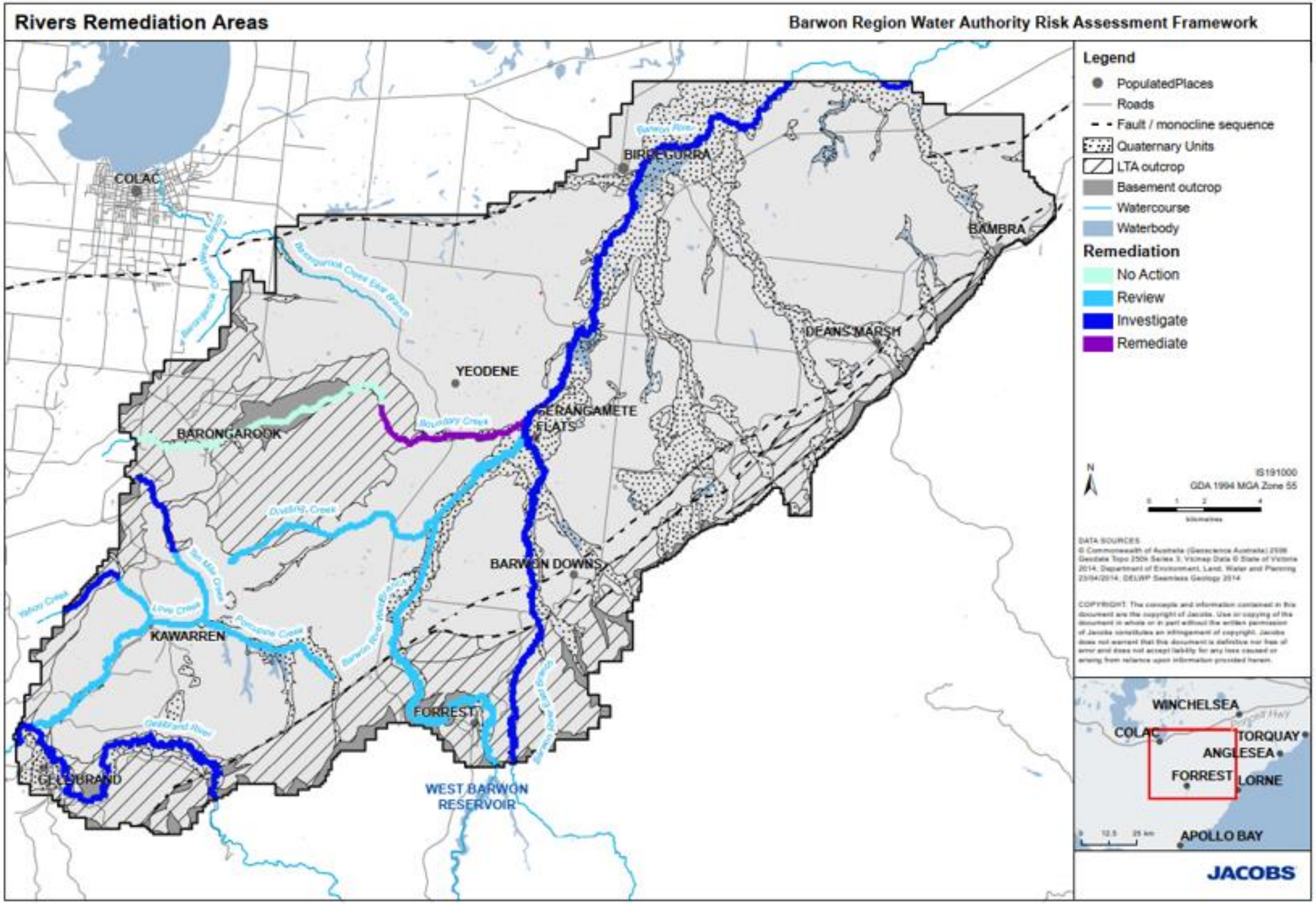

Figure 12: Areas outlining no action, review, investigate and remediate

8 Areas prioritised for remediation - Environmental Assessments

To remediate areas with confirmed impact, detailed environmental assessments are required to inform the remediation plan. Figure 13 and Table 16 summarise key activities to be performed under the scope of works grouped according to the assessment categories stipulated under clause 2.5 of the Section 78 Notice.

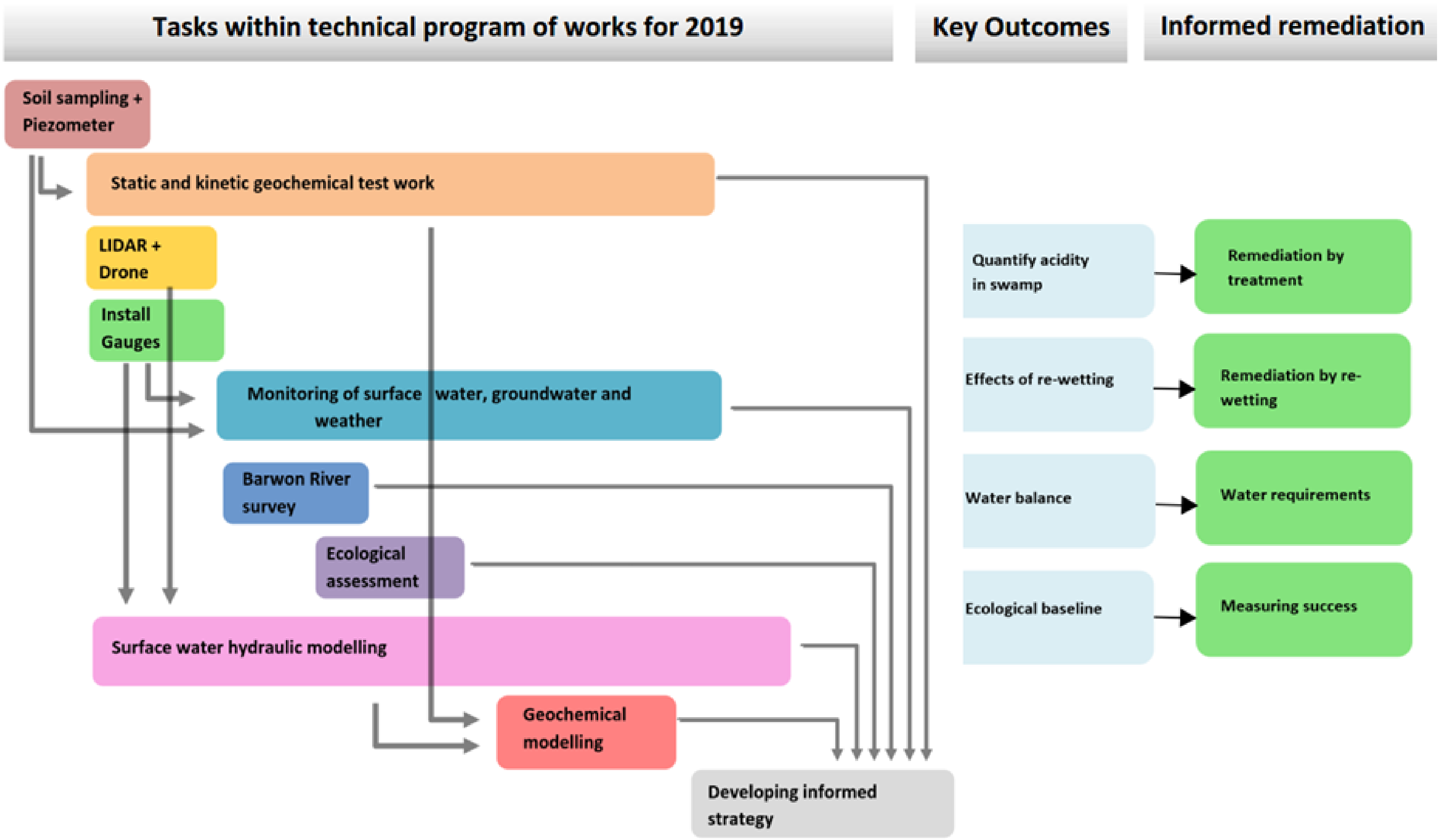

Figure 13: Task summary and key outcomes

Table 16: Summary of activities for the field program

Assessment category	Activities
Hydrogeological Condition	• On-going water level monitoring of existing bores. • Monitoring of water quality (pH, sulfate and heavy metals) in bores that intersect the Lower Tertiary Aquifer near Boundary Creek. • Installation of shallow groundwater piezometers in Big Swamp. • Soil collected during installation of piezometers to be used for subsequent soil geochemical analysis and incubation tests.
Hydrology	• On-going monitoring of surface water flows in Boundary Creek, including below 'McDonalds Dam'. • Installation of additional stream gauges in Boundary Creek at the eastern and western edges of Big Swamp. • Analysis of flow data to inform system water balances and surface water modelling.
Ecological Assessment	• Continue on-going vegetation monitoring in the Damplands and Big Swamp. • Assessment of sediment quality in the Barwon River downstream of Boundary Creek. • Assessment of macro-invertebrate community structure in Boundary Creek and the Barwon River downstream of the confluence with Boundary Creek.
LIDAR Mapping	• Undertake a LIDAR survey of Big Swamp.
Results of Soil Sampling	• Use the soil collected during installation of piezometers to determine SCr, KCl extractable pH, TAA, net acid soluble sulfur, and acid neutralising capacity, sulfate and at least one of total carbon, charcoal density or magnetic susceptibility. • Use the soil collected during installation piezometers to undertake lab incubation studies to determine the amount of bioavailable carbon in Big Swamp, whether or not it is possible to re-instate sulfate reduction in the wetland and whether or not other biogeochemical processes can lead to an increase in alkalinity.

8.1 Task 1 - Soil sample collection and installation of piezometers

8.1.1 Objective

The objective of this task is to address key knowledge gaps outlined in Baldwin (2018) with regard to understanding soil chemistry, groundwater levels and aquifer properties of the peat and alluvial sediments in Big Swamp. Specifically, this task has been included to help answer the following priority research questions documented in Baldwin (2018):

- Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer?
- Are there preferential surface or subsurface flow paths in Big Swamp?
- How much actual and potential acidity is currently stored in Big Swamp?
- How much sulfate remains in the sediment profile in Big Swamp?
- How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
- Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in the Big Swamp?
- Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?
- How extensive is fire damage to the peat in Big Swamp?

The installation of piezometers will also allow for collection of sufficient soil samples for static and kinetic geochemical testing and ongoing groundwater level and quality monitoring.

8.1.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for collection of soil samples and installation of piezometers:

- Jacobs (2018) Yeodene Swamp study

- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Minimum construction guidelines for water bores in Australia (NUDLC, 2012)
- National acid sulfate soils sampling and identification methods manual (Sullivan et al., 2018)
- Australian Soil and Land Survey Field Handbook (NCST 2009).

8.1.3 Description

Baldwin (2018) identified a need to align soil characterisation in Big Swamp with the national acid sulfate soils sampling and identification methods manual (Sullivan et al., 2018). Therefore, collection of soil samples at various locations throughout Big Swamp is required.

Further, Baldwin (2018) highlights that where drawdown is expected, as is the case with Big Swamp, then sampling should go to a depth of at least one metre below the lowest estimated groundwater drawdown. Baldwin (2018) also recommended sampling to greater depths to enable characterisation of deeper portions of peat in the soil profile and discussion of sub-surface flow.

There is limited information on the historical fluctuations in the groundwater level in Big Swamp. The estimated depth to groundwater within the swamp in 2017 was less than 1 m below ground surface at all but one of the existing piezometers, even though groundwater levels in the underlying Lower Tertiary Aquifer are several meters below the ground surface. Therefore, soil sampling to a depth of 4 m has been deemed sufficient to account for the thickness of the peat and likely historical drawdown in the peat.

Given access limitations to Big Swamp and to minimize disturbance to the area the method proposed for soil sample collection and subsequent piezometer installation is a 60 mm diameter hand held petrol driven soil corer with plastic tube inserts to maintain intact cores. Samples will be collected at 0.5 m intervals and logged according to the Australian Soil and Land Survey Field Handbook (NCST 2009).

After collection of soil samples, each 50 mm open hole will be fitted with a 25 mm PVC piezometer in accordance with the Minimum Construction Guidelines for water bores in Australia (NUDLC, 2012).

All piezometers will be subsequently fitted with a level logger and slug tested to assess the hydraulic conductivity of the geological material at each location. Following the completion of piezometer installation, each bore will be surveyed to give groundwater elevation at each point.

It is also proposed that additional survey points be collected from key points along the fire trenches and any apparent drainage lines. This will provide points to which LIDAR data can be reviewed and calibrated if required.

Eighteen piezometers will be constructed in a grid pattern across the swamp to allow for development of understanding of spatial distribution of key constituents across the swamp. The number of piezometers required has been determined in accordance with the new national guidance for sampling acid sulphate soils (Sullivan et al 2018a) which stipulates for sites over 4 hectares 10 bores are required for the first 4 hectares plus 2 bores per hectare over the 4 hectares. Given Big Swamp is 8 hectares in size, 18 piezometers are required.

8.1.4 Outputs

A summary of the completion of the works will be provided within the body of an environmental assessment report, with further details (including soil logs, piezometer installation specification, logger deployment and slug test analysis) to be included as an appendix to the main report.

The summary discussion in the environmental assessment report will cover piezometer installation, field water quality, stratigraphy, groundwater levels, and interpretation of slug test data.

The soil sampling and bore completion report to be provided as an appendix to the report will include laboratory certificates of compliance, bore logs, logger deployment details, slug test analysis, survey results, and a map of piezometer locations and photo sites.

The data collected as a result of this task will be used to inform further work to better understand soil chemistry, groundwater and surface water movement through Big Swamp, groundwater quality, and aquifer properties of the peat and alluvial sediments in Big Swamp.

8.2 Task 2a – Static geochemical testing and analysis

8.2.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) to improve understanding of the soil chemistry and better inform the Remediation Plan. The static geochemical testing will also assist to quantify the amount of acid in Big Swamp, which will in turn inform consideration of different treatment scenarios if required. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- How much actual and potential acidity is currently stored in Big Swamp?
- How much sulfate remains in the sediment profile in Big Swamp?
- How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
- Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in Big Swamp?
- Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?
- How extensive is fire damage to the peat in Big Swamp?

The static geochemical testing will allow assessment of the current concentration of acidity (in its various forms) stored in the soils at Big Swamp, assessment of the concentration of carbon and sulfate available for bacterial sulfate reduction and assessment of the current concentration of metals/metalloids that could be released from the soils in Big Swamp.

8.2.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for static geochemical testing and analysis:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts

- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- National acid sulfate soils identification and laboratory methods manual (Sullivan et al., 2018)

8.2.3 Description

This task aims to provide sufficient information to geochemically characterise the soils in Big Swamp and subsequently allow the selection of samples for incubation as described in Task 2b below. As indicated above, various soil cores will be taken to a depth of 4 m with samples to be collected at 0.5 m intervals. The number of samples required will be informed through consultation with the nominated technical experts and the outcomes of Task 1. The primary geochemical testing will include analysis of physical properties, chemical analysis for acidity hazards and chemical analysis for reactants necessary for bacterial sulfate reduction. This will include assessment of soil moisture content, bulk density, KCl extractable pH, total actual acidity, chromium reducible sulfur, net acid soluble sulfur, acid neutralizing capacity, sulfate concentration, and total carbon concentration.

In addition to the primary geochemical test work, a sub set of samples will be analysed for a selection of total metals to determine the potential risks that could result from changes to redox or acid-base chemistry. Samples will be analysed for acid soluble and crystalline oxide extractable fractions in accordance with the National Acid Sulfate Soils Guidance (Sullivan et al., 2018).

In conjunction with metal and metalloid analysis, a sub set of samples will also be analysed for particle size analysis to characterise the sand, silt and clay size fractions in the soils and validate the soil descriptions made during soil logging.

The results of the static geochemical analysis and field logs will subsequently be used to classify the key ”soil types” in Big Swamp. Once the key “soil types” have been identified they can then be used to inform the selection of a sub set of soils for incubation and kinetic geochemical laboratory testing.

8.2.4 Outputs

The results of the static geochemical test work will be assessed along with field observations to determine:

- The stratigraphy through Big Swamp based on soil logs and physical characteristics
- The spatial and stratigraphic distribution of acidity (in its various forms), as well as the distribution of sulfate and carbon in Big Swamp

- The influence of drying and fire in Big Swamp
- The key soil types (physically and chemically) in Big Swamp
- The selection and prioritisation of soils to be incubated for kinetic geochemical assessment

This will be submitted as an interim report for independent review prior to undertaking the kinetic geochemical testing, with findings to be included within the overall environmental assessments report. This will include a summary report, laboratory results, stratigraphic cross sections or rail diagrams, and prioritisation of samples for incubation and kinetic geochemical testing.

8.3 Task 2b – Kinetic geochemical testing and analysis

8.3.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) so as to improve the understanding of soil chemistry and better inform the Remediation Plan. The kinetic testing will also assist to determine if re-wetting is a feasible remediation option for inducing sulfate reduction or if other additives may be required. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
- Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in Big Swamp?
- Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?

The kinetic geochemical testing will allow a preliminary assessment of how submerging soils in Big Swamp will affect the concentration of acidity and metals in the soil and water as well as determine if additional soil treatment may be necessary to achieve soil and water quality objectives.

8.3.2 Inputs used to define task requirement and objectives

The following sources have informed (or will inform) the objectives, requirements and subsequent methodology for kinetic geochemical testing and analysis:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Baldwin and Mitchell (2012) Impact of sulfate pollution on anaerobic biogeochemical cycles in a wetland sediment
- Outcomes of Task 2a – Static geochemical testing and analysis
- Independent review comments from Task 2a – Static geochemical testing and analysis

8.3.3 Description

The primary focus of the kinetic geochemical testing is to determine if increasing flows and "wetting" or "submerging" soils in Big Swamp will lead to the desired hydro-geochemical outcomes, such as the prevention of further acidity generation via pyrite oxidation, activating bacterial sulfate reduction to neutralise existing stores of acid, and reducing the concentration of dissolved metals and metalloids that are leached from the soils.

The methodology for the kinetic geochemical testing will be based on that described in Baldwin et al. (2012) in which soil slurry was submerged in 1L bottles under lab conditions. In these experiments, in order to simulate anoxia driven by inundation, water and head space within each bottle was purged with argon gas. While this is useful for providing a rapid assessment of sediment response to inundation, it may not accurately reflect the timing of similar reactions under field conditions. Therefore, it is also proposed that a sample be maintained with head space open to the atmosphere in order to better simulate field conditions. It is also proposed that the progress of the incubation testing be monitored through the sampling and analysis of water in the bottles.

The proposed number and type of treatments to be considered in the testing, as well as the frequency of analysis and the suite of analytes to be included will be confirmed following review of the scope of works by, and further consultation with, the nominated technical experts.

The results of the incubation tests will be monitored on an ongoing basis in accordance with reporting from the laboratory. This will be analysed and reported and issued in the form of interim reports for review by the independent review panel in order to facilitate augmentation of the experiment as necessary. The interim reports will subsequently be compiled within the environmental assessments report.

8.3.4 Outputs

The results of the incubation tests will be monitored and analysed on an ongoing basis with interim reports issued for independent review in order to facilitate augmentation of the experiment as necessary. The interim reports will subsequently be compiled within the environmental assessments report.

8.4 Task 3 – Collection of LIDAR data and drone footage

8.4.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) in relation to improved understanding of the surface water flow through Big Swamp. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- Are there preferential surface or subsurface flow paths in Big Swamp?
- How has drying and fire affected the overall geomorphology of the swamp?

Obtaining current LIDAR data and detailed surface elevation data of Boundary Creek and Big Swamp will also inform surface water hydraulic modelling and provide footage of surface water flow paths and vegetation that may help inform flow modelling and ecological assessments.

8.4.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for the collection of LIDAR data and drone footage:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts

- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Existing LIDAR
- Existing Imagery

8.4.3 Description

Previous investigations and reports have highlighted significant changes to Boundary Creek and Big Swamp over recent decades. As highlighted as part of the Yeodene Swamp Study, this has included the construction of a dam upstream of Big Swamp, reduced baseflow to the creek from groundwater extraction, climate change, peat fires in Big Swamp and the construction of fire trenches along the southern boundary of the swamp (Jacobs, 2018).

These factors have led to drying in the swamp and changes to its drainage regime. As highlighted by Baldwin (2018) "*drying leads to significant shrinkage in peat which in turn causes subsidence*", which may alter the nature of surface water flow and drainage from the swamp. The existing LIDAR flown over the swamp in 2006/07 has not captured the excavation of fire trenches, nor any subsidence that may have occurred in subsequent years.

8.4.4 Outputs

This task will provide detailed elevation data that will help to determine the nature of surface water flow through Big Swamp via hydraulic modelling and how the excavation of the fire trench may have altered the flow of water through Big Swamp. Additionally, footage from the drone will be used to provide a visual confirmation of any existing surface water flow paths to which surface water modelling can be calibrated. Finally, the footage may be able to help inform classification of vegetation throughout the swamp.

8.5 Task 4 – Installation of surface water flow gauges and a weather station

8.5.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) in relation to improving the understanding of water losses in Big Swamp through collection of inflow and outflow data. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- Is 'McDonalds Dam' a net sink for surface water from late spring to early autumn?
- Is Reach 2 of boundary Creek a net losing in terms of water balance?

The collection of ongoing streamflow and water quality data upstream and downstream of Big Swamp coupled with localised weather data will also assist to inform water balance estimates and water quality assessments for Big Swamp.

8.5.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for installation of surface water flow gauges and localised weather station:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated expert panel
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek

8.5.3 Description

A stream flow gauging station will be installed at a suitable location on Boundary Creek upstream and downstream of Big Swamp to allow recording of instantaneous water level data and subsequently flow data. A weather station will also be installed at one of these sites to allow collection of localised weather information.

The assessment of trends in surface water flow coupled with assessment of groundwater level, groundwater and surface water quality, and weather data will assist to spatially define groundwater and surface water interaction in Big Swamp and inform development of a water balance for Boundary Creek and Big Swamp.

8.5.4 Outputs

Two surface water flow gauging stations and ongoing instantaneous surface water level and flow data for locations on Boundary Creek upstream and downstream of Big Swamp.

8.6 Task 5 – Surface water, groundwater and weather data monitoring and analysis

8.6.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) and improve the understanding of water losses in Big Swamp through analysis of inflow and outflow data and surface water and groundwater quality. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- Is 'McDonalds Dam' a net sink for surface water from late spring to early autumn?
- Is Reach 2 of boundary Creek a net losing in terms of water balance?
- Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer?

The assessment of trends in surface water flow, groundwater level, groundwater and surface water quality, and localised weather data will assist to spatially define groundwater and surface water interaction in Big Swamp and inform the development of a water balance for Boundary Creek and Big Swamp.

It will also provide a preliminary characterisation of the hydro-geochemical processes occurring within Boundary Creek and Big Swamp and any subsequent impacts on surface and groundwater chemistry.

8.6.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for surface water, groundwater and weather data monitoring and analysis:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek

- Groundwater sampling guidelines (EPA, 2000)
- Existing streamflow and monitoring of Boundary Creek and the Barwon River available on the Water Measurement Information System (WMIS)
- Existing groundwater monitoring of groundwater bores available on Visualising Victorian Groundwater (VVG) and collected by Barwon Water.

8.6.3 Description

As part of the Yeodene Swamp Study (Jacobs, 2018), investigations were undertaken to assess groundwater and surface water interaction along the length of the Boundary Creek as well as changes in surface water quality. While the study provided a preliminary assessment of conditions it was based on limited data and therefore contains a considerable level of uncertainty, as highlighted in Baldwin (2018).

In addition, the review by Baldwin (2018) emphasised the point that insufficient data was currently available to assess how changing flow conditions in Big Swamp may drive groundwater level increase and the subsequent reducing conditions necessary for pH recovery. This task aims to resolve these data gaps by undertaking comprehensive surface and groundwater monitoring and analysis for Boundary Creek and Big Swamp. This will include:

8.6.3.1 Surface water monitoring

- Continuous surface water level and flow monitoring at the two gauges described for Task 4
- Monthly field water quality analysis (pH, EC, DO, ORP, T)
- Monthly sampling for laboratory analysis of pH, acidity, salinity (TDS), dissolved sulfate, and dissolved metals

8.6.3.2 Groundwater monitoring

- Continuous groundwater level monitoring in piezometers via level loggers (number and location to be determined)
- Monthly field water quality analysis (pH, EC, DO, ORP, T) in each piezometer
- Quarterly sampling for laboratory analysis of pH, acidity, salinity (TDS), dissolved sulfate and dissolved metals

8.6.3.3 Weather station monitoring

- Ongoing monitoring of a weather station to be installed at Big Swamp

Analysis of this information will allow characterisation of surface water flow and quality to help refine the understanding of the effects of Acid Sulfate Soils in the swamp on surface water quality including the potential impacts that water quality is currently having (and may historically have had) on downstream receptors. It will also improve understanding of the flux of acid from the swamp which could inform alternative treatment/remediation options such as lime dosing.

Groundwater level and quality data will also be used to assess how flows through Big Swamp translate into groundwater level change and subsequently how this might influence shallow groundwater quality.

This data will also be used to build a robust water balance for Big Swamp which will account for inflows, outflows, groundwater-surface water exchange, evaporation and rainfall/runoff.

The groundwater level data will also be used to build a groundwater potentiometric surface which will subsequently be combined with the surface water elevation generated by the hydraulic model proposed in Task 8 below. This will be used to generate a map which describes the spatial variability in the gaining-losing nature of Big Swamp over time.

8.6.4 Outputs

Outputs will include a section in the Environmental Assessment Report that discusses temporal trends in surface water flow and groundwater level, temporal trends in surface and groundwater quality, and the potential risk of groundwater contamination in the Lower Tertiary Aquifer resulting from Acid Sulfate Soils. Maps illustrating the spatial distribution of gaining and losing conditions through Big Swamp will also be produced along with monthly water balance estimates for Big Swamp.

8.7 Task 6 – Water, sediment and macroinvertebrate survey of the Barwon River

8.7.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) and determine monitoring requirements for the Barwon River to adequately assess potential future impacts on the Barwon River as a result of poor water quality from Boundary Creek. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- Have inflows from Boundary Creek impacted on sediment quality in the Barwon River?
- Have inflows from Boundary Creek impacted on the ecological condition of the Barwon River?

The collection and analysis of water quality, sediment and macroinvertebrate data from the Barwon River will be used to assess the spatial extent of impacts resulting from acidic discharge from Boundary Creek to the Barwon River.

8.7.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for water, sediment and macroinvertebrate survey of the Barwon River:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Existing streamflow monitoring of Boundary Creek and the Barwon River available on the Water Measurement Information System (WMIS)
- Third Index of Stream Condition Report Corangamite region (ISC3, 2010)
- Boundary Creek aquatic ecology investigation. Jacobs Melbourne (Jacobs, 2017)

8.7.3 Description

Surface water pH monitoring in the Barwon River undertaken on a weekly basis suggests that the spatial extent of surface water impacts is variable, extending as far as Winchelsea when certain flow conditions are met. However, this only takes into account pH monitoring. As such, trends in other water quality indicators such as dissolved metals are less well understood.

To build on this understanding, surface water samples collected from the Barwon River will be analysed for dissolved metals and field water quality (pH, EC, DO, ORP, T). Samples will be taken approximately 500 metres upstream and downstream of the confluence with Boundary Creek, and at further locations along the Barwon River downs to Winchelsea.

In addition to surface water quality, such as pH and dissolved metals, sediment quality can pose a chronic risk to aquatic ecological communities. As sediment accumulates over time, changes in the quality of the sediment can provide an indication of the spatial extent of impacts to the Barwon River resulting from the poor surface water quality entering the river from Boundary Creek. Given this, and that little is known about the sediment quality in the Barwon River, sediment samples will be collected for analysis in conjunction with the surface water samples.

Sediment samples will be collected at two depths, surface to 20 cm and 20 cm to 40 cm, sieved and then analysed for metals. Results will subsequently be reported against the Australian sediment quality standard (Simpson et al, 2013).

In addition to water and sediment quality, it is necessary to continue to monitor the macroinvertebrate community structure in Boundary Creek and the Barwon River. While this has been undertaken at some sites throughout the area (Boundary Creek, East Barwon River, West Barwon River and Barwon River u/s Penny Royal Creek) this has not been undertaken near the confluence of Boundary Creek and the Barwon River to assess the impact of acidic discharge. Further, this was last completed in 2010 (ISC3, 2010) and ongoing impacts have not been assessed. To address this, and provide a baseline to which future remediation may be measured, a macroinvertebrate survey (in conjunction with the sediment and surface water sampling) will be undertaken using both the SIGNAL and AUSRIVAS protocols.

8.7.4 Outputs

The GPS location of sample points will be recorded, along with site photos, descriptions, field water quality, soil core photos and observations. The results will be analysed, mapped and reported within the environmental assessments report with discussion on the:

- Extent of surface water impacts (considering ANZECC water quality guidelines)
- Extent of sediment quality impacts (considering Simpson et al, 2013)
- Extent of impact on macroinvertebrate community structure
- Potential chronic impacts on aquatic ecological communities

8.8 Task 7 – Ecological assessment of Big Swamp

8.8.1 Objective

The objective of this task is to improve the understanding of the ecological characteristics of Big Swamp which will in turn inform the potential impacts of any proposed remediation options. Specifically, this task has been included to help establish baseline ecological characteristics for Big Swamp through confirmation of the extent of swamp vegetation, current floristic composition, Ecological Vegetation Class (EVC) mapping, EVC condition assessments and vegetation health assessments will also assist to better understand the effects of altered flow regimes through Big Swamp.

8.8.2 Inputs used to define task requirement and objectives

The following sources have informed the objectives, requirements and subsequent methodology for the ecological assessment of Big Swamp:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical experts
- Baldwin DS, (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Current DELWP biodiversity spatial data
- Field survey (flora)
- Field campaign (remote sensing)

8.8.3 Description

The vegetation of the Big Swamp will be characterised by its baseline floristic composition and EVC extent and condition. This will be ascertained through comprehensive and representative transect and plot survey techniques. Permanent survey points will be established as future monitoring points.

The baseline health of the vegetation in Big Swamp will be detected using remote sensing technology, including drone-mounted multispectral imagery capture, data processing, and imagery analysis to classify the vegetation health across Big Swamp. This data can then also be used to identify other contributory environmental variables, including the current extent of fire impact. This approach will enable efficient data capture and analysis that can be repeated for future monitoring events.

8.8.4 Outputs

A standalone floristics and vegetation condition and health assessment report will be produced that will include a comprehensive description and interpretation of the floristics, vegetation and health of vegetation in Big Swamp. The report will also include maps depicting the location of floristic survey transects and plots, Big Swamp EVC and vegetation health.

8.9 Task 8 – Surface water modelling

8.9.1 Objective

The objective of this task is to address key knowledge gaps identified in Baldwin (2018) and improve the understanding of surface water flow patterns throughout the swamp and simulate the extent of inundation of Big Swamp if a hydraulic barrier was constructed in the fire trenches. Specifically, this task has been included to help answer the following priority research questions as outlined in Baldwin (2018):

- Are there preferential surface or subsurface flow paths in Big Swamp?

The surface water modelling will also help to estimate flow patterns in Big Swamp under a variety of conditions, provide inputs to the hydro-geochemical modelling, and assess how hydraulic barriers may influence flow and water levels within Big Swamp.

8.9.2 Inputs used to define task requirement and objectives

The following sources have informed (or will inform) the objectives, requirements and subsequent methodology for the surface water modelling:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated technical expert

- Baldwin DS (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Existing flow records on Boundary Creek
- LIDAR data
- Survey information

8.9.3 Description

The development of a hydrological model will consist of two key components. Development of a rainfall-runoff model for hydrologic inflows to Boundary Creek; and development of a 2D hydraulic inundation model for Big Swamp.

Whilst there are existing flow records on Boundary Creek these records are variable in terms of length and completeness. The gauge at Yeodene has a continuous record from 1985 to current, however the records upstream and downstream of MacDonald's Dam are incomplete with a gap in data between 1994 and 2014. Given these discontinuous records a rainfall-runoff model of the catchment is to be developed to produce a continuous data set for runoff at multiple points throughout the Boundary Creek catchment. The rainfall-runoff model will consider the catchment area, land use type and both natural and manmade storages, namely Big Swamp and MacDonald's Dam. The rainfall-runoff modelling will have a number of advantages which include the production of a complete runoff series that includes climatically variable periods such as the Millennium drought and the high rainfall period during the late 1990's.

The model will also provide characterisation of the hydrological regime, such as dry periods and filling periods through the generation of monthly flow patterns and flow duration curves. This analysis will in turn determine the flows to be applied to the detailed inundation model to best assess the impacts to Big Swamp and test remediation options.

In addition to the above, the model will improve the ability to investigate upstream management practices such as land use management and dam operations as well as the ability to generate future climate series data allowing for the assessment of potential climate change impacts.

Once the catchment runoff data has been developed it will be applied to a detailed 2D hydraulic model that will calculate the spread of inundation within Big Swamp and include flow depths, levels and velocities throughout the swamp. The model will be run for representative periods determined from the hydrologic analysis.

8.9.4 Outputs

The results and findings will be presented as a report that documents the model setup, input data and model quality assurance details such as model calibration. This will be included as an appendix in the Environmental Assessments Report along with a section summarising the outcomes of both the rainfall-runoff modelling and 2D Hydraulic modelling.

8.10 Task 9 – Hydro-geochemical modelling

8.10.1 Objective

The key objective of this task is to use the information on soil chemistry, water quality and hydraulic modelling to improve the understanding of how the chemistry of the swamp may change as a result of inundation.

- How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
- Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in the swamp?
- Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?

The hydro-geochemical modelling will assist to characterise the major geochemical processes that might occur within Big Swamp under different hydrological conditions, as well as consider the rate at which these processes and changes may occur, and predict potential changes in soil and water chemistry over time under different scenarios.

8.10.2 Inputs used to define task requirement and objectives

The following sources have informed (or will inform) the objectives, requirements and subsequent methodology for hydro-geochemical modelling:

- Jacobs (2018) Yeodene Swamp study
- Boundary Creek remediation working group
- Boundary Creek remediation working group nominated expert panel

- Baldwin DS (2018) Listing and prioritising research needs and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek
- Task 2a - Static geochemical laboratory results and report
- Task 2b - Kinetic geochemical laboratory results and report
- Task 5 - Surface and groundwater monitoring results
- Task 8 - Surface water hydraulic modelling outputs

8.10.3 Description

It is proposed to initially develop a conceptual geochemical model that presents major aqueous (and where practicable) solid phase chemical species and major aqueous chemical reactions under the current conditions observed in Big Swamp. The model will also consider the hydrological and hydrogeological conditions and present potential effects of different remediation strategies.

Results from the above conceptual model will be used to clarify the objectives of mathematical modelling if it is deemed required and, based on the agreed objectives, evaluate potential geochemical modelling tools and approaches that may be available. Once an appropriate hydro-geochemical modelling tool has been selected an agreed approach to the geochemical modelling will be established. This will give consideration to the scenarios to be modelled and the level of sensitivity. This will include whether the hydro-geochemical model can be integrated with the hydrological model to clarify impacts of Acid Sulphate Soils and acidity load discharges from the swamp.

8.10.4 Outputs

The conceptual geochemical model report would be developed along with a technical model report that would present the approach taken to undertaking the modelling as well as detailing the model inputs, outputs, sensitivity analysis, and discussion of the overarching conceptual geochemical model and potential conditions predicted from the modelling. This information could then be used to inform assessment of potential remediation options.

9 Investigation of unconfirmed impact areas

As outlined in section 5, the groundwater model was used to inform the risk assessment process which identified a number of potential '**high**' risk areas. These areas and values contained within these areas, will require further site specific investigations to 'ground-truth' the model's predictions of potential risk given that the model is based on conservative assumptions.

The risk assessment process identified that monitoring data is typically lacking in one or more of the following:

Recent surface water flow

Recent surface water quality monitoring

Shallow groundwater bores monitoring the alluvial aquifer or the shallow regional aquifer

Groundwater bores monitoring the (deeper) regional aquifer.

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

These site-specific studies will be included in the remediation plan under the 'investigation plan' – refer to Figure 1 – for implementation in parallel to remediation of Boundary Creek and Big Swamp.

Findings from the investigation plan will be provided to SRW. Should SRW determine that remediation is required for these areas, Barwon Water will submit an amendment to the remediation plan capturing required remediation actions for these areas.

9.1 Rivers

Further work is required to investigate the potential impact from historic groundwater pumping for the East Barwon River, Barwon River, Gellibrand River, Yahoo Creek and Ten Mile Creek, which have all been classified as potential '**high**' risk.

The type of information and monitoring required for each site specific study is outlined below, noting that this an overview with further detail to be provided in the remediation plan.

9.1.1 East Barwon River

- Confirm appropriate methods and locations for installation of surface water flow gauges along the East Barwon River. This will be undertaken as a priority and in collaboration with the Corangamite CMA to ensure monitoring aligns with their requirements for management of environmental flows.
- Confirm the survey data required to determine elevation along the East Branch of the Barwon River.

- Confirm the number, location and depth of groundwater monitoring bores required to be installed along the East Barwon River where the river flows over the regional aquitard.

9.1.2 Barwon River

- Confirm the number, location and depth of groundwater monitoring bores required to be installed along the Barwon River downstream of the confluence between the East and West Branches to confirm groundwater levels in the shallow regional aquifer and the alluvial aquifer.
- Confirm appropriate methods and location for installation of an additional stream flow gauge on the Barwon River downstream of the confluence of the East and West Barwon Rivers.

9.1.3 Gellibrand River

- Confirm that there are sufficient surface water gauges located on the Gellibrand River and that they are providing the data required to form the further investigations.
- Confirm the number, location, and depth of groundwater monitoring bores required along the Gellibrand River.
- Identify any existing bores that may require condition assessments to ensure they are providing accurate data suitable for informing the site specific study for the Gellibrand River.

9.1.4 Ten Mile Creek

- Confirm appropriate methods and location for monitoring of surface water flow along Ten Mile Creek.
- Confirm the number, location, and depth of groundwater monitoring bores required along Ten Mile Creek.

9.1.5 Yahoo Creek

- Confirm appropriate methods and location for monitoring of surface water flow along Ten Mile Creek.
- Confirm the number, location, and depth of groundwater monitoring bores required along Ten Mile Creek.

9.2 Vegetation

The risk assessment process has identified that there are other areas within the area of drawdown where the potential risk is high. This includes:

- areas of potential high risk in the west of the graben to the north of Yeodene
- areas of potential high risk in the east of the graben, extending from the area around Barwon Downs to Deans Marsh
- areas of potential high risk in the south of the graben along the Gellibrand River. The monitoring data in these areas will be reviewed to understand if there is sufficient information to confirm if impacts have occurred and confirm the details of any further monitoring that may be required, such as groundwater monitoring bores.

A review of existing vegetation studies undertaken within the area of drawdown will also be undertaken to help inform any site specific studies that will be required to be undertaken as part of the remediation plan.

9.3 Potential acid sulfate soils

The existing PASS monitoring sites were selected as they were considered to be the most sensitive to potential impact from pumping from Barwon Downs based on the predictions of the groundwater model.

These monitoring sites have provided sufficient information to confirm that there has been no impact to the PASS at these locations. This is because either drawdown has not propagated to these sites, or there is an alluvial aquifer present that buffers the impact from groundwater pumping.

No other PASS sites are specifically recommended for further investigation, however, ASS sites that are at risk of drawdown impact are also likely to coincide with vegetation at risk of drawdown impact. Opportunities to confirm the findings of existing PASS investigations will be considered.

10 Methodology

10.1 Developing a remediation strategy for areas of confirmed impact

This section provides a summary of the steps necessary to develop, assess and put forward a preferred remediation option that meets the requirements listed in clause 2.5 of the section 78 notice.

The development of the Remediation Plan will take a step wise approach that will draw on guidance from the rehabilitation planning process outlined in Planning for river restoration (Lovett and Edgar, 2002).

The full planning process developed by Lovett and Edgar (2002) is provided in Appendix D.

The following sections summarise three of the twelve key phases required by the guidance. This includes (1) assessing what needs doing, (2) narrowing it down and (3) doing it.

10.1.1 What needs doing?

The initial step in the development of the remediation strategy will be to define the goals and objectives of the remediation strategy. This will draw on an understanding of current systems conditions through the studies undertaken to date. Existing information gaps will be closed through the undertaking of the environmental assessments detailed within this document.

Monitoring data from newly installed piezometers and stream gauges will be used to improve the conceptual understanding by enabling a more accurate representation of the geology, surface water and groundwater flows and the soil profile of Big Swamp.

Investigations to address specific information gaps include updating LIDAR imagery, static and kinetic testing (incubation tests) of soils; sediment, water quality and macro-invertebrate surveys in the Barwon River and vegetation surveys.

It will also incorporate direction from Southern Rural Water whose responsibility is to regulate the section 78 and feedback from the remediation working group and their nominated expert panel.

10.1.2 Narrowing it down

Once potential issues and objectives have been outlined, these will be prioritised to allow subsequent assessment and evaluation of all possible remediation options.

A comprehensive list of potential remediation options will be compiled drawing on previous options assessments (Jacobs, 2018), existing literature and discussion with the remediation working group and their nominated expert panel.

Each option, or where appropriate, combination of options, will be assessed against evaluation criteria. The evaluation criteria will be specific and measureable, taking into account the requirements of the section 78 notice, objectives set in step 1, and the feasibility of achieving them.

The process will draw on the Information collected in the stage above and outcomes of the coupled models – a hydrological (surface water) model and a geochemical model.

These models will be used to simulate the system in the Boundary Creek catchment to predict the system response to physical processes such as groundwater and surface water flows, soil chemistry and water quality changes. Key outcomes include the quantification of acid in Big Swamp, the water balance within the swamp and any significant changes in the chemistry that could result from inundation (rewetting the swamp).

The options assessment will also consider community values and their measures of success.

This process should result in a preferred remediation option – *based on preliminary incubation results* – or a suite of remediation strategies which will be developed to concept design level.

The remediation plan will be developed on the basis of the preferred option.

Where actions and triggers are defined, Barwon Water will ensure that the remediation plan will be underpinned with an adaptive management approach.

Environmental targets will be developed for the preferred remediation approach based on SMART principles, i.e. that they are specific, measurable, achievable, relevant and time limited.

The development of this plan will be in consultation with the remediation working group and their expert panel and any other specialists as needed.

The scope of works aims to ensure that the development of a Remediation Plan, to be submitted by 20 December 2019, considers the input of the community via the remediation working group and contains controls and actions that can be practicably carried out to achieve improved environmental outcomes for the areas covered by the Plan.

For more detail on key deliverables and the timeframes that Barwon Water are proposing to meet the development of the Plan, please see Figure 15.

10.1.3 Doing it

This represents the third and final phase of remediation and involves the detailed design, implementation and evaluation of the remediation plan as it is executed.

The section 78 notice requires that the remediation plan be accepted by Southern Rural Water and that Barwon Water must finalise the plan (including any changes required by Southern Rural Water) for implementation by 01 March 2020.

10.2 Development investigation plan and assessment of areas of unconfirmed impact

A groundwater model was used to identify areas of potential 'high' risk. Further work is required to confirm if historic groundwater pumping has had a measurable negative impact to any beneficial uses or environmental values in the broader catchment beyond Boundary Creek.

Barwon Water proposes that an investigation plan for these potential 'high' risk areas be developed and documented in the remediation plan due in December 2019 – refer to Figure 1.

Following the implementation of the investigation plan for the potential '**high**' risk areas, a review of the risk assessment will be undertaken before proceeding with any investigations for potential 'medium' risk areas. This review will consider the additional data collected for the '**high**' risk areas that may be relevant to the review of the risk assessment.

The investigation plan will be based on an adaptive management approach – refer to Figure 14 – which will be flexible enough to respond to observable data and what is being measured on the ground. An adaptive approach means that the investigation plan will be responsive to and will be adjusted as any new information is obtained.

The investigation plan will include the scope of the investigations necessary to confirm if there has been impact, and timeframes for completion of these investigations.

The purpose of these investigations will be to validate the model's predictions with observable monitoring data and 'ground-truthing'. Therefore, the investigation plan will need to outline any additional monitoring and studies that may be required to fill information gaps, such as:

- Number, location, method and flow ranges for any surface water monitoring required for each of the high risk rivers
- Number, location and depth of any groundwater monitoring required for the identified high risk areas
- Number and location of any existing bores requiring condition assessments to confirm suitability for ongoing monitoring or if refurbishment may be required

- Assessment of existing vegetation surveys and information to inform assessment of impacts on vegetation
- Desktop assessments of historic reports, monitoring data and surveys

The findings from the investigation of potential '**high**' risk areas will be provided to SRW. Should SRW determine that remediation is required for these areas, Barwon Water will submit an amendment to the remediation plan capturing the remediation actions for these areas.

10.3 Community & stakeholder engagement

Barwon Water is committed to working closely with the local community, key agencies and technical experts throughout the development and implementation of both the Scope of Works and Remediation Plan.

A key component of our engagement will be continued engagement with the Boundary Creek and Big Swamp remediation working group.

Barwon Water is also proposing to engage with the broader community to be open about progress on the remediation plan.

Barwon Water has designed an engagement approach that is aligned with the IAP2's public participation spectrum. The key stages of engagement with our community and stakeholders are outlined in the roadmap provided in Figure 16.

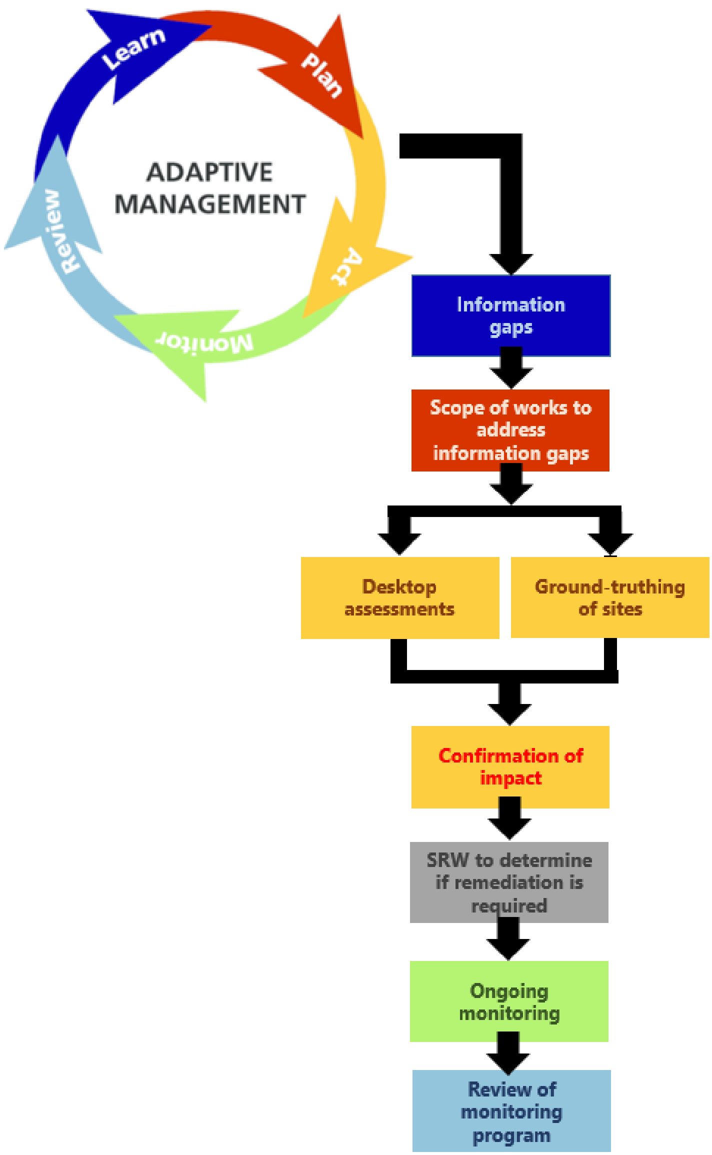

Figure 14: Adaptive management framework for the investigation plan

Activity	Relevance to s78
ACTIVITY: EXPERT PANEL INVOLVEMENT OBJECTIVE: To involve the working group nominated expert panel throughout the development of the Plan	2.6f
ACTIVITY: PREPARE AND DELIVER COMMUNITY AND STAKEHOLDER ENGAGEMENT PLAN OBJECTIVE: To engage with the local community including the Boundary Creek and Big Swamp working group to seek their ideas and feedback and consult with the Corangamite CMA	2.6d, 2.6f
ACTIVITY: REFINEMENT OF SCOPE OF WORKS OBJECTIVE: To refine the scope of works based on feedback by the nominated expert panel and the SRW appointed expert reviewer	2.6e, 2.6f
ACTIVITY: PROVIDE QUARTERLY UPDATE TO SRW OBJECTIVE: To provide an update on the progress of the Plan to SRW	2.5i, 2.6c
ACTIVITY: FIELD PROGRAM OBJECTIVE: To collect necessary data as per the scope of works approved by SRW	2.5a, 2.6a, 2.6b
ACTIVITY: INCUBATION TESTS (LABORATORY) OBJECTIVE: To understand level of certainty/success of preferred concept design	2.5a, 2.6a, 2.6b
ACTIVITY: HYDROLOGICAL AND GEOCHEMICAL MODELLING OBJECTIVE: To conceptually determine the feasibility of the preferred remediation option	2.5a, 2.6a, 2.6b
ACTIVITY: HYDROLOGICAL AND GEOCHEMICAL MODELLING OBJECTIVE: To conceptually determine the feasibility of the preferred remediation option	2.5a, 2.6a, 2.6b
ACTIVITY: DESIGN REMEDIATION OPTION OBJECTIVE: To run an options assessment process to select a preferred remediation option up to a concept level design	
ACTIVITY: DEVELOP INVESTIGATION PLAN OBJECTIVE: To have an investigation plan scoped to assess areas of potential 'high' risk areas of unconfirmed impact to be incorporated into the remediation plan	
ACTIVITY: PREPARATION OF THE BOUNDARY CREEK, BIG SWAMP AND SURROUNDING ENVIRONMENT – REMEDIATION AND ENVIRONMENTAL PROTECTION PLAN OBJECTIVE: To have the Plan ready to submit to SRW by 20 DEC 2019	2.5b, 2.5c,2.5d, 2.5e, 2.5f, 2.5g, 2.5h, 2.6b, 2.6g, 2.6h
ACTIVITY: SUBMISSION OF THE BOUNDARY CREEK, BIG SWAMP AND SURROUNDING ENVIRONMENT – REMEDIATION AND ENVIRONMENTAL PROTECTION PLAN OBJECTIVE: To submit the Plan to SRW by 20 DEC 2019	2.7, 2.8

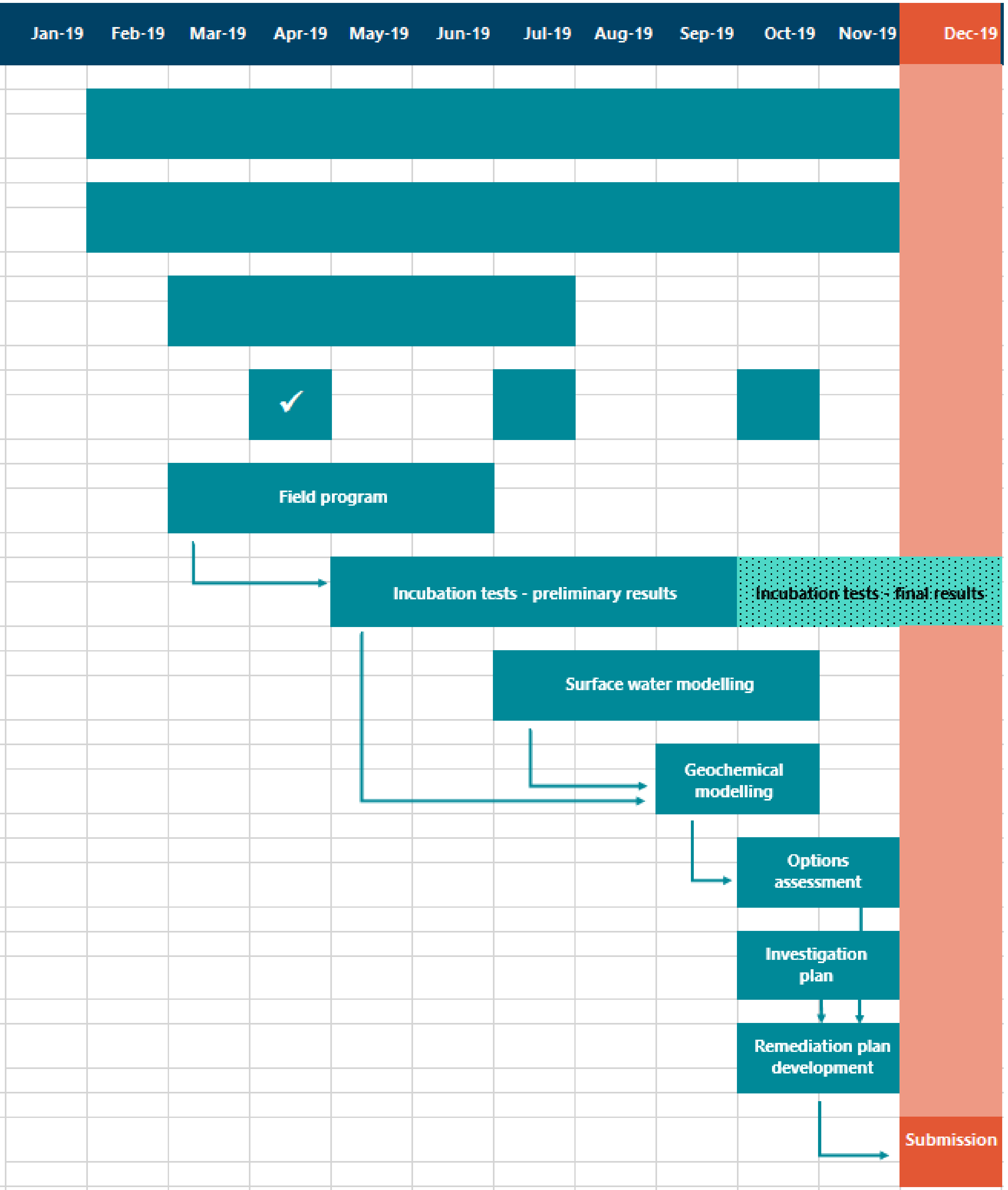

Figure 15: Indicative timeline for key deliverables to develop the Plan

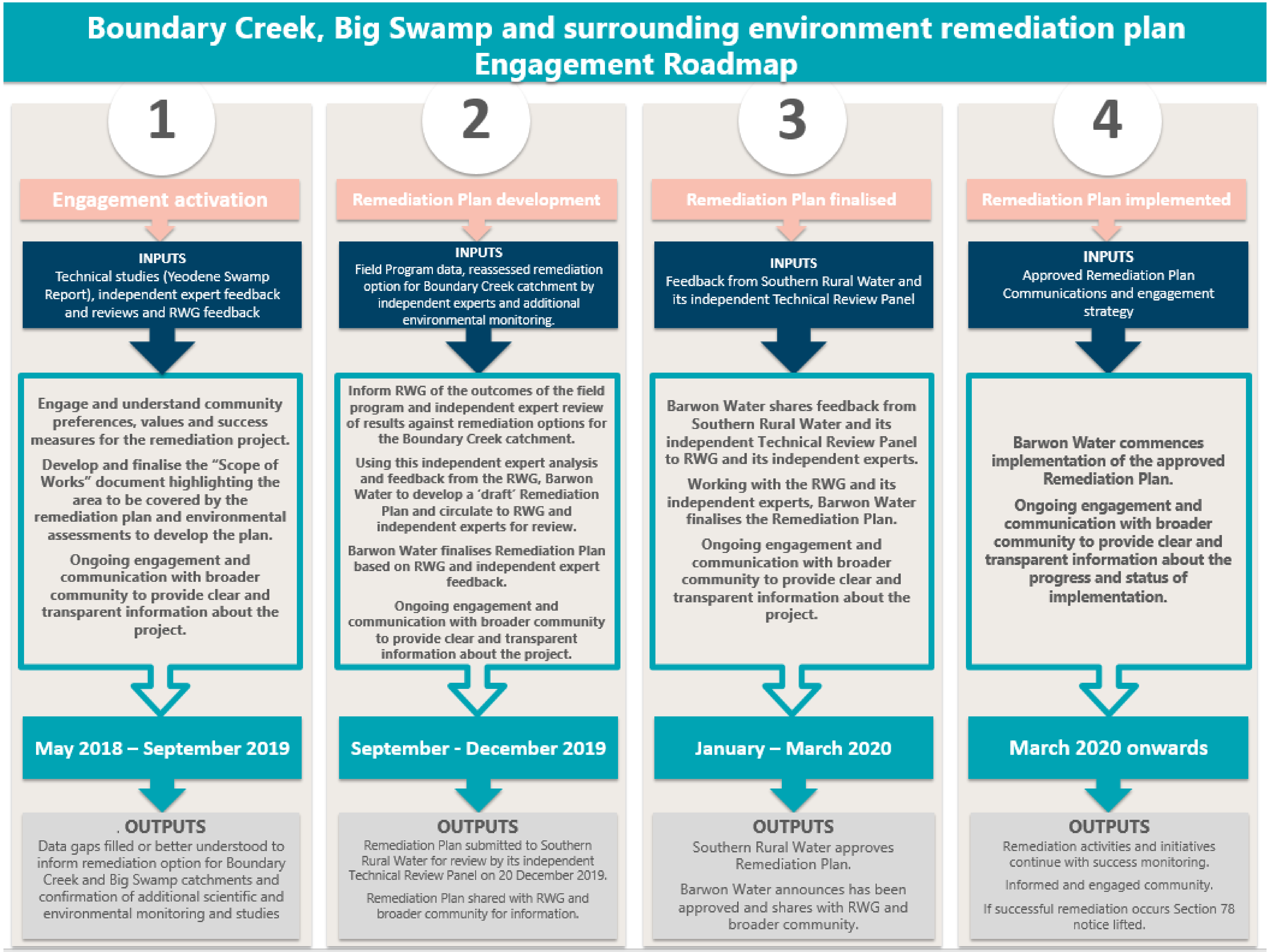

Figure 16: Community & stakeholder engagement roadmap

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Appendix A

Information gaps in proposed remediation concept design

Theme	What is the question?	Why do we need it?	How will it help?	Nominated by
Will it rewet the higher end	Confidence that the wall will sufficiently wet the swamp over the 8 – 10m gradient	Confidence in rewetting option		
Success criteria on reversal	Criteria to measure the success of the reversal of chemical reaction	Need to know if working (basic documentation)	Stop or continue	
Design of barrier / dam wall	Is the proposed dam wall design the most appropriate			
	If the hydraulic barrier is only a metre above ground level at the downstream end of the swamp, while at the other end, ground level is 15 metres higher, how can the swamp be inundated without leakage?			Peter Greig
	How much water is retained and how much will flow over the barrier?	Understanding the chemistry and volumetric study		Meeting with Jacobs on 06 June 2018
	What is the predicted amount of acid that will be flushed out following inundation of the swamp?			
	How much will the remediation cost and how long will it take?			Meeting with Jacobs on 06 June 2018

Theme	What is the question?	Why do we need it?	How will it help?	Nominated by
Site visit	Site visit!	To better visually appreciate what is being proposed		
Options assessment	Give the options a rating or weight	To give a better understanding of the relative merits of each option (Jacobs)		Joey Chatfield
	Look at each remediation option – does groundwater level impact on outcome	Link between options and groundwater level		
Location of Lower Tertiary Aquifer	Where is the LTA under the swamp	Leakage to depleted aquifers	Help re: volumes needed to flood the swamp	
	If water leaks from the swamp into the aquifer under the swamp, will extra supplementary water be required to maintain streamflow in Boundary Creek downstream?			Peter Greig
	Contamination of the LTA and understanding if the chemistry of the aquifer will be affected due to swamp (i.e. poor water quality extracted from the borefield as a result of acidic water leaking into the aquifer from the swamp).			Meeting with Jacobs on 06 June 2018
Performance Evaluation Review Technique	PERT chart for option 5	To see key management choices during process (Jacobs)		Charley Kohout
Peer review on reversal	Confidence the equation can be reversed	Will the preferred option work	Small scale proof of concept	

Theme	What is the question?	Why do we need it?	How will it help?	Nominated by
	Analysis of what is being neutralised	Need to know how to treat / does reversal work on all compounds	May have to change direction / treatment	
	Data showing neutralise process re: flooding with the 8 – 10m rise front to back of swamp	Whole idea to flood is to neutralise BUT if the 3 ML/d doesn't do this need to know	May have to change direction	
	How much of the swamp might be non-inundated (being elevated) and so fire prone	If bits of swamp catch fire, what are consequences (e.g. CFA puts more channels?)	Foresee an operational consequence	Cameron Steele
	What could go wrong and what could happen? E.g. identification of brown coal, ignition of fire			Meeting with Jacobs on 06 June 2018
Approvals and permits	Does a process / legal requirement similar for that of a mine contamination need to be followed for Big Swamp?			Meeting with Jacobs on 06 June 2018
	Does the remediation concept design need to be submitted to obtain regulatory / statutory approvals?			Meeting with Jacobs on 06 June 2018
Core samples	Please source core sample data from Professor Richard Bush / Phil Hurst What is the analysis of the core samples?			Meeting with Jacobs on 06 June 2018

Appendix B

MONASH University

REVIEW OF THE CONCEPT DESIGN IN THE YEODENE SWAMP STUDY REPORT

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Review of the Concept Design in the Yeodene Swamp Study Report

Background

The Barwon Downs borefield licence is due for renewal in June, 2019. In preparation for the licence application, a series of studies and monitoring programs have been completed by Barwon Water over the past five years to improve understanding of impacts caused by groundwater pumping which has been a concern of the local community. Recent technical work confirmed that historic use of the borefield has had an adverse impact on flows and drying of a peat swamp in the Boundary Creek catchment which has been the main contributor to a deterioration of water quality and acid water events. A remediation plan has been designed and implemented to improve water quality and flows and reduce the risk of future acid events.

This study reviews the proposed remediation plan under the following themes:

- The design, constructability and confidence of rewetting the swamp
- The confidence in the chemistry and chemical reactions
- The influence of the hydrogeology
- If there is a benefit in completing an options assessment, and
- Identify the information gaps

Yeodene Swamp

Yeodene Swamp, also known as Big Swamp, is a peat swamp with known acid sulfate soils, located in the Boundary Creek catchment to the south of Colac and east of Yeodene. The flow of water in to the Swamp is affected by McDonald's Dam upstream, which is subject to licence conditions including the passing of flows.

Reduction in base flow of Boundary Creek has largely allowed Yeodene Swamp to dry out, oxidising the underlying sulfidic sediments to form acid sulfate soils and allow for acidic water and high concentrations of heavy metals to discharge downstream. Furthermore, Yeodene Swamp was also affected by fires in 1997, 1998 and 2006.

It is agreed that the reduction in baseflow has largely been caused by a combination of lower than average rainfall and extraction of groundwater during drier periods to supply water for Geelong and the surrounding townships.

Remediation Plan

The aim of the remediation plan is to address community concern regarding poor water quality due to the presence of acid sulfate soils and to improve water quality by increasing the pH and decreasing the transport of heavy metals.

The options reviewed in the remediation plan include:
i) do nothing
ii) direct treatment of soils with neutralising agents in Yeodene Swamp
iii) in-drain water treatment with limestone in Reach 3 of Boundary Creek
iv) diluting acidic discharge in Reach 3 of Boundary Creek
v) revising flow release location to Reach 3 of Boundary Creek and isolating the swamp from the creek
vi) inundating Yeodene Swamp

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1. Do Nothing

This option is the status quo. The acid sulfate soils have already oxidised due to the low water levels and are generating acidity which is transported to Boundary Creek and further downstream. Current monitoring data suggests that water quality is likely to remain low and acidity will continue to discharge during dry periods.

Knowledge Gaps: An understanding of the spatial distribution of acid sulfate soils in Yeodene Swamp and depth to sulfidic layers is currently missing. The Jacobs study only sampled from 7 sites across the Swamp, which is estimated to be 11 ha and at depth increments of 1 m. These sampling points should not be used as representative of the swamp given their location, the few that are used, and the high variability of soil characteristics in these peat swamps. High variability in soil samples has also been seen in the Marshy Creek peat swamps in Anglesea in a current study by Wong et al (data not shown). The *Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils* and the Victorian EPA suggest that samples should be taken every 0.5 m.

It is recommended that surface water levels, groundwater levels, water quality parameters and rainfall continue to be monitored to establish a longer term record such that step changes can be discerned from temporal variability. It is also recommended that an acid sulfate soil study should be completed to understand the variability in terms of depth to the sulfidic layer to prevent oxidation in future dry periods.
Feasibility: not feasible
Does groundwater level impact on outcome? Yes

2. Direct Treatment of Soils with Neutralising Agents

This option aims to neutralise the acidity that is present with application of a neutralising agent such as lime. The option presented only considers application of lime via a slurry. A previous study (Wong *et al.* 2016) has shown that direct application of lime to a degraded swamp environment can assist in remediation. The graphical abstract is shown in Appendix A.

Knowledge Gaps: Application of lime via means other than a slurry should be considered to reduce costs and identify potential methods and logistics to deliver lime for neutralisation.
Feasibility: low to medium feasibility if conducted in conjunction with inundation
Does groundwater level impact on outcome? Not directly. However, if groundwater levels remain low and sulfidic sediments continue to oxidise, then larger doses of lime with more frequent application will be required

3. In Drain Treatment with Limestone

This option aims to neutralise acidic water by installing a drain with a neutralising agent such that acidic water is neutralised as it flows downstream. However, particle size of the neutralising agent is an important consideration for efficiency and should be < 0.5 mm to be effective (Watling *et al.* 2010), which is then susceptible to mobilisation downstream under higher flow conditions. Larger particle sizes are likely to form a coating of either an iron precipitate or calcium precipitate which may render the lime ineffective.

Knowledge Gaps: The impact of channel construction on the hydrology and hydrogeology of Yeodene Swamp is unknown and can potentially exacerbate the problem in the swamp itself.
Feasibility: low feasibility
Does groundwater level impact on outcome? Potentially, but this is largely unknown as it is dependent on the design and location of the drain

4. Dilution of Acidic Discharge

This option aims to decrease the effect of acidic water by increasing the volume of water flowing through the swamp via increased flow releases upstream to dilute acidity and heavy metals. However, as the data show, there is limited buffering capacity in the water that would be released upstream and the effect would be dilution alone. Furthermore, there is unlikely to be enough water during the periods when large volumes of water are required for dilution flows ie. during summer dry periods when water availability has been lower according to the monitoring data.

Knowledge Gaps: The impact of large volumes of water released on the physical environments downstream is unknown and not considered. As suggested, it is likely to result in flooding of downstream areas.
Feasibility: low feasibility
Does groundwater level impact on outcome? Not directly. However, the volume of water available for dilution may be dependent on availability of groundwater depending on the source.

5. Revising flow release location/swamp isolation

This option aims to hydrologically isolate Yeodene Swamp from Boundary Creek to reduce acidic discharges. However, during higher flows, it is likely that the two areas will be hydrologically connected, which may results in higher impact acid discharge events compared to what is currently experienced. This is because Yeodene Swamp is likely to continue to oxidise and accumulate acidity and acidic products in the swamp, which will be rapidly discharged to Boundary Creek during high flow or high rainfall events.

Knowledge Gaps: A more complete understanding of the surface water-groundwater interactions in the Boundary Creek catchment is required.
Feasibility: low feasibility
Does groundwater level impact on outcome? Potentially. This would depend on the location and design of the flow release location

6. Inundating Yeodene Swamp

This option aims to reintroduce reducing conditions to neutralise acidity in Yeodene Swamp and reform sulfidic sediments to reduce the impact of heavy metals. This would take place by infilling the fire trench and the agricultural drain to prevent water draining to the base levels of these channels. This approach has been undertaken successfully at other sites, as identified by Jacobs. However, the impact of the changes in soil chemistry after the fires in 1997, 1998 and 2006 has not been considered and is likely to play a significant role in the success of this option. The soils are most likely dominated by hematite and maghemite following heating and burning of organic matter, which are likely to take a long time to react. It is also possible that inundation may result in pooling of a larger volume of acidic water as it appears that sulfate concentrations are low, which can also limit the formation pyrite.

Knowledge Gaps: The effect of fire-affected acid sulfate soils following inundation is unknown, and the rate of neutralisation is likely to be very slow, but is unknown. The absence of vegetation in the inundated areas of the swamp suggest acidic water, and this can potentially be exacerbated with inundation if the surface water is acidic. Despite these issues, this option is most likely the most feasible option
Feasibility: medium feasibility
Does groundwater level impact on outcome? Yes, because groundwater levels will need to remain high for oxidation to cease and reduction processes to occur

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Further Considerations
The effects of the three fires in 1997, 1998 and 2006 have not been considered in these management options. As mentioned previously, the fires have significantly altered the soil chemistry and therefore, it is unlikely that inundation will result in rapid reformation of pyrite and monosulfides as in prior studies. It is recommended that an investigation in to the effects of inundation on surface water quality and soil chemistry be undertaken.

Furthermore, the recommendation that the drainage regime of pre-1999 be re-established due to the decreased frequency in acidic discharges. However, again, the effects of the fires have not been considered as a large volume of acidity is likely to have been generated following each event. The soil properties and flow paths are also likely to have been irreversibly altered following these fires. Therefore, it is erroneous to assume that the pre-1999 surface hydrology and hydrogeology can be re-established.

Specific Questions

Will it rewet the higher end?
This question is difficult to answer without elevation data

Success criteria on reversal
The criteria will depend on the aim of the remediation plan. To improve water quality downstream, then the ANZECC guidelines can be used, with all of the caveats that have been discussed via email in the current discharge event. It is assumed, however, that success will be determined on decreased frequency of acidic discharge events and decreased oxidation of acid sulfate soils. However, as mentioned earlier, the effects of the fires may have irreversibly altered the hydrogeology and soil chemistry and therefore, a return to pre-1999 conditions is unlikely to be a useful criteria to measure success.

Design of the barrier/dam wall (and all questions therein)
There is not enough information provided in the report to answer this question. The critical information that is missing is the elevation data, however, a better understanding of the hydrogeology and surface water-groundwater interactions of the area is also required.

Options Assessment
See discussion of options above

Location of Lower Tertiary Aquifer
Jacobs has suggested that saturated peat and alluvial sediments in Yeodene Swamp are separated by an aquitard.

If water leaks from the swamp into the aquifer under the swamp, will extra supplementary water be required to maintain streamflow?
An investigation in to the hydrogeology and surface water-groundwater interactions would answer this question

Performance Evaluation Review Technique
There is not enough information provided to answer this question

Confidence the equation can be reversed
A controlled laboratory study focusing on inundation of these soils with water sourced from upstream could address this question

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Analysis of what is being neutralised
This can also be addressed with a controlled laboratory study

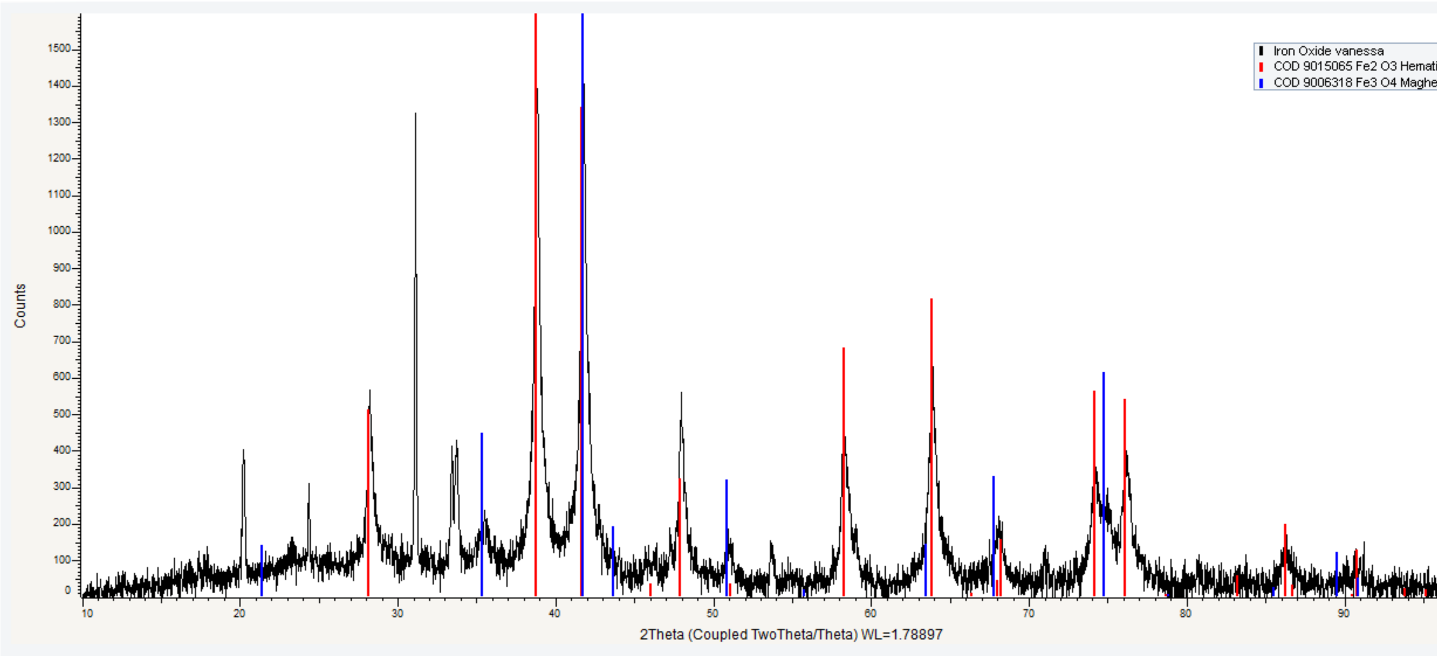
Data showing neutralisation process re. flooding
Additional surface water quality data loggers located in the swamp can potentially address this question

How much of the swamp might not be inundated?
This can be estimated with a GIS analysis providing a recent high resolution digital elevation model (DEM) is available

What could go wrong and what could happen?
Fire has already occurred and changed the soil chemistry. Dry peat swamps are a high fire risk in summer. An in depth desktop assessment of the geology will be a useful exercise to determine the likelihood of the presence of brown coal.

Approvals and permits
I suggest that Victoria EPA and local council would be the first organisations to contact

Core samples
Below is an X-ray diffraction spectra of a single sample collected from Yeodene Swamp with hematite and maghemite as the dominant minerals.



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References

Watling, K.M., Sullivan, L.A., McElnea, A., Ahern, C.R., Burton, E.D., Johnston, S.J., Keene, A.F., and Bush, R.T. Effectiveness of lime particle size in the neutralisation of sulfidic acid sulfate soil materials. In '19th World Congress in Soil Science: Solutions for a Changing World', 1-6 August 2010 2010, Brisbane,

Wong, V.N.L., McNaughton, C., and Pearson, A. (2016) Changes in soil organic carbon fractions after remediation of a coastal floodplain soil. *Journal of Environmental Management* **168**, 280-287.

Appendix A

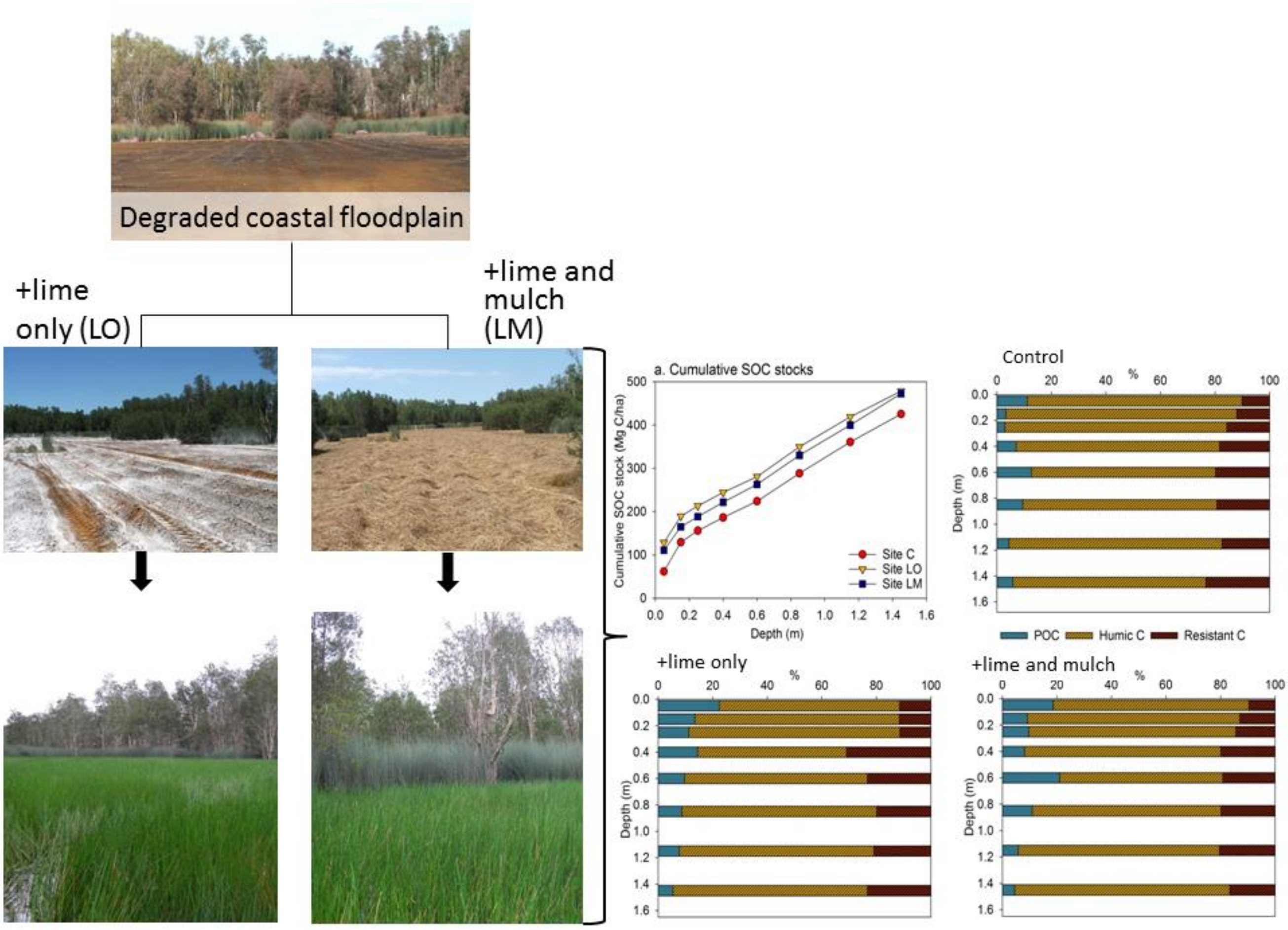

Figure A1. Effects of remediation of a degraded acid sulfate soil swamp after 3 years (Wong et al. 2015)

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Independent Expert Review of the Acid Sulfate Soil Preferred Management Options for Yeodene Swamp

File note prepared for Barwon Water.

Date: 18th November, 2018.

Report Prepared by:

RICHARD BUSH

International Centre for Balanced Landuse

University of Newcastle, NSW, 2308.

Scope:

- To review the preferred concept design (management strategy) in the Yeodene Swamp study report.

Task:

- Complete a desk top review of the preferred concept design. This should include your expertise on whether the preferred management strategy put forward is appropriate to meet the objective of the remediation plan and for the environmental circumstances present.
- Propose additional management strategies appropriate for this remediation plan other than the six represented (this can include hybrids of the six presented).
- Preparation of a short file note.

Source Document:

- JABOBS 016 - 2017 Technical Works Program, Barwon Water, Yeodene Swamp Study. S191000-GW-RP-001, FINAL DRAFT 9 November 2017

Context:

Jacobs (2017) provide evidence that groundwater extraction over the past 30 years by Barwon Water has reduced streamflow in the lower reach of Boundary Creek.

The managed allocation of a 2 ML/day supplementary flow has not been adequate to prevent persistent drying of Yeodene Swamp (i.e. Big Swamp) and the consequent oxidation of naturally occurring acid sulphate soils and related release of acidic water (pH less than 4) and heavy metals downstream of the swamp.

A number of studies and reports have demonstrated that acid sulfate soil conditions impact the environmental condition within, and downstream of Yeodene Swamp. The impacts become evident in the early 1990's and have intensified over the past two decades. The acid sulfate soil impacts are chronic and without remedial land management intervention, can reasonably be expected to persist for decades.

The community is aware of the environmental degradation in Yeodene Swamp and more broadly, the extent of groundwater drawdown and the implications for stream flow and water quality. They have raised issues about ecological impacts at various points along Boundary Creek, the potential to increase acid sulphate soil and fire risks at the Yeodene peat swamp, and the sustainability of current and forecast extraction limits and the current operational regime of the borefield.

Jacobs (2017) report differentiated groundwater extraction and climate effects on the groundwater system, predict water table and stream flow changes, and comments on potential ecological impacts. The investigation by Jacobs (2017) discusses:

- groundwater extraction versus seasonal climate variability on groundwater system
- potential risks of acid sulphate soils and whether that could change in the future
- if the current compensatory flow is effective at protecting Boundary Creek
- groundwater dynamics in the aquitard
- groundwater and surface water interaction along Boundary Creek.

From my review of Jacobs (2017), drawing on my experience over the past 20 years of investigating similar environmental systems, the evidence linking acid sulfate soil conditions and declining water quality in the Boundary Creek -Yeodene Swamp to groundwater extraction is compelling.

Remediation plan for boundary creek

The stated environmental objective of the remediation plan for Boundary Creek is to *"prevent – to the best of our ability –any further low pH (pH<4) events in the Barwon River"*. The objectives of the Yeodene Swamp Study by Jacobs (2017) were to:

1. Improve the conceptual understanding of the processes that affect the volume and quality of water between McDonalds Dam and the Barwon River.
2. Recommend future management options for Yeodene Swamp to improve the condition and water quality downstream of the swamp (i.e. Reach 3 of Boundary Creek).

Jacobs divide Boundary Creek into three distinct reaches based on the geology and groundwater setting as follows:

- **Reach 1** (upstream of McDonalds Dam): the creek flows over basement and receives minor groundwater inflows.
- **Reach 2** (downstream of McDonalds Dam to Yeodene Swamp): the creek flows over the regional aquifer (Lower Tertiary Aquifer). Yeodene Swamp is located at the downstream end of the Reach 2 and is considered to be losing water to the surrounding alluvial aquifer.

- **Reach 3:** The creek flows over aquitard and receives minor groundwater inflow.

Remediation options for Yeodene Swamp presented by Jacobs (2017)

Potential management strategies to improve the quality and volume of water flowing in Reach 3 of Boundary Creek were considered. Six options were reviewed and summarised in Table 0-1-2:

1. Do nothing
2. Direct treatment of soils with neutralising agents in Yeodene Swamp
3. In-drain water treatment with limestone in Reach 3
4. Diluting acidic discharge in Reach 3 of Boundary Creek.
5. Revising flow release location to Reach 3 of Boundary Creek and isolating the swamp
6. Inundating Yeodene Swamp (Preferred Option)

Option (6) - "Inundating Yeodene Swamp", is presented as the preferred concept. The working premise is that inundation will neutralise the acid in the swamp by reversing the chemical reactions from oxidising (acid generating) to reducing (acid consuming) by limiting oxygen in the soil profile. The design involves the construction of a low bundwall to raise groundwater in the Big Swamp and increased supplementary flow from 2ML/day to 3 ML/day to effectively inundate the lower end of the swamp.

In addition to the increased supplementary flow, the fire trenches and agricultural drain that are present on the eastern end the swamp will be infilled to further minimise water losses by drainage.

Jacobs (2017) expect their preferred strategy will reinstate the acid generation profile of the Swamp to pre-1999 conditions. I am not certain this has been fully considered and is justified based on the information presented. The 1999 condition also would be difficult to benchmark. Is this simply referring to surface water quality in Boundary Creek for just pH, or will it consider the broader, and potentially more critical impacts.

Comments on Conceptual Understanding and utility of the report by Jacobs.

Point 1: In my opinion the Jacobs (2017) report provides an adequate characterisation of the basic soil, hydrological, terrain and groundcover conditions in the Yeodene Swamp-Boundary Creek Catchment for the purpose of interpreting the landscape architecture and processes. Sufficient data and interpretation is presented to identifying the severity and extent of acid sulfate soil conditions at this location, its spatial relationship to the shallow and deeper groundwater systems, conceptual hydrological processes and variability in surface and groundwater water quality.

Point 2: In my opinion Jacobs (2017) provides sufficient information to implicate the compounding effects of groundwater extraction and seasonal drought conditions in the progressive lowering of the regional groundwater system.

Point 3: In my opinion the soil assessment undertaken by Jacobs (2017) **do not** adequately quantify parameters relevant to predicting biogeochemical response and implications of inundation. The testing regime is adequate to demonstrate the occurrence and severity of acid sulfate soils and related metal contaminants in the peat soils of Yeodene Swamp. The soil sampling, array of analytical tests and acid-base accounting approach to characterise the acid sulfate soil hazard (Refer to Appendix C) are consistent with national guidelines for estimating lime requirements to treat acid sulfate soil and assess potential environmental hazards.

Point 4: I find the report provides insufficient information to understand sufficiently the ecological and environmental condition and values of Boundary Creek and Yeodene Swamp to evaluate the potential merit of the management design concepts (Options 2-6). Although a vegetation survey was undertaken (as described in Section 3.7 and reported in Section 4.7), the environmental attributes and their significance to the local terrestrial and aquatic ecology is not clearly defined.

Without a clear understanding of the environmental attributes that include ecological function and environmental condition, it is difficult to consider the appropriateness of management objectives and concept designs for Yeodene Swamp-Boundary Creek.

Point 5: Jacobs (2017) acknowledge that a robust understanding of the water balance through Reaches 1-3 is a key knowledge requirement for understanding the drivers to water quality, acid sulfate soil degradation and potential management concepts. Quantifying water movement and budgets accurately is a complicated task, generally requiring sophisticated approaches (including tracers and saturated and un-saturated hydraulic assessment) to assess exchange and preferential flow-paths, and intensive continuous monitoring of surface and ground water conditions over timeframes sufficient to generate enough data to satisfy statistical testing rigour across the spectrum of climate and management variability.

Point 6: I am satisfied with the general soundness of methods use to assess the water budget, yet it is apparent that considerable uncertainty remains in the interpretation of water balance. This is as expected when the detailed study includes only two detailed field spot measurements (May and Aug), and field based detailed investigation extends only to 7 months. Similar studies can take 2-4 years in my experience. For example, is Section 4.6 “Surface and Groundwater Interaction”, there is uncertain about the sources and flow paths of surface water and reasons behind the large variability of losses between 2.1ML/d to 9.9ML/d in Reach 2 are inconclusive.

Point 7: Jacobs (2017) acknowledge that soil hydraulics are a major factor governing the dynamics and processes for shallow ground water re-charge/discharge and the movement of acidity and related materials vertically and horizontally within the acid sulfate soil profile and its discharge from Reach (2) ’Big Swamp’ to Reach (3) ‘Boundary Creek’. The results as described in Table 7-3 indicate hydraulic conductivity of the sediments in Yeodene Swamp and Reach 3 ranged between 0.02 and 0.2 m/day and falls within the range of hydraulic conductivities given for silty material. The exception to this range was YS05 which recorded a hydraulic conductivity of 1.5 m/day. This type of variability can have significant impacts on water movement and the mobilisation of contaminants, essentially acting as preferential flow pathways.

Point 8: High (i.e. 1.5m/day) conductivity observed in parts of the catchment may be the result of soil macro structure or charcoal layers, and not higher sand content as suggested by Jacobs (2017). The conventional displacement method used to measure hydraulic conductivity as described by Jacobs (2017) (see Appendix D) does not necessarily represent the behaviour of acid sulfate soils. Water movement in acid sulfate soils is mostly through macro-pores and fissures (Cracks) (Wilson et al 1999). Jacobs (2017) considered the microstructure and porosity based on particle size. Furthermore, fire and the presence of vertical cracks that penetrate deep into the sub-soil and charcoal layers in the subsoils of Reach (2) at the Big Swamp will have a marked effect on hydraulic conductivity and implications for water management.

Point 9: The effects of fire on the physical, chemical and biological characteristics of the Big Swamp, have not been fully considered by Jacobs (2017). When considering the causes for the observed step-change in Boundary Creek water quality around 2000, (see Figure 2-12 Number of cease to flow days in Boundary Creek at Yeodene vs monthly pH at Yeodene). The long-term stream water quality data indicates that pH declined below 4 from about 2000 onward as a result of no/little stream flow. Jacobs (2017) discount the potential influence of peat fire in Reach (2) on the drop in base flow and chronically low pH. The effect of fire may have been under-estimated in thgis instance, having personally seen the transformative effects of fire on the soil profile at the Big Swamp.

Point 10: Peat fires have the potential to significantly affect both water balance and water quality in peat acid sulfate soils. Peat layers in wetland environments can markedly influence water balance through the capacity to store and slowly release water. The peat acts as a massive sponge, protecting subsoils from drying out and providing resilience to streams by maintaining base flow conditions during dry periods. In my opinion formed from working on peatlands over the past 20 years, even small disturbance to the upper peat layers can substantially diminish the capacity of peats to provide a resilient baseflow during dryer periods, directly leading to the loss of flow in downstream reaches. Fire also renders the soils prone to accelerated oxidation and leaching of acidity and metals.

The effects of fire may not have been fully estimated in the Jacob's investigation, or consideration in the management concept designs, based on the information provided in the report.

COMMENTS ON MANAGEMENT OPTIONS

Point 11: Summary comments provided in Table below

TABLE 1

OPTION	DESCRIPTION - JACOBS	COMMENT – R Bush	Feasibility
(1) Do Nothing	• Yeodene Swamp will continue to release acidic water in Reach 3. • This is considered unacceptable.	• This is not an acceptable option based on the likely persistence, and possible exacerbation of the environmental hazard. • Yeodene Swamp will continue to release acidity, metals and impact the environment for potentially decades. The impacts could also be exacerbated by predicted climate change scenarios. • One significant hazard is the risk of fire and further loss of peat coverage, causing a deepening of the oxidation process and generation of more acidity. The hazard is likely to increase under this option	**Not Feasible**
(2) Treatment of Soil	• Significant works would be required to access the entire swamp to distribute neutralising agents, which will be very disruptive to existing flora and fauna.	• There is insufficient data in the report to exclude the use of neutralising agents on the grounds of feasibility and risk-reward assessment.	**Unresolved**

	• Significant costs associated with first application and subsequent applications are likely to be required.	• More details explanation given below.	
(3) Installation of a lime drain	• A limestone drain has the potential to improve water quality during low flow periods, however there would be limited benefit during high flow events. • Significant capital costs would be required which would result in major modifications to Reach 3 and ongoing maintenance would also be necessary. Furthermore, water quality in Yeodene Swamp would not improve. • This option is more fixing the symptom rather than the problem.	• There is insufficient data in the report to justify the exclusion of limestone drain on the grounds of feasibility and 'risk-reward' assessment. • While acknowledging the limitations highlighted by Jacob's (2017), these structures can assist in protecting and improving downstream environments as part of an integrated solution, most commonly as an intermediate intervention.	**Unresolved**
(4) **Diluting acidic discharge**	• Volumes of water required for dilution cannot be sourced in this region and would increase flooding and adversely impact Reach 3: 250 ML/day during low flows / 1,200 ML/day during high flows	• The modelling and field based observations demonstrate that dilution is ineffective at protecting downstream (Reach 3) from acidic events. • Furthermore, the dilution strategy does not address the source of acidity and environmental conditions within Reach (2)	**Not Feasible**
(5) Revising flow release location	• Require the hydraulic isolation of Yeodene Swamp from Boundary Creek. • This is likely to cause adverse impacts on water quality under high flow conditions when the swamp floods as pent up acid would be flushed out in high flows • This would increase drying in the swamp, which would exacerbate the acid sulphate soils in the swamp.	• There is insufficient data in the report to justify the exclusion of revising flow release locations on the grounds of feasibility and 'risk-reward' assessment. • Hydraulic diversion can provide an opportunity to minimise the chronic discharge of acidity under conditions of low-moderate flow.	**Unresolved**

		• When considered as part of an integrated approach, this intervention can potentially deliver significant benefits to Reach (3). • Other management activities could mitigate the potential for increased drying.	
(6) **Inundating the swamp**	• Key indicator for low pH events is "cease to flow" conditions at the Yeodene Swamp. This objective of inundating the swamp is to prevent cease to flow events at Yeodene. • Technically feasible and cost effective option to inundate swamp by increasing supplementary flows and infilling fire trenches and agricultural drain at eastern end. Approach to complete this would involve: • Infill the fire trenches and block the agriculture drain, ideally before April 2018 (pending approvals) to allow the swamp to retain more water over the winter months. • Minimum flow required initially is 3 ML/day as measured below McDonald's Dam. • Low flow requirement of 3 ML/day is a best estimate based on a detailed assessment of the historical data. It is possible that more water could be required for short time periods during very dry conditions. Equally	• The conceptual description, operation and assumption underlying this option provide insufficient information to consider the merit of the approach and assess the risk-reward. • Explained in more detail below.	**Unresolved**

	it's also possible that this volume could be reduced to 2 ML/day within 2-3 years as the swamp remains saturated. • Ongoing adaptive management is required that involves regular monitoring and site visits are recommended to ensure the minimum flow requirement is meeting the objective.		

Point 12: In isolation, options (2), (3), (5) and (6), may not deliver the stated objective of sustainably preventing acidification (pH< 4) under variable seasonal conditions.

Point 13: With specific reference to **Preferred Option (6) "inundation"**, there is a need for more detail on aspects of both management, design and land conditions to adequately consider the feasibility and effectiveness of this strategy.

The concept based on inundation although simple on first principles, raises may questions about the environmental processes and potential remediation outcome/s. I will address the key issue below:

- Jacobs (2017) refers to several acid sulfate soil wetlands where re-wetting strategies have been used to improve environmental conditions. These include the Lower Lakes (SA), Bottle Bend (NSW), Partridge Creek (NSW), Maelup (WA) etc. I can add several others including East Trinity National Acid Sulfate Soil Demonstration Site (QLD) and Seven Oaks (NSW). It is important to recognise that a reasonable comparison of these wetland systems with the Big Swamp on important soil and landscape factors would be required to make a relevant comparison for the purpose of indicating the potential benefits and likely outcomes of inundation.

- Even on a superficial level, most of the wetlands being used as a guide have soils of differing properties such as the availability of reactive organics for biogeochemical reactions, physical, chemical and biological properties that affect mineral transformations, stores of acidity, geochemistry, hydrological and climatic settings. It is over-simplistic and potentially unreliable, to anticipate the outcome of inundating the Big Swamp, based on studies and data highlighted by Jacobs, as the Big Swamp is by comparison, unique in the Australian context.

- Inundation (or re-wetting) strategies have proven effective at triggering the onset of chemical and microbe-driven reactions that consume organic matter, transform minerals and generate alkalinity in acid sulfate soils. But it is important to recognise these processes can, and do, occur at vastly differing rates, and can result in an unexpected impacts during the on-set of reduction. They can even create new hazards that need to be managed. For example, The East Trinity re-wetting/inundation process caused a massive accumulation of reactive iron on the soil surface, loss of all vegetation, mobilisation of acidity, mobilisation of metals, nutrients and fine floc (suspended sediment), and the formation of a highly reactive potential acid sulfate soil layer at the upper – most soil layer.

- Multi-million dollar investment in capital works and operations was required that included active management intervention such as lime dosing of waterways to prevent off-site impacts, lime application on soil surfaces to accelerate biogeochemical reduction, installation and maintenance of sedimentation traps, targeted re-vegetation and the construction of water retention basins flow diversion structures to partition parts of the wetland (Luke 2016). Inundation of acid sulfate soils in principal appears simple. In practice, the consequences, short and long term, are ill defined and difficult to predict without considerably more information that provided in the Jacobs (2017) report.

- A simple decision flow diagram for inundation in acid sulfate soils is provided in Appendix A. Elements of this outline have not been fully addressed in the conceptual design of Option (6) at this point in time.

Point 14: Questions arising:

A) Will the inundation at Big Swamp result in a static free standing water, or will it be fluctuating in depth and circulating? Each scenario will create different effects.

B) Is the Option (6) strategy targeting the remediation of sub-soil, surface soil, the entire soil profile?, or the entire profile?

C) Are the soil conditions conducive to reductive geochemistry on a scale and rate that will consume? Or will some amendment of the soil be required to enable the soils to respond in a positive way?

D) Will the bund be sufficient to provide a favourable hydraulic gradient across the entire wetland, or will a series of bund walls be needed to achieve suitable inundation? What is the flood hazard of the bund and what will be the predicted water quality during a major flood event?

E) Is waterlogging the sub-soil, or permanent inundation of the topsoil and therefore wetland, likely to create different ecological/environmental outcomes and how could this be assessed?

F) What will be driving the biogeochemistry underpinning the recovery of the soils at Big Swamp, and how will this change over the short-medium and long-term? What is the major limiting factors and will be the implications of the shifting biogeochemistry for the environmental condition and will this create an on-going water quality management issue for Boundary Creek? Will the biogeochemistry need intervention to kick-start the process?

G) It is possible the hazard of potential acidity will increase as a result of inundation through the reformation of pyrite? Could cycling between wet and dry conditions mitigate the hazard and yet treat the issue. What sort of water management infrastructure and plans would be needed to achieve this outcome, and could it be feasible at the Big Swamp?

H) Acidity is one aspect of the impacts that follow from the draining and oxidation of acid sulfate soils. Others include irreversible soil shrinkage and physical changes to the soil, emissions of greenhouse and toxic gases, changes to soil biota, changes soil nutrient cycles and soil erosion. Have these aspects been considered, as they are not explained in the report?

I) The potential for 'black-water' events, hyper-deoxygenation and the release of certain metals known as metalloids are particularly problematic for acid sulfate soils that become inundated (e.g. arsenic, are major issues. Have these been considered? What would be the cost of intervention and management if these issues were to develop as a result of inundation? Can they be avoided through different hydrological manipulation, and would this require a different capital investment for water management and monitoring?

References

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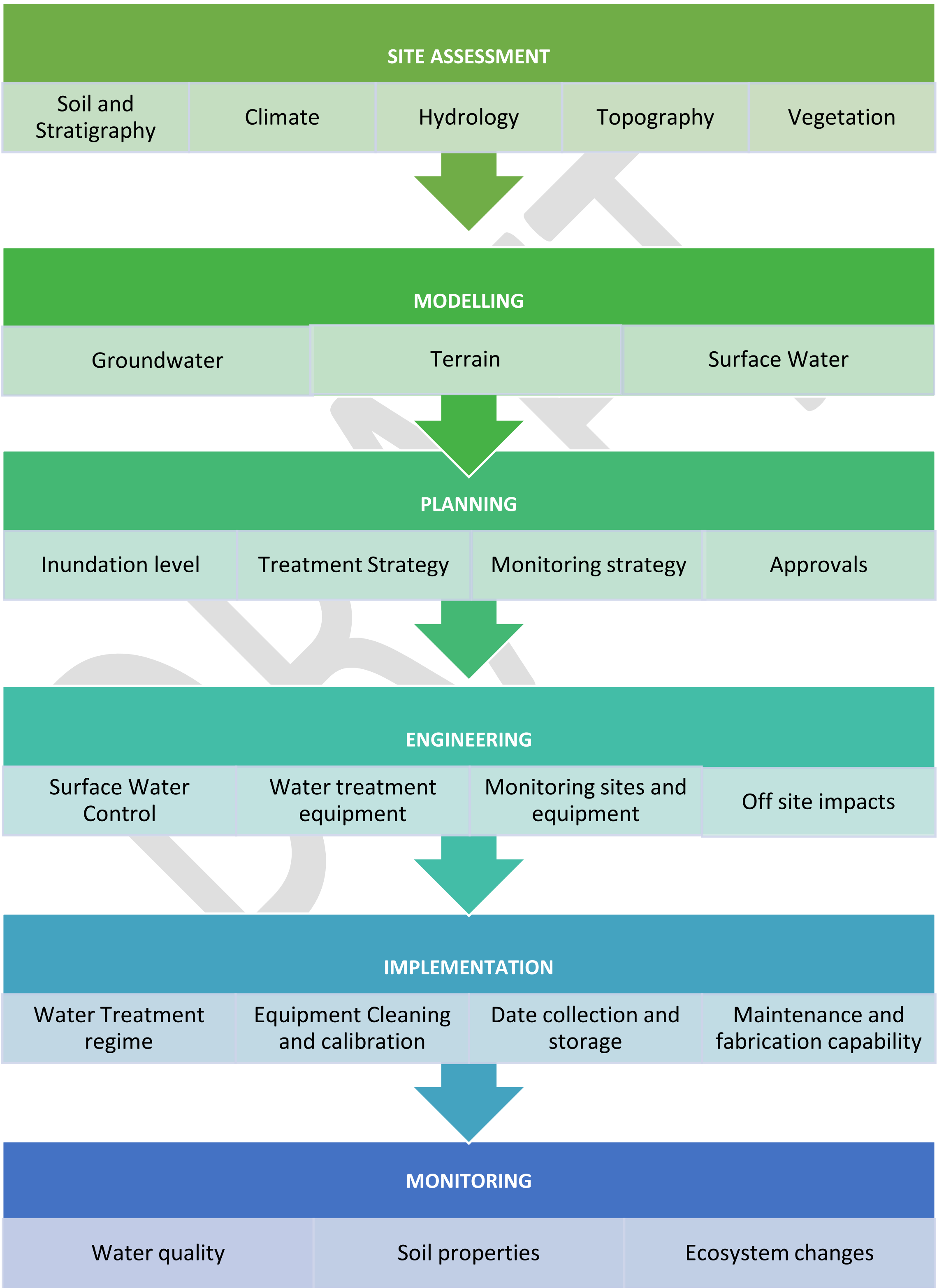
APPENDIX A (Luke et al 2016)



Expert Panel for the Boundary Creek remediation plan: Review of the preferred concept design

Prepared by: Darren S. Baldwin
Rivers and Wetlands

July 2018

Expert panel for the Boundary Creek remediation plan: Review of the preferred concept design

A report prepared for Barwon Water

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Summary

1. Consensus must be reached on the purpose of the rehabilitation project - protecting downstream environments, improving the ecological condition of Yeodene Swamp, or both.
2. Drying of the swamp exposed acid sulfate soils, creating acidity.
3. Shifts in the hydrology and hydrogeology of Yeodene Swamp were caused by climate change, lowering of the Lower Tertiary Aquifer through groundwater extraction, and the operation of McDonald's Dam - all often acting together during periods of drought.
4. Re-flooding will stop any additional acid formation, but it will mobilise any acid in the peat profile. A more accurate assessment of the current store of acid in the swamp is recommended.
5. Simply re-flooding the swamp, without adding additional alkalinity, will not completely solve the problem. More acid will be produced in the next drying event.
6. There is some question of whether or not re-wetting Yeodene will actually result in a re-introduction of sulfate reduction. This needs to be tested in small scale experiments prior to installing the barrier.
7. It is possible that the barrier will need to extend below the shallow aquifer to the aquitard below Yeodene swamp.
8. Reversibility of changes that occurred to the peat on drying and being burnt should be explored.
9. Adding more alkalinity (as lime) is strongly recommended both in the swamp, and downstream, to manage acidification events in the short-term.
10. Trying to promote other anaerobic reactions, other than sulfate reduction, that can create alkalinity should be explored.

Review of Concept Design

1. A "wicked" problem

There are a number of legitimate competing interests for the water in question. Water for Geelong, water for McDonald's Dam, water for Yeodene Swamp and water quantity and quality downstream of Yeodene Swamp (including the Barwon River). The issue at hand has the hallmarks of a 'wicked problem'.[1] One aspect of wicked problems is that, because of complex interdependencies, the effect to resolve one aspect of a wicked problem may reveal or create other problems. Because of their nature, it is rare that wicked problems are actually solved, rather any 'solutions' are often, by their nature, compromises between legitimate competing outcomes.

2. A clear statement needs to be made about the purpose of the rehabilitation.

There doesn't seem to be a clear consensus on the overall goal of the project. If it is to stop pulses of acid reaching the Barwon River, then the approach taken may be entirely different to processes for rehabilitating or even restoring Yeodene Swamp.

The "*National guidance for the management of acid sulfate soils in inland aquatic ecosystems* (2011)"[2] outlines a framework for assessing the options for remediating inland acid sulfate soils (ASS). The framework starts with an assessment of risk followed by a clear statement of management objectives and the activities that will achieve those objectives. The activities can be grouped into five broad classes:

- No intervention;
- Minimising the formation of ASS in the first instance;
- Preventing oxidation;
- Protecting connected ecosystems;
- Controlling or treating acidification through neutralisation or bioremediation.

Yeodene Swamp contains ASS, and the ASS have been oxidised, so the potential activities in those two classes don't apply to the Swamp in its current condition. If the objective of the project is to minimise impact below Yeodene Swamp ('protecting connected ecosystems') the activities undertaken will be different than if the objective is to rehabilitate Yeodene

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[1] A 'wicked problem' is a problem that is difficult or impossible to solve because of incomplete or contradictory knowledge, the number of people and opinions involved, changing requirements that are often difficult to recognise and, the interconnection with other problems. The use of the term "wicked" denotes resistance to resolution, rather than evil intent. See https://www.wickedproblems.com/1_wicked_problems.php for an introduction to the concept.

[2] See: http://www.environment.gov.au/water/publications/quality/guidance-for-management-of-acid-sulfate-soils.html

Swamp. For example, in their report, Jacobs (2017; at page 49) dismissed liming downstream because it wouldn't impact on water quality in the swamp, but clearly would impact on water quality in the Barwon River.

3. Promoting sulfate reduction ('reversal of reaction') to mitigate the effects of acidification

Life exists in the absence of oxygen. There are bacteria that use the chemical compound sulfate (SO_4^{2-}) the same way we use oxygen. Instead of producing carbon dioxide, they produce another chemical called sulfide (S^{2-}). Sulfide can react rapidly with metals, mostly iron, to produce metal sulfides. Metal sulfides are the active ingredient in ASS. When metal sulfides are exposed to oxygen they revert back to sulfate, in the process creating acid.

The conversion of sulfate to sulfide and back to sulfate is pH neutral. The conversion of sulfate to sulfide creates the same amount of alkalinity as the amount of acid produced when the sulfide is converted back to sulfate. It is the conversion of sulfate to sulfide (in the process creating more ASS) which the proponents are relying on to 'rehabilitate' Yeodene Swamp.

Will it work? The answer is maybe. Firstly, re-inundation will significantly slow, if not completely stop, the production of any more acid. This is because there isn't a lot of oxygen that can be dissolved in water - typically 10 parts per million. It will, however mobilise any retained acidity in the swamp which will need to be managed in the short term. I haven't been given sufficient information to determine exactly how much acid will be immediately mobilised, therefore I don't know how much lime needs to be deployed to neutralise the first flush. Jacobs (2017) only took 3 cores during their assessment. The Victorian guidelines[3] suggest 2 cores per hectare (ha) for sites larger than 4 ha to assess the risk posed by ASS. I estimated the area of Big Swam to be about 9 ha, meaning that the appropriate sampling effort would be closer to 18 cores rather than 3. *I believe a more detailed sampling program needs to be undertaken to quantify the amount of ASS and acid that is currently stored in the wetland.*

Whether or not re-inundation will re-ignite sulfate reduction (the conversion of sulfate to sulfide) depends on a number of factors. Sulfate reduction requires:-

- A zone without oxygen;
- A source of sulfate and;
- A source of bioavailable carbon (a food source for the bacteria).

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[3] EPA Victoria (2009) *Acid Sulfate Soil and Rock*. EPA publication 655.1; Also see Department of Sustainability and Environment (2010) *Victorian Best practice guidelines for assessing and managing coastal acid sulfate soils*, Melbourne Victoria.

Re-inundation of Big-Swamp should create a zone of low oxygen. What is uncertain is the source of sulfate and bioavailable carbon. It is assumed that the source of sulfate to Yeodene Swamp, used to create the ASS in the first case, is from upstream. Specifically, where Boundary Creek intersects with an outcropping of the Lower Tertiary Aquifer (LTA). The data around this is uncertain, and requires further investigation. (There has only been at most one water sample analysed in the 30+ year history of the existing bores in the region)[4]. However, if we assume that groundwater from the LTA is the source of the sulfate to Yeodene Swamp, lowering of the water table means that there isn't an inflow of groundwater from the LTA into Boundary Creek, and therefore there won't be a new source of sulfate for sulfate reduction. If that is the case, then the source of sulfate for the formation of new ASS will be the sulfate that is currently stored in Yeodene Swamp; bearing in mind that a lot of the sulfate produced when the ASS in Yeodene Swamp were exposed to the air, has now been washed downstream. *I would suggest an investigation to accurately identify the source of sulfate to Yeodene Swamp, and the amount of sulfate currently stored in the swamp, be instigated*.

Sulfate reduction also requires a source of bioavailable carbon. When Yeodene Swamp was almost permanently wet, this would have come from the plant litter growing in the wetland. Especially the carbon that is leached from the litter (like tea from tea leaves). Now that the wetland has dried out, it is not certain that the peat that supported the vibrant plant growth in the wetland will return to its previous state. When peat dries out it undergoes a series of potentially irreversible changes. Peat is mostly made up of the structural polymers found in plants (cellulose, lignin etc). This material doesn't break down when it is saturated with water and has no or very low oxygen concentrations because the micro-organism that can break down this material (mostly fungi) can't live in zones without oxygen. When the peat is dried, fungi can colonise the peat and start to break it down (that is why you get subsidence). The peat loses its ability to store as much water as it did prior to drying and the surface of the peat is more likely to shed water than adsorb it (it becomes hydrophobic). Therefore, it remains to be seen if the plant community will return to the same condition as it was in prior to inundation. *A small-scale study should be undertaken to specifically determine if simply inundating peat will result firstly in anoxia and then promote sulfate reduction.*

The other issue with the proposed inundation strategy has to do with the differences in speed of the various chemical and biochemical reactions. As noted above, the conversion of sulfate to sulfide and then back to sulfate should be pH neutral. Sulfate reduction produces alkalinity (as carbonate or bicarbonate ions), sulfide oxidation produces acid. The two cancel each other out. The problem is that the precipitation of metal sulfides (the active ingredient in ASS) is rapid, so that they accumulate very close to where the sulfate reduction

[4] Bores 109108, 109110 - 109113, 109130 and 109143.

occurs. Conversely, for the most part, bicarbonate compounds are quite soluble and while some carbonate salts are insoluble in water, it takes time (months to years) for them to fall out of solution at the concentrations you would expect to see following sulfate reduction. This means that if the system isn't closed (hydrologically isolated), the alkalinity produced in ASS formation can be lost from the system (Figure1).

We have published some work on predicting the likelihood that alkalinity would be trapped in a system like Yeodene Swamp.[5] It depends in part on the calcium concentration in the source groundwater, the calcium to sulfate ratio in the source groundwater, the buffering capacity of the soil and the rate of groundwater movement in the system. In other words, alkalinity capture in these systems cannot be guaranteed. Because Yeodene swamp has acidified, it means that the system is not closed and alkalinity is being lost from the system.

Because Yeodene is an open system that does not retain all of the alkalinity produced during ASS formation, the approach of inundating Yeodene Swamp, and only relying on alkalinity created during new ASS formation to neutralise acidity produced in previous ASS formation events, is flawed. It creates a pool of ASS in the swamp that doesn't have any associated neutralising capacity associated with it, because this neutralising capacity has already been used up to neutralise previous acidity - a bit like robbing Peter to pay Paul (Figure 1). When the swamp dries out again, there will be another acidification event.

It is highly likely Yeodene Swamp will dry out in the future, notwithstanding the introduction of the proposed barrier and new flow rules downstream of McDonald's Dam. The drying of Yeodene Swamp will most likely be caused by three factors - a drying climate, lowering of the water table through groundwater extraction, and the operation of McDonald's Dam - all often acting at the same time during extended periods of drought.

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[5] K.L Whitworth, E. Silvester and D.S. Baldwin (2014). Alkalinity capture during microbial sulfate reduction and implications for the acidification of inland aquatic ecosystems. *Geochimica et Cosmochimica Acta* 130, 113-125.

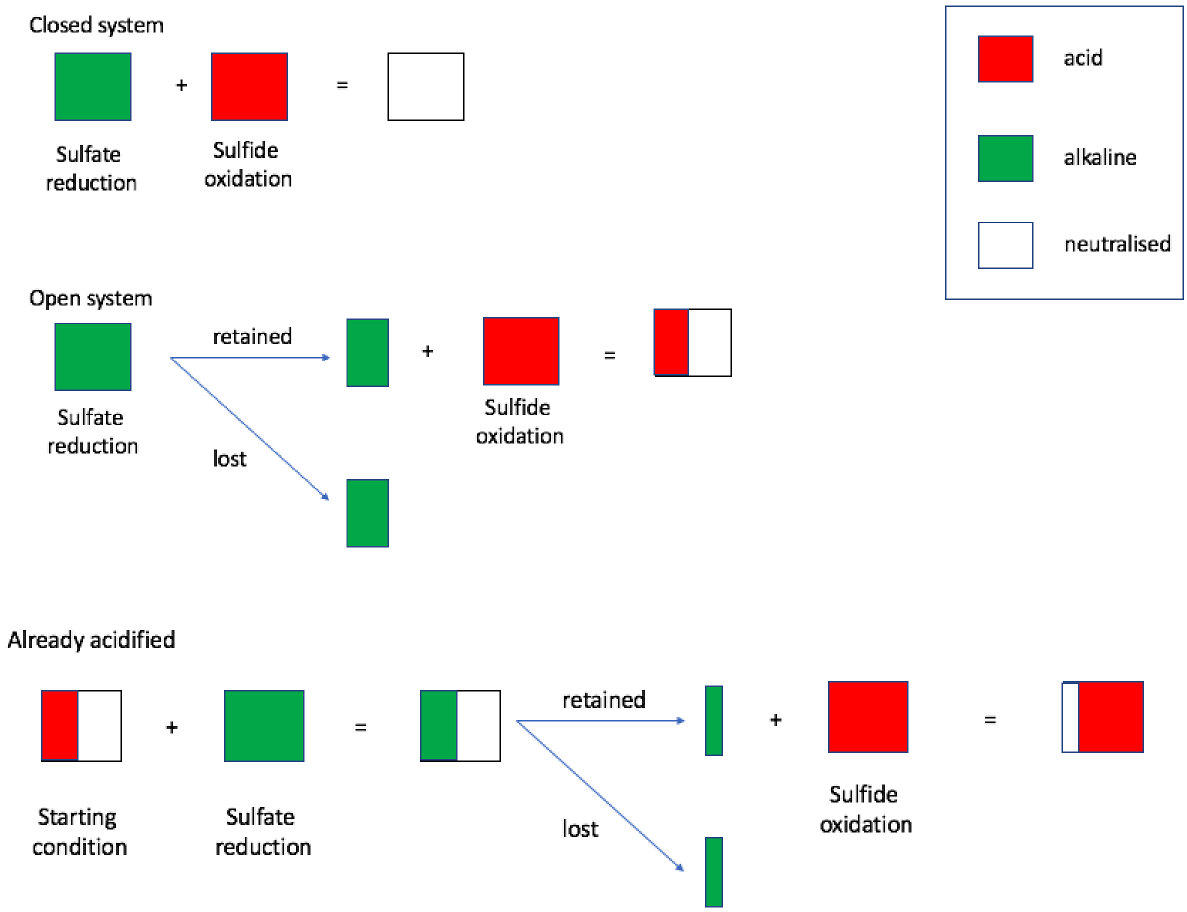

Figure 1: A schematic diagram representing the flow of acid and bases during a sulfate-reduction/sulfide oxidation cycle in a closed system (without any export), an open system where alkalinity can be exported downstream (like Yeodene Swamp) and re-introducing a sulfate-reduction/sulfide oxidation cycle in an open system that has already acidified (the preferred concept design).

4. Has the re-inundation approach been successful in the past for treating ASS in inland waterways?

Jacobs (2017) state "[t]his management strategy has been shown to be effective in a number of freshwater acid sulfate soils .... [t]his includes Partridge Creek and Darawakah Wetland (Johnston et al, 2008), the Lower Murray Lakes (Baker et al, 2014), Lake Mealup (Jenkins and Appleyard 2014) and in Bottle Bend Lagoon" (at page 56).

This is not quite an accurate summary of the literature. For example, Johnston et al (2008)[6] state "while the reformation of reduced inorganic sulfur species (RIS) is partially responsible for the generation of alkalinity and wetland scale recovery from acute acidification, the fact that these species tend to be most abundant near the surface 0.2 m of the reflooded soils, presents a long-term management challenge. In particular, these near-surface stores are potentially vulnerable to atmospheric oxygen during the next ENSO induced drought episode. Such exposure may lead to pyrite oxidation and temporary re-acidification of surface sediments and waters with attendant risks for surface water quality degradation." The authors note that the period when the wetland was re-inundated was during the 4th wettest period on record.

Baker et al (2014)[7] indeed report an increase in soil alkalinity as a result of re-inundation; and subsequent re-formation of ASS. However, they also noted that some hotspots were still acidic 3 years after re-inundation; and the initial flushing resulted in the mobilisation of acid and metals through the sediment profile and into the water column. They didn't re-consider what would happen if the re-inundated sediments were exposed again.

I was unable to source the Jenkins and Appleyard 2014 paper, but an analysis of the restoration project suggests that at least some of the rapid change in alkalinity of the wetland was likely caused by decomposition of a large amount of bulrush (*Typha sp.*), that was mulched prior to the re-inundation of the lake. Lake Mealup is now managed as a permanently inundated system using drainage water. While there are plans to re-introduce a drying cycle, the Peel Harvey Catchment Council note that liming will be necessary because of exposure of ASS.[8]

Bottle Bend lagoon. I have done extensive work on Bottle Bend Lagoon. The lagoon was dry from 2002 to 2010. The initial drying was associated with lowering the Mildura Weir Pool. This resulted in a substantial lowering of the local ground water table, exposing sediments and causing acidification. Re-filling of the Mildura Weir Pool did not result in a re-filling of the wetland. The wetland was re-filled by the 2010 flood and the water replenished by floods in 2012 and again in 2016. To the best of my knowledge, the sediments in Bottle Bend Lagoon still contain ASS.

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[6] S. Johnston, E. Burton, T. Aaso and G. Tuckerman (2008) *Remediation of coastal acid sulfate soils by freshwater flooding.* Found at: www.coastalconference.com/2013/papers2013/Scott%20Johnston.pdf
[7] A. Baker, P. Shand, R. Fitzpatrick, AM Jolley, L. Barnett (2014) Neutralisation of soil acidity in re-flooded acid sulfate soil environments around Lake Alexandrina and Lake Albert, South Australia. http://scu.edu.au/nationalassconference/index.php/3/
[8] Annon. https://www.eianz.org/document/item/3153

5. An alternate approach to re-introducing sulfate reduction

An alternate option than promoting sulfate reduction and producing more ASS in the process, is to promote an alternate reaction - specifically nitrate reduction. This would require adding nitrate fertiliser (and possibly a source of bioavailable carbon) to the swamp. Before nitrate addition is considered as an alternate to re-instating sulfate reduction, it would be necessary to undertake a small-scale trial to determine whether or not this approach can be successful (e.g. whether or not the peat can return to a state to promote anoxic conditions, to what extent the added nitrate will oxidise any residual sulfides in the swamp, etc). The dose of nitrate would need to be carefully monitored because of the potential for nitrate export downstream leading to nuisance algal blooms.

6. Will the proposed additional water reach Yeodene Swamp?

It has been reported that the reach above Boundary Creek above Yeodene Swamp has gone from a gaining reach to a losing reach. That means instead of water going into the swamp, it is going in to refill LTA. Furthermore, Jacobs (2017) has shown that flows above McDonald's Dam are greater than flows downstream of McDonald's Dam at times (e.g. November 2015 to May 2016); which is not consistent with the dam's operating rules.[9] So the question remains of how much of the proposed 3 ML/day flow will reach the swamp.

7. How much did winter and spring flow add to the recharge of the LTA prior to the construction of McDonald's Dam?

If McDonald's Dam operates within its rules, it is able to harvest winter runoff. In the current state, with the reach above Yeodene Swamp being a losing reach to the LTA, winter and spring runoff unimpeded by McDonald's Dam should contribute to ground water levels. *I would suggest a study that modelled groundwater levels in the LTA and the shallow aquifers along Boundary Creek over the last several decades both with and without McDonald's Dam to see how large that effect actually would be.*

8. The peat's response to re-wetting

As mentioned above, I have questions as to whether or not the peat in the swamp will revert to its previous state upon re-wetting. Some of the peat in the swamp has been burnt. Some will have been broken down by fungi, which will lead to subsidence. In other peat swamps, peat drying has resulted in substantial changes to the peat. It can become hydrophobic (water repelling), which substantially reduces the amount of water the peat can hold. Reversal of this process can be slow. *A study should be undertaken to determine the extent that the peat will recover its physical properties (particularly water holding*

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[9] "*Unless otherwise directed by the Authority, water may only be harvested into the on-waterway dam during the period from 1 July to 31 October inclusive; at all other times, the entire stream flow must be passed downstream of the dam.*"

capacity) on re-wetting. This will affect the plant community that can grow in the swamp (the source of bioavailable carbon) as well as the soil microbial community.

9. Liming downstream of Yeodene Swamp

One of the options considered, and rejected, in Jacobs (2017) was the installation of a lime drain below the swamp. The lime would neutralise the acid produced in the swamp before it reached the Barwon River. One of the reasons for rejecting the lime drainage was because the process would modify the reach downstream of the swamp. This reach has already undergone significant modifications. The land around the reach has been extensively drained, and the lowest part of the reach appears to have been straightened at some stage. While I agree with the Jacob's report that this is only treating the symptom and not the problem, nevertheless acidification events will continue in Boundary Creek, at least in the short-term.

Dosing the reach below Yeodene Swamp with lime (calcium carbonate or $CaCO_3$) during acid events is feasible. A back of the envelope calculation[10] would suggest that it would take 50 - 75kg of lime per ML per day to neutralise pH 3 water. Therefore, installing a manual or automated liming station in Boundary Creek to neutralise acid events in the short term should be considered. It is only a short-term solution though. This is not without its issue. Permits would probably be required to dose a stream. Furthermore, neutralisation would result in the precipitation of any metals dissolved in the acidic water. The metal accumulation can be monitored and assessed against the Australian Sediment Standards. *As a preliminary action, the current status of surficial sediments in Boundary Creek downstream of Yeodene Swamp needs to be evaluated against the Australian Sediment Quality Standards.*

Response to the specific question raised

A. Confidence that the wall will sufficiently wet the swamp over the 8 - 10 m gradient.

I have been able to get a digital elevation model of the swamp. The last LIDAR data was collected in 2008 i.e. before drying, subsidence, the 2010 fire and the fire trench being dug. *It is recommended that new LIDAR data be obtained*.

Examination of the site using *Google Earth Pro* suggests the gradient is probably closer to 4 metres. Jacobs have stated that the purpose of the structure is not to totally re-inundate the site but to increase the height of the water table. If that is the case, then the structure

[10] pH 3 = 10^{-3} moles H^+/L. 1 ML of water at pH = 3 would contain (10^{-3} x 10^6) = 10^3 moles of H^+. One mole of $CaCO_3$ can neutralise 2 moles of acid therefore you would need 5 x 10^2 moles of $CaCO_3$ to neutralise 1 ML of pH 3 water. The molar mass of $CaCO_3$ is about 100g/mol. Therefore, you would need (5 x 10^2 x 100g) = 50 000 g = 50 kg of $CaCO_3$/ day. Using a safety factor of 1.5 would require 75 kg.

needs to be designed such that groundwater out-flows downstream of the structure are impeded. Google Earth images suggest that there are local expressions of groundwater downstream of Yeodene Swamp. *A hydrogeological investigation needs to be undertaken to see if the structure needs to extend all the way through the shallow aquifer to the aquitard to minimise groundwater outflows.* Minimising groundwater losses will also overcome the problem of alkalinity transfer from the swamp downstream.

B. Criteria to measure the success of the reversal of the chemical reaction
As noted above, I am not entirely sure that the approach will work in the current situation; and if it does it will not prevent acidification happening into the future. Again, I would suggest that the idea be tested in small scale experiments before embarking on an engineering solution.

Technically, for a true long-term solution, the criteria for success of the project would be that the acid neutralising capacity (ANC) of the sediment in the swamp exceeds the actual and potential acidity arising from oxidisation of reduced sulfur species in the sediments.

C. Is the proposed dam wall design the most appropriate?
As noted above (At question A), I think additional information is required regarding the structure's ability to retain groundwater - especially whether or not the structure needs to extend to the aquitard.

D. If the hydraulic barrier is only a metre above ground level at the downstream end of the swamp, while at the other end ground level is 15 metres higher, how can the swamp be inundated without leakage?
See answer to Question A (above).

E. How much water is retained and how much will flow over the barrier?
I can't answer this question based on the information supplied in Jacobs (2017).

F. What is the predicted amount of acid that will be flushed out following the inundation of the swamp?
It is difficult to answer based on the available data. Jacobs (2017) only took 3 cores during their assessment. The Victorian guidelines[11] suggest 2 cores per hectare for sites larger than 4 ha for assessing the risks posed by ASS. I estimated the area of Big Swam to be about 9 ha, meaning that the appropriate sampling effort would be closer to 18 cores rather than 3.

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[11] EPA Victoria *Acid sulfate soil and rock* Publication 655.1 (2009); also see Department of Sustainability and Environment (2010) *Victorian Best practice guidelines for assessing and managing coastal acid sulfate soils*, Melbourne Victoria.

G. How much will remediation cost and how long will it take?
I cannot comment on cost or construction time. The question of how long reversal of acidity takes it will depend on:

- Whether or not other strategies in addition to the barrier being built are used
- How much sulfate (or other electron acceptors) and bioavailable carbon are present in the swamp
- How long it takes for the peat returns to a semblance of its previous condition
- Local hydrology and hydrogeology
- The temperature (microbial processes are temperature dependendant).

H. Site Visit
I agree with this comment; so that all stakeholders have an opportunity to explain what they 'see' in the landscape, what their values are and where they see solutions (see 'wicked problem' above).

I. Give the options a rating or weight.
Do nothing - Zero rating. While 'do nothing' is a legitimate management decision in some instances (e.g. in an unconnected wetland of little ecological or economic value), in the current situation, if no action is taken then there will be ongoing ecological harm to downstream ecosystems. Therefore, this is not an option.

Treatment of soils - Low rating if this is the only option; moderate to high ranking if done in conjunction with other activities. This isn't a long-term solution and, as pointed out by Jacobs (2017), it is highly impractical to inject the treatment to depth. However, as a short-term stop gap, it will help deal with the acidity, both in the swamp and downstream. In plot trials at Bottle Bend Lagoon, soil amelioration with lime or calcium hydroxide were the only activities that affected soil pH.[12] *At a minimum, a feasibility study of aerial application of fine lime to the swamp should be undertaken.*

Instillation of a lime drain in Reach 3 - Liming (in some form) has a medium to high rating in the short to medium term, but needs to be done in conjunction with other activities. I think the highest priority in the short-term is to minimise impact of acid events on the Barwon River, which means liming. Jacobs (2017) has suggested a lime lined drain, which will irreversibly impact on the nature of lower Boundary Creek. As noted at point 8 above, manual dosing of lime should also be considered.

Diluting acidic discharge - Zero Rating. There isn't enough water. pH is measured on a negative log scale. This means that a fall in pH by one unit means a ten-fold increase in acid

[12] M. Fraser, D. S. Baldwin, G.N. Rees, E. Silvester and K. Whitworth (2012) Rehabilitation options for inland waterways impacted by sulfidic sediments - Field trials in a south-eastern Australian wetland. *Journal of Environmental Management*, 102, 71-78.

concentration. So, to dilute 1 ML of water at pH 3, to pH 6, would require 1000 ML of water (assuming no buffering capacity in the dilution water).

Revising Flow Location - Low Rating. Isolation is a legitimate approach, analogous to triage in medicine if the objective of the study is to minimise impacts on downstream ecosystems. In this scenario the swamp is essentially abandoned as an ecosystem. Notwithstanding the societal ramifications of this approach, to be an effective strategy requires the site to be completely isolated from adjacent ecosystems. Given the substantial ground- and surface water connectivity in Boundary Creek, while this approach might be feasible, it certainly would be expensive.

Inundating Yeodene Swamp - High Rating in the long-term but needs to be done in conjunction with other activities (liming and soil treatment), and there are a number of caveats. As outlined in the first section of this report, there are still a number of knowledge gaps that need to be addressed. Acid will be mobilised on re-flooding, which will need to be neutralised (hence the soil treatment and downstream liming). Simply re-instating sulfate reduction (if that can actually be achieved) only postpones the problem until the next large drought - hence the idea of introducing other electron acceptors to compete with sulfate reduction.

J. Look at each remediation option - does groundwater level impact on outcome.

Do nothing - No
Treatment of soils - Yes, because the amount of ameliorant used will depend on how much unoxidised ASS (referred to in Jacobs (2017) as potential ASS) are in the system. As the localised groundwater level falls, more ASS will be oxidised, creating more acidity.

Liming (noting the expansion of the original proposal to include direct liming) - indirectly. It is based on expressed acidity, which in turn is based on groundwater level (as above).

Diluting acidic discharge - not relevant

Revising Flow Location - Yes, because, to be a successful strategy, the remnant ecosystem needs to be completely isolated from downstream ecosystems.

Inundating Yeodene Swamp - Yes, for the reasons outlined in the first part of this report.

K. Where is the LTA under the swamp?
Earlier modelling by Jacobs suggests that the swamp is lying over a shallow aquifer that is separated from the LTA by an aquitard. Direct contact between the LTA and Boundary Creek is upstream of the swamp.

L. If water leaks from the swamp into the aquifer under the swamp, will extra supplementary water be required to maintain streamflow in Boundary Creek downstream?
I have addressed this at point 5 in the *Review of Concept Design.*

M. Contamination of the LTA and understanding if the chemistry of the aquifer will be affected due to swamp (i.e. poor water quality extracted from the bore field as a result of acidic water leaking into the aquifer from the swamp).
I would expect little impact of poor water quality from Yeodene Big Swamp impacting on water quality extracted from the bore field except in the very long-term (millennia). Firstly, given the proposed connectivity (Question M, above) direct connectivity between the shallow aquifer below the swamp and LTA is through an aquitard, so movement will be very slow. Any acid produced would most likely be neutralised by dissolution of rocks forming the aquitard. While this would produce a plume of metals, the sheer volume of water in LTA would dilute the metal signal before it reached the bore field.

N. PERT chart for option 5
For reasons that I hope I have articulated clearly enough, I don't think the project is sufficiently advanced for a PERT analysis.

O. Confidence the equation can be reversed
This is addressed at Points 3 and 4 of the *Review of Concept Design.*

P. Analysis of what is being neutralised
This is also addressed at Points 3 and 4 of the *Review of Concept Design*.

Q. Data showing neutralise process re: flooding with the 8 – 10m rise front to back of swamp
I'm not entirely sure of the meaning of this question, but I believe I may have already addressed the key points.

R. How much of the swamp might be non- inundated (being elevated) and so fire prone
This was addressed at Question A.

T. What could go wrong and what could happen? E.g. identification of brown coal, ignition of fire
What could go wrong already has.

U. Does a process / legal requirement similar for that of a mine contamination need to be followed for Big Swamp?
This is a question for Barwon Water's legal advisors. Potentially relevant policy documents include:-

- Victorian *Industrial Waste Management Policy (waste acid sulfate soils) 1999;*
- EPA Victoria *Acid sulfate soil and rock* Publication 655.1 (2009);
- *Victorian Coastal Acid Sulfate Soil Strategy* and

- *Victorian Best practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils.*

V. Does the remediation concept design need to be submitted to obtain regulatory / statutory approvals?
This is a question for Barwon Water's legal advisors.

W. Please source core sample data from Professor Richard Bush / Phil Hurst
I haven't seen the results from Richard's Core samples. The relevance to the current discussion would depend on how long ago they were taken.

Appendix C

Listing and prioritising research questions and activities to address the on-going management of Yeodene Big Swamp and Boundary Creek

Prepared by: Darren S. Baldwin
Rivers and Wetlands

November 2018

This report was prepared for Barwon Water by Darren Baldwin trading as *Rivers and Wetlands* (ABN 85741766412)

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Note this document supersedes DS Baldwin (2018) *Discussion Paper: Listing and prioritising research needs to address the on-going management of Yeodene Big Swamp and Boundary Creek.* It has been updated to include feedback from community stakeholders as well the outcomes of the research prioritisation meeting held in Geelong on the 13th November 2018.

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Executive Summary

In the past several decades change in water management coupled with periods of climatic drought has resulted in the drying of Yeodene Big Swamp, exposing acid sulfate soils and causing acidification events in Boundary Creek and the Barwon River. A *Ministerial Notice* was issued pursuant to Section 78 of the *Water Act* 1989 by Southern Rural Water on the 11th September 2018 directing Barwon Water to prepare a remediation plan for Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping. Barwon Water was directed to produce a 'scope of works' that informs the scientific knowledge gaps that need to be addressed to inform the remediation planning process. The nature of this scope of works needs to be communicated to Southern Rural Water by 20th December 2018. This document outlines the processes undertaken to identify and prioritise the knowledge gaps, and hence activities, that will make up the scope of work. Grouped according headings outlined at Item 2.5 (a) of the *Ministerial Notice*, the identified activities are:

Hydrogeological Condition

1. On-going water level monitoring of existing bores
2. Regular (6 monthly) monitoring of water quality (pH, sulfate and heavy metals) in bores that intersect the LTA near Boundary Creek.
3. Instillation of up to 18 shallow groundwater monitoring bores in Big Swamp. The soil collected during drilling will be used for subsequent chemical analysis and incubations - see below

Hydrology

4. On-going monitoring of surface water flows, including below McDonalds Dam.
5. Instillation of v-notch weirs in Boundary Creek at the eastern and western edges of Big Swamp.

Ecological Assessment

6. Continue on-going vegetation monitoring in the Damplands and Big Swamp.
7. Assessment of sediment quality in the Barwon River downstream of Boundary Creek.
8. Assessment of macro-invertebrate community structure in Boundary Creek and the Barwon River downstream of the confluence.

LIDAR Topographic Mapping

9. Undertake a LIDAR survey of Big Swam.

Results of Soil Sampling

10. Using the soil collected for determine the current actual and potential acidity in the swamp, sulfate concentrations and an assessment of the extent of burning based on the chemical properties of the soil
11. Also sing the soil collected undertake lab incubation studies to determine the amount of bioavailable carbon in Big Swamp, whether or not it is possible to re-instate sulfate reduction in the wetland and whether or not other biogeochemical processes can lead to an increase in alkalinity.

Furthermore, it is anticipated that the biogeochemistry of Big Swamp will be linked to the hydrology and hydrogeology of Boundary Creek and the LTA through a modelling exercise.

1. Purpose

In the past several decades change in water management coupled with periods of climatic drought has resulted in the drying of Yeodene Big Swamp, exposing acid sulfate soils and causing acidification events in Boundary Creek and the Barwon River. A *Ministerial Notice* was issued pursuant to Section 78 of the *Water Act* 1989 by Southern Rural Water on the 11th September 2018 directing Barwon Water to prepare a remediation plan for Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping. After a review of the initial proposal into actions to remediate Big Swamp (Jacobs, 2017a), and following consultation with the Boundary Creek Remediation Working Group, it was evident that there are a number of critical knowledge gaps/questions that need to be addressed prior to undertaking a program of works and measures to address the issues faced at Big Swamp and Boundary Creek.

The purpose of this document is firstly to: [1]

- List the knowledge needs/questions identified for Boundary Creek (including Big Swamp) and impacted reaches of the Barwon River by Boundary Creek Remediation Working Group and, the working group's nominated experts[2];
- Summarise any previous studies that have been undertaken in the area that may help address those questions;
- Broadly outline potential research activities that could be undertaken to address the knowledge needs with indicative (but not prescriptive) costs;
- Identify any risks associated with the research activities that could preclude them from being achieved.

This document then outlines the outcomes of the research prioritisation process that was undertaken by the Panel of Experts convened by Barwon Water at a meeting in Geelong on 13th November 2018 to identify the activities that would form the scope of works that will underpin the plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping.

2. Identifying Knowledge Gaps

2.1 Approach

Knowledge gaps were first identified from a review of proposed interventions for Big Swamp (Jacobs, 2017) by the working group's nominated experts. Additional knowledge gaps were identified by stakeholders during a meeting of the Boundary Creek Remediation Working Group in August 2018 as well as following feedback of an earlier version of this

[1] Note the current document supersedes DS Baldwin (2018) *Discussion Paper: Listing and prioritising research needs to address the on-going management of Yeodene Big Swamp and Boundary Creek* where these questions were first explored. It has been updated to include feedback from community stakeholders as well the outcomes of the research prioritisation meeting held in Geelong on the 13th November 2018.

[2] Dr Vanessa Wong (Monash University), Prof. Richard Bush (University of Newcastle) and Prof. Darren Baldwin (*Rivers and Wetlands* and Charles Sturt University)

document. Where appropriate, these knowledge gaps were subsequently consolidated, and then framed in the form of questions by *Rivers and Wetlands*.

Then, for each of these questions:

- *The previous knowledge around the questions was assessed*. All previous scientific studies on Boundary Creek and Big Swamp were identified through the Barwon Water database created as part of its renewal application[3], the reference lists in previous reports and searches of both the *Web of Science* and *Google Scholar* databases.[4] I was unable to locate any studies that pre-date pumping of the Lower Tertiary Aquifer. In order to address the lack of earlier studies, I also searched TROVE (the National Library of Australia's database) looking for reports, Government Gazette or newspaper accounts of the condition of Boundary Creek, Big Swamp and the Barwon River. Copies of all scientific reports were then critically reviewed - examining methodology, results and conclusions.
- *Potential approaches to address the question were explored*. The proposed activities are described only in the broadest of terms, and serve as a "discussion starter" rather than an outline of a definitive approach.
- *Feasibility of these approaches was considered* and;
- *Indicative cost assigned*. Indicative costs are meant to be a guide only and will need to be tested against the market. Indicative costs are grouped as:

$	< $10,000
$$	$10,000 - $25,000
$$$	$25,000 - $50,000
$$$$	$50,000 - $100,000
$$$$$	$100,000 - $250,000

The questions were then grouped by geographical location[5]:

- McDonald Dam;
- Boundary Creek between McDonald Farm and Big Swamp (Reach 2);
- Big Swamp;
- Boundary Creek between Big Swamp and the junction with the Barwon River (Reach 3) and,
- Barwon River.

Then, for each location, the questions were grouped (sometimes arbitrarily) into 5 broad topics:

- Water balance and flow paths
- Current concentrations of key constituents
- Likelihood of restoring biogeochemical processes

[3] Found at https://www.yoursay.barwonwater.vic.gov.au/barwon-downs-borefield-licence-renewal/documents

[4] The vast majority of scientific reports that I could locate were government reports, studies commissioned by Barwon Water and student theses. For the most part these reports were not externally peer reviewed - with the possible exception of the student theses which would have be marked by external examiners. The absence of external peer-review does not necessarily mean that these studies are not scientifically credible. All studies cited in this report were critically reviewed by *Rivers and Wetlands*.

[5] No knowledge gaps were identified for Boundary Creek above McDonald Dam.

- Current ecological condition
- Historical ecological condition to inform future target settings.

(Noting that not all locations had assigned questions for each topic.)

While it is anticipated that during the research prioritisation processes individual question and activities will likely be grouped together to create coherent bodies of work, to ensure all questions are considered in the prioritisation processes, they are considered separately in the following discussion (see Section 2).

2.2 Questions

2.2.1 McDonald Dam

McDonald Dam is an in-stream water storage on Boundary Creek constructed in 1979. The dam has a capacity of 160 ML.

Water Balance and flow paths

Question 1: Is McDonald Dam a net sink for surface water from late spring to early autumn?
Context: While groundwater extraction and climatic drought have both been implicated in the drying of Big Swamp, the diversion of water from Boundary Creek, facilitated by the operation of McDonald Dam may also have also have been a contributing factor.
Previous Studies: Jacobs (2017a) has indicated that, particularly during the warmer months, and contrary to the operational licence conditions, the flow downstream of McDonald Dam is less than the inflows into the dam; at least for the period from 2014 to 2017[6].
Suggested Activity: Compliance monitoring. Actively monitor the flows at Gauges 233231 (upstream of McDonald Dam) and 233230 (downstream of McDonald dam) and undertake further investigations if discrepancies are noted.
Feasibility: Feasible
Cost: $

2.2.2 Reach 2

Reach 2 is between McDonald Dam and Big Swamp. The western part of the reach is in cleared farmland, while the eastern portion of the reach (known as the "damplands") is "floristically complex" (Jacobs, 2017b) and therefore is ecologically significant.

Water Balance and flow paths

Question 2: Is Reach 2 net losing?
Context: A quick analysis by *Rivers and Wetlands* of flows at Flow gauges 233229 (downstream of McDonald Dam and 233228 (Boundary Creek at Colac-Forest Bridge)

[6] There is a gap in the data for flows downstream of the dam from 1994 to 2014.

between September 2014 and September 2018 suggests that this whole section of Boundary Creek is net losing (at a rate of about 1.6 ML/day). If most of the loss is in Reach 2 then this needs to be factored into the design of environmental flows for Big Swamp. Furthermore, an understanding of the hydrology and hydrogeology of Reach 2, is necessary to understand water dynamics in Big Swamp

Previous studies: Jacobs has undertaken both modelling (Jacobs, 2017c) and field work (Jacobs, 2017a) to examine the hydrology and hydrogeology in this reach. Based on the most recent fieldwork Jacobs (2017a) suggests that the western section is net gaining (from local inflows from the immediate catchment) while the eastern section is net losing. These conclusions are based on a limited set of observations.

Potential Activities: Undertake a more detailed (and on-going) assessment of water dynamics in Reach2. This would include the installation of a v-notch weir on Boundary Creek immediately upstream of Big Swamp as well as a series of piezometers in the damplands to measure water depth and hydraulic pressure.

Feasibility: Identifying a suitable site for the installation of the v-notch weir may be difficult. Site access for machinery for the installation of the weir and piezometers may prove to be problematical.

Cost: $$$$? for installation; $ for on-going monitoring

Current Ecological Condition

Question 3: Can surface water alone sustain the ecological condition of the damplands?

Context: It is probable that the ecological condition of the damplands has be sustained by groundwater inflows from the lower tertiary aquifer (e.g. See Jacobs 2017b). Loss of these inflows may impact on the ecological condition of the damplands.

Previous studies: This area was included in the survey by Carr and Muir (1994) and was recently surveyed by Jacobs in 2014, (Jacobs 2015) and 2016 (Jacobs 2017d).

Potential Action - on-going condition assessment through the establishment of photo points supplemented by periodic (5 year?) ground assessments. Results interpreted based on hydrology and hydrology identified at Question 2.

Feasibility: Feasible

Cost: Photo points - $; Ground Survey - $

2.2.3 Big Swamp

Big Swamp is a highly modified peat bog on Boundary Creek. In the past the swamp was drained for agricultural purposes. More recently water inflows into the swamp have been altered through a combination of groundwater extraction, surface water harvesting and climate change. Drying has exposed acid sulfate soils in the soil profile causing episodic acid events downstream. As a consequence of drying there have also been a series of peat fires in the swamp. To contain the fires a trench has been dug through the swamp, further altering the hydrodynamics within the swamp. There is strong community support to restore the ecological condition of the swamp.

Water balance and flow paths

Question 4: Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer (LTA)?

Context: There is community concern that Big Swamp is directly connected to the LTA and poor water quality originating from the swamp (metals, metalloids and acidity) is impacting on water quality in the aquifer. Understanding where the LTA intersects Boundary Creek is critical in understanding the hydrology and hydrogeology of the region, which in turn is critical in assessing potential management interventions.
Previous Studies: Based on modelling and earlier bore logs Jacobs (2017a and 2017c) have suggested that Big Swamp lies over an aquitard and the outcropping of the LTA is in Reach 2. No detailed drilling has been undertaken within the swamp to determine the substrate under Big Swamp.
Potential Activity 1: Undertake a drilling program to determine the extent of the aquitard under Big Swamp.
Feasibility: The problem with this proposed activity is physically getting a drilling rig capable of drilling through to the aquitard onto the swamp. Even if the remaining peat could support the weight of a drilling rig, there would be substantial damage to the swamp through clearing of access tracts.
Cost: $$$$ - $$$$$?

Potential Activity 2: Undertake surface water mass balance accounting using the three extant gauging stations on Boundary Creek plus the additional gauge immediately upstream of Big Swamp proposed to address Question 2.[7]
Feasibility: Identifying a suitable site for the installation of the v-notch weir may be difficult. Site access for machinery for the installation of the weir may prove to be problematical.
Cost: $ (excluding construction of the v-notch weir).

Potential Activity 3: Use remote sensing, specifically ground penetrating radar and or electromagnetic (EM) surveys to determine location of the aquitard and LTA.
Feasibility: Deploying ground penetrating radar in Big Swamp may be difficult given the terrain. Aerial EM surveys may have already been flown over the region
Cost: $$ - $$$$?

<u>Question 5:</u> Are there preferential surface or subsurface flow paths in Big Swamp?
Context: Jacobs (2017a) preferred mitigation approach was to construct a barrier across the swamp to permanently wet the swamp. The design of the barrier (including depth) needs to be based on a detailed understanding of the alter flow paths in the swamp.
Previous Studies: As a part of its recent investigation into Big Swamp, Jacobs installed 5 piezometers in the swamp - each to a maximum depth of about 3 metres.
Proposed Activity: It is proposed that up to an additional 18 piezometers are installed to determine groundwater dynamics. The piezometers would be evenly distributed across the

[7] During the review process of the original Discussion paper it was suggested to include a second v-notch weir at the eastern end of Big Swamp.

site. The bores should extend all the way through the peat. Surface water pathways could be determined through aerial inspection - probably using drones.
Feasibility: It will prove challenging to bore all the way through the peat layer and then line the bore hole as it will most likely need to be done by hand. That being said coring to depth is routinely undertaken in peat bogs elsewhere, often using a specialized peat corer. It is of note that the cores collected in this exercise will be used to address other questions (discussed below). It may be necessary to undertake a pilot study to determine the most practical way of coring.
Cost: Surface water monitoring - $; piezometers - $$$$

Current concentration of key constituents

<u>Question 6</u>: How much actual and potential acidity is currently stored in Big Swamp?
Context: Acidification events have occurred over the last several decades in Reach 3 and the Barwon River. While peat systems can be naturally acidic, a series of studies has shown that the acidification in Big Swamp was produced by exposure of acid sulfate soils within the peat profile. All three experts appointed by Barwon Water to review Jacobs (2017a) report into management options expressed the opinion that there was insufficient information available to quantify the risk posed by the actual and potential acidity within the swamp. New national guidance on sampling acid sulfate soils (Sullivan et al, 2018a) recommend for sites where more than 1000 m^3 of material is potentially that for sites over 4 ha in area that there are 10 boreholes drilled plus an additional 2 boreholes/ha over 4 ha. Assuming Big Swamp has an area of 8 ha this would equate to 18 bore holes. In addition, where alteration of ground water is expected, as is the case with Big Swamp, then sampling should go to a depth of at least one metre below the lowest estimated groundwater drawdown. Given that there is a potential for Big Swamp to potentially fully dry out, sampling should go to the full length through the peat.
Previous Research: Davidson and Lancaster (2010; cited in Glover 2014) collected sediment samples from the northern edge of the swamp in March 2010 (to a depth of about 0.08 m) and showed elevated TAA and S_{Cr}) with values of up to 1175 moles H^+/t and 16% respectively. Glover (2014) sampled at three sites along the fire trench on the southern boundary of the swamp to a maximum depth of 2.5 m. TAA varied from about 50 to 260 moles H^+/t and S_{Cr} varied from 0.02 to 0.05%. Jacobs drilled 5 cores in 2016, 2 at the western end of the swam and three along a transect to the east of the swamp. Cores were drilled to a maximum depth of about 3 metres. Actual acidity ranged from 3.7 to 910 moles H^+/t and potential acidity (from S_{Cr}) up to 9000 moles H^+/t.
Proposed Activity: Analyse material collected from cores collected during the installation of the piezometers (described at Question 5) for the suite of analytes recommended in the new Australian Guidelines - S_{Cr}, KCl extractable pH, TAA, net acid soluble sulfur, and acid neutralising capacity (Sullivan et al, 2018b).

Feasibility: Notwithstanding the issue associated with coring in the swamp (discussed at Question 5) this approach is feasible.
Cost - Excluding the cost of coring - $$$ to $$$$ for analysis and reporting.

Question 7: How much sulfate remains in the sediment profile in the swamp?
Context: For Jacobs (2017a) the principal reason for suggesting the construction of a barrier across the eastern edge of Big Swamp was to create alkalinity by reinstating sulfate reduction within the swamp. Given that there have already been acidification events and, the swamp is not a closed system, it is likely that sulfate may have been exported from the system.
Previous Research: I am unaware of any available data on sulfate concentration in the sediment profile of Big Swamp.
Proposed Activity: determine water extractable sulfate concentrations in the material collected from cores collected during the installation of the piezometers (described at Question 5).
Feasibility: Notwithstanding the issue associated with coring in the swamp (discussed at Question 5) this approach is feasible.
Cost: Excluding the cost of coring - $ to $$ for analysis and reporting.

Question 8: How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
Context: Generation of biogeochemical processes to create alkalinity requires a source of carbon that is relatively bioavailable for use by the microbes that drive biogeochemical processes. Bioavailable carbon is derived mostly from plant litter. Drying and fire will both impact on the amount of bioavailable carbon currently stored in the swamp, as well as affecting the extant vegetation. Some sense of bioavailability of the peat can be assessed in the mesocosm experiments discussed at Question 9.
Previous Research: I am unaware of any available data on bioavailable carbon concentration in the sediment profile of Big Swamp.
Proposed Activity: Determine the specific oxygen uptake rate, concentration of volatile solids and moisture content of a *subset*[8] of the samples taken at Question 5.
Feasibility: Notwithstanding the issue associated with coring in the swamp (discussed at Question 5) this approach is feasible.
Cost: Excluding the cost of coring - $$ - $$$ for analysis and reporting

Likelihood of restoring key biogeochemical processes

Question 9: Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in the swamp?

[8] To reduce costs (SOUR analysis costs about $100/sample).

Context: Jacobs (2017a) proposed the construction of a barrier at the eastern end of Big Swamp to allow re-inundation of the peat in the swamp. While inundation will stop the on-going acidification caused by the oxidation of sulfides in Big Swamp, the principle justification for the proposal was to re-instate sulfate reduction. The microbially mediated reduction of sulfate to sulfide results in the production of alkalinity, which could neutralise actual acidity currently present in the swamp. Leaving aside the question of whether or not a process should be considered which will increase the potential acidity in the swamp, questions remain to whether or not re-inundation alone will result in levels of sulfate reduction sufficient to produce enough alkalinity to neutralise the acidity currently in the swamp. There are questions about whether or not there is sufficient sulfate or bioavailable carbon in the swamp (addressed at Questions 7 and 8 above), but questions also on the effect of drying and burning on biogeochemical processes in the swamp.
Previous Studies: Although these types of studies have been undertaken elsewhere, I am unaware of these types of studies being undertaken at Big Swamp.
Proposed activity: Undertake a series of mesocosm "slurry" experiments using a subset of material collected in the coring exercise described for question 5. Replicate samples of undamaged peat, peat that has been dried (identified at Question 14) and peat that been damaged by fire (identified at Question 13) would be incubated under a range of experimental conditions which could include, but are not limited to:

- Inundated but exposed to the air (to see if there is sufficient bioavailable carbon to generate anoxia in an open system)
- Inundated in a closed system following purging with nitrogen or argon
- As above but with added bioavailable carbon (probably as acetate)
- As above but with added sulfate
- As above but with added sulfate and carbon.

Key analytes would include (but are not limited to) dissolved oxygen concentration, pH, carbon concentration, sulfate concentration and AVS formation. These experiments would be followed through time to determine the kinetics of the reactions. For potential experimental designs see Baldwin et al. (2006), Whitworth and Baldwin (2011) and/or Baldwin and Mitchell (2012).
Feasibility: These types of experiments have been undertaken elsewhere in the past.
Cost: $$ - $$$$ depending of design - see also Question 10.

<u>Question 10:</u> Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?
Context: While Jacobs (2017a) proposed re-instating sulfate reduction as a means to generate alkalinity, active promotion of other anaerobic reactions - specifically nitrate reduction or iron reduction could also generate alkalinity.

Proposed Activity: Expand the experiments outlined under Question 10 to include addition of nitrate or iron with or without added carbon. Key analytes would be expanded to include nitrate and Fe(II).
Feasibility: These types of experiments have been undertaken in the past.
Cost: $$ - $$$$ depending of design - see also Question 9.

Question 11: Is it necessary to directly introduce alkalinity (in the form of lime or other ameliorants) directly into the swamp?
Context: Depending on the outcomes from activities outlined for question 6, 9 and 10, ultimately it may be necessary to active introduce an alkalising agent directly into the peat. Field experiments at Bottle Bend Lagoon (Fraser et al, 2012) indicated that out of 20 approaches the only successful agents in raising pH for an extended period of time were lime and calcium hydroxide.
Proposed activity: Based on the outcomes for Question 6, calculate the amount of neutralising capacity required to raise the pH in Big Swamp up to a desired level (e.g. >6). Then using the results from the kinetic studies from Questions 9 and 10, determine if it feasible to raise the pH in the swamp with or without additions of electron acceptors and donors, and over what time frame. A decision then would need to be made on whether or not to actively add an alkalising agent to the swamp. The second part of the study would first focus on a desktop assessment of possible methods of introducing an alkalising agents into the swamp. This would be followed by field trials of one or more of the available approaches and, on-going monitoring of the results of the interventions.
Feasibility: The initial assessment of the amount of alkalinity required and desktop assessment of the different approaches is feasible. The on-ground activities are, by their nature feasibility studies.
Cost: Assessment of alkalinity required and desktop assessment of approaches - $; Field trials - $$$ -$$$$.

Question 12: Is it possible to scale outcomes observed in laboratory experiments outlined in Question to the field?
Context: While the processes underlying the experiments outlined at Question 9 and 10 operate at very small spatial scales (sub-micron) and therefore are applicable across many spatial scales, it would be prudent to test the approach at larger scale before proceeding to full implementation.
Proposed activity: This would require isolation of parts of the peat (typically 10 - 50 m^3) and apply the best treatment as outlined in the laboratory experiments. There would need to be replicate studies.
Feasibility: This would depend on the final design, but typically these experiments are difficult to undertake.
Cost: $$$$$

Current Ecological Condition

Question 13: How extensive is fire damage to the peat in Big Swamp?
Context: A number of fires have occurred in Big Swamp over the past several years, including periods where it was probable that subterranean fires may have burnt for an extended period of time. Understanding the impacts of fire on the ecological condition of the peat needs an understanding of the spatial extent of fire damage to the swamp.
Previous Research: Work by Philip Hirst (SCU) has demonstrate a complete mineralogical transformation induced by heat, resulting in highly crystalline and biologically inert iron and aluminium oxides, collapse of clay minerals and loss of organic carbon. The implications of fire on soil behavior have not been fully assessed, yet it is known that neutralizing capacity has been completely stripped, and the ability of these soils to be remediated by reductive microbial processes compromised.
Proposed Activity 1: As a surrogate for fire damage determine total carbon concentrations (either by LECO analysis of loss on ignition) in the material collected from cores collected during the installation of the piezometers (described at Question 5).
Feasibility: Notwithstanding the issue associated with coring in the swamp (discussed at Question 5) this approach is feasible.
Cost: $$ for analysis and reporting.

Proposed Activity 2: Use drone photogrammetry to determine the areal extent of fire damage.
Feasibility: May be hampered by increase in vegetation since the fires (see Appendix 1)[9]. The approach can't estimate the vertical extent of fire damage.
Cost: $

Question 14: Has drying or fire affected the physical properties of the peat?
Context: Prior to drying and fire damage, the peat would have been able to store a significant volume of water which would have buffered moisture content within the swamp during dry periods. Drying and fire damage has most likely affected the peat, including its ability to store moisture.
Previous Research: Richard Bush and his student P. Hirst have examined the impact of fire on the peat. The information in the full version is not in the public domain. The primary object of the study was to understand the compounding effects of fire on acid sulfate soils. Fire can affect mineralization processes, physical and biological properties, decreasing the soil moisture holding capacity and exchange reactions with nutrients and metals. The results demonstrate that fire has greatly intensified the acidification and mobility of contaminants, increased soil density and accelerated the weathering of clays and iron minerals.

[9] The images used in Appendix 1 were supplied to rivers and Wetlands by Dr Nicolass Unland from Jacobs.

Proposed Activity: Using a subset of the material from the cores taken for Question 5 undertake an assessment of peat characteristics (particle size, particle density, bulk density), matric potential[10], water drop penetration time (a measure of hydrophobicity) [11] of undamaged peat, dried peat and fire damaged peat. This activity could be extended by taking undamaged peat from the wetland and subject it to different drying regimes and fire intensities in the laboratory.
Feasibility: Once cores have been collected this is quite feasible.
Cost: Once cores have been taken $$$. Some of this would be well suited to a student project.

Question 15 - How has drying and fire affected the overall geomorphology of the swamp?
Context: Drying leads to significant shrinkage in peat which in turn causes subsidence. The extent of subsidence can be estimated by comparing elevation data previously collected by LIDAR with new LIDAR data. In doing so it will also be possible to address a number of community members' questions about the vertical height difference across the swamp.
Previous Research: LIDAR was previously flown over the swamp in 2006/07[12].
Proposed Activity: Undertake a new LIDAR survey of the swamp.
Feasibility: Highly feasible.
Cost: $$

Historical ecological condition

Question 16 - What is an appropriate target for restoring the vegetation community structure of Big Swamp?
Context: Based on the August 2018 meeting of the Boundary Creek Remediation Working Group there is strong community commitment to restore the vegetation community structure of Big Swamp to something approaching its original condition - with a benchmark of the vegetation community structure in Big Swamp prior to substantial groundwater harvesting starting in the 1980's.
Previous Studies: The first comprehensive assessment of the vegetation community in Big Swamp was undertaken by Carr and Muir in 1994, i.e. after the construction of McDonald Dam and commencement of groundwater extraction from the LTA. A preliminary assessment of vegetation community structure based on historical aerial photography and Google Earth imagery was undertaken by *Rivers and Wetlands* to assess the change in vegetation in Big Swamp (Appendix 1). An initial assessment is that vegetation community structure in the swamp is highly variable over time - and had been strongly influenced by human intervention even prior to the shifts in hydrology starting in the 1980's. For example, an aerial image from 1946 shows that there was active drainage within what is now the current boundary of the swamp. Furthermore, based on analysis of shadow length

[10] See Gebhardt et al, 2010 for potential methodology.
[11] See More et al, 2017 for potential methodology.
[12] CIP04-2006-07 Corangamite LiDAR 15cm and 50 cm data available from the Corangamite CMA

of vegetation within the swamp and in the paddocks to the east of the swamp, trees were restricted to the eastern end of the swamp. The middle half of what is now the current swamp had no overstory at all. The western quarter of the swamp had more dense vegetation, but that the shadow cast by the vegetation its height was approximately 1/3 of the length of that cast by paddock trees to the east of the swamp - suggesting that these were shrubs rather than trees. In 2011, following fires, there was little in the way of any overstory vegetation within the swamp. However, by 2017, a distinct overstory is evident.
Proposed activity: An analysis of seeds and pollen throughout the peat profile (at a limited number of sites but spread across the wetland) is undertaken to better gauge what the community structure of the wetland was prior to substantial human perturbations - which clearly pre-date 'living memory".
Feasibility: This is feasible.
Cost: $$ - $$$. This activity could be structured as a student project.

2.2.4. Reach 3

Reach 3 extends from the current edge of Big Swamp to the confluence of Boundary Creek with the Barwon River. Although Boundary Creek in this reach is highly modified from its natural condition (mostly through channelisation), nevertheless the local community have valued this reach in the recent past both as an almost perennial source of stock and domestic water as well as habitat for recreationally important species of fish (see Tumbridge, 1988) and crustacea. There are anecdotal reports of platypus previously inhabiting Boundary Creek. The flows in the reach each has gone from being near permanent to being ephemeral - drying out most summers. Water quality in this reach is poor, with episodic acidification events.

Likelihood of restoring key biogeochemical processes/ Historical ecological condition

Question 17: If attempts to restore the conditions in Big Swamp are unsuccessful, what are the options for restoring Reach 3 to its prior (post -European) ecological condition?
Context: There are numerous issues facing the successful restoration of Big Swamp and the outcomes are far from certain. One option to be considered when managing inland wetlands already impacted by acid sulfate soils is isolation of the wetland to protect downstream ecosystems (EPHC & NRMMC, 2011). This was not considered in potential restoration activities suggested by Jacobs (2017a). While isolation of Big Swamp through triage is not a desired outcome for either the community nor Barwon Water, nevertheless it would be prudent to at least explore the feasibility of this option as a contingency. For example, it may be necessary to isolate Big Swamp from Boundary Creek and the Barwon River for a period of time during restoration (see for example the experiences in East Trinity - CRC CARE, 2018).
Proposed activity: Explore options for isolating Big Swamp and at the same time maintaining near permanent flows of neutral pH water in Reach 3. As examples, this could include piping water from Reach 2 (or even the LTA) to Reach 3, or creating an impervious channel through Big Swamp using the previously installed fire break.
Feasibility: This is a desktop study.
Cost: $ - $$.

Question 18: Is installation of a liming station on Boundary Creek downstream of Big Swamp a feasible option for managing periodic acidification in Reach 3 and the Barwon River?
Context: One of the options explored, and ultimately rejected, by Jacobs (2017a) was the instillation of a lime drain downstream of Big Swamp. Two of the nominated experts suggested direct liming of Boundary Creek as an alternate to instillation of a lime drain, recognising there is the potential for the precipitation of metals in the creek.
Proposed Activity: Undertake a cost-benefit analysis of instillation of a liming station on Boundary Creek, including hydro-chemical modelling of metal accumulation in Boundary Creek as a consequence of liming.
Feasibility: This is essentially a feasibility study.
Cost: $ - $$

2.2.5. Barwon River

The Barwon River is a regionally important river that flows through the town of Winchelsea and the City of Gelong. Boundary Creek joins the Barwon River about 1 river km below the confluence of the East and West Barwon Rivers. Acidification events impact on water quality in the Barwon River through both lowering of pH as well as through elevated heavy metal concentrations.

Current concentration of key constituents

Question 19: Have inflows from Boundary Creek negatively impacted on sediment quality in the Barwon River?
Context: Elevated metal concentrations have been recorded in the Barwon River coinciding with acidic inflows from Boundary Creek. As the pH increases downstream of the confluence metals will begin to precipitate from solution, ultimately lodging in the sediments. This question will determine the extent that Boundary Creek inflows has already impacted on the Barwon River and serve as a baseline for assessing inflows into the river following rehabilitation activities in Boundary Creek and Big Swamp.
Previous Studies: A literature survey suggests that there has only been one study on metal concentrations in the non-estuarine reaches of the Barwon River (Fabris et al, 2006). That study used trace metal concentrations to try to determine the source of sediments to Lake Connewarre, near the mouth of the Barwon River. Data from that study may be relevant in the current study.
Proposed Activity: Collect replicate sediment samples from the river bed upstream and downstream of the confluence with Boundary Creek (suggested intervals - at least triplicate samples taken 500 m upstream and 500 m, 1 km, 2 km, 4 km, 8km and 16 km downstream of the confluence of Boundary Creek ad Barwon River). Samples sieved to 63 µm, and metals analysed either by ICP-OES, ICP-MS or XRF (major and minor elements). Data to be interpreted against the Australian sediment quality standard (Simpson et al, 2013). Monitoring to be undertaken every 3 to 5 years until pH in Boundary Creek returns to circum-neutral.
Feasibility: These types of studies are routinely undertaken elsewhere.

Cost: $$ - $$$ per sampling occasion

Current Ecological Condition

Question 20: Have inflows from Boundary Creek impacted on the ecological condition of the Barwon River?

Context: Acidic inflows with elevated metal concentrations have the potential to impact on the aquatic flora and fauna in the Barwon River. Using the logic used in planning the Victorian Index of Stream Condition (ISC - Ladson and White, 1999), the best indicator of aquatic community structure is invertebrate community structure. These organisms are not as motile as other organisms, (e.g. fish) and their community structure has been shown to reflect changes in aquatic condition, including water quality. This part of the study will identify any current impacts of Boundary Creek on the ecological condition of the Barwon river, as well as serve as a baseline to gauge restoration activities in Boundary Creek and Big Swamp.

Previous Research: Aquatic invertebrate community structure has been determined in Boundary Creek as part of the current investigations into Boundary Creek and Big Swamp (Jacobs, 2017b) as well as in Boundary Creek and the Barwon River as part of the ISC study (ISC3, 2010). The ISC study had 4 sites relevant to the current study

- Site 33 on Boundary Creek;
- Site 27 on the East Barwon River;
- Site 6 on the West Barwon River and;
- Site 5 Upstream of Penny Royal Creek on the Barwon River (I.e. downstream of the confluence of Boundary creek and the Barwon River)

In 2010, the last year for which data is available the numeric value for "aquatic life" (based on macroinvertebrate community structure measured using both the SIGNAL and AUSRIVAS protocols, on a scale of 1- 10, with 10 being the highest) were:

- Site 33 (Boundary Creek) = 4
- Site 27 (East Barwon River) = 6
- Site 6 (West Barwon River) = 9
- Site 5 (Barwon River u/s Penny Royal Ck.) = 6.

Proposed Activity: On going monitoring (3 to 5 yearly) using the ISC methodology at the ISC sites (above) as well a site 500 m upstream of the confluence of Boundary Creek with the Barwon River and 500 m, 1 km, 2k km, 4 km and 8 km downstream of the confluence.

Feasibility: These types of studies are routinely undertaken elsewhere.

Cost: $$ - $$$ per sampling occasion.

2.2.6 Additional questions arising from review of the original Discussion Paper

Following circulation of the original discussion paper, members of the Boundary Creek Remediation Working Group raised three additional questions to be considered during the research prioritisation process:

Question 21. What has been the impact on the Big Swamp of lowering the hydraulic head of the LTA from metres above the swamp to metres below?
Question 22. What was the pre-groundwater extraction levels of this head in relation to Big Swamp?
Question 23. Would Boundary Creek have dried up, losing its summer base flows despite climate change, if groundwater extraction had not taken place?

3. Research Prioritisation

A meeting was held at the offices of Barwon Water in Geelong on the 13th November 2018 to prioritise the research questions outlined in the preceding section; as well as broadly outlining the activities that would need to be undertaken to address these questions. These activities would then be expanded to produce 'a scope of work' required by Southern Rural Water (hereafter SRW) in their Section 78 notice to Barwon Water (discussed below).

In addition to Barwon Water staff, present at the meeting were:

- Prof. Darren Baldwin (*Rivers and Wetlands* and Charles Sturt University)
- Prof. Richard Bush (The University of Newcastle)
- Louise Lennon (Jacobs)
- Nic Unland (Jacobs)
- A/Prof John Web (La Trobe University)
- Dr Vanessa Wong (Monash University)

3.1 The Section 78 Notice and research priority setting

The Ministerial Notice issued pursuant to Section 78 of the *Water Act* 1989 by SRW on the 11th September 2018 was used to inform to prioritise the research questions outlined in Section 2.2. The relevant section of the Ministerial Notice are Items 2.2, 2.3, 2.4 and 2.5 (a).

"2.2. Barwon Water must prepare and implement the 'Boundary Creek, Big Swamp and Surrounding Environment- Remediation and Environmental Protection Plan' (the Plan) in accordance with the requirements set out in this notice.

2.3. For the purpose of this Plan, remediation is deemed to be the controls and actions that could be practicably carried out to achieve improved environmental outcomes for Boundary Creek, Big Swamp and the surrounding environment that has been impacted by groundwater pumping at Barwon Downs.

2.4 By 20 December 2018 Barwon Water must submit a scope of works approved by SRW. The scope of works should include the identification of the area covered by the plan, the environmental values to be included, and the necessary environmental assessments and methodology for how it proposes to develop the plan.

2.5 By 20 December 2019 Barwon Water must submit to SRW the Plan which includes: (a) A description of the current environmental condition of Boundary Creek, Big Swamp and the surrounding environment; this will include:

- Hydrogeological Conditions (groundwater levels and quality)
- Hydrology (surface water quality and flow monitoring)
- Ecological Assessment
- LIDAR topographic mapping
- Results of soil sampling program (soil chemistry, peat profile incubation tests)
- Additional matter arising from the scope contemplated in Item 2.4."

3.1.1 Item 2.5 (a)

Because hydrological condition, hydrology, ecological assessment, LIDAR mapping and soil sampling are specifically identified in Item 2.5 a, priority would be given to research questions that address these issues or activities.

3.1.2 Remediation, Rehabilitation and Restoration

Remediation, restoration and rehabilitation describe different environmental end points for stream condition: "[r]estoration involves returning the stream to the original, pre-European condition. Rehabilitation involves fixing only some aspects of the stream, but generally making the degraded stream closer to the original condition. Remediation recognises that the stream has changed so much that the original condition is no longer relevant, and aims for some entirely new condition" (Rutherford et al, 2000 at p. 16). The Section 78 Notice states that the Plan is for the remediation of Boundary Creek, Big Swam and the surrounding environment. Furthermore, the remediation must be practicable and achieve improved environment outcomes. Therefore, it follows that research questions that relate to the previous condition of the area, or how previous activities have impacted on that condition would be important in informing rehabilitation and restoration activities, but would have less relevance to remediation. Consequently, questions that relate to previous condition or the impact of previous actions were ranked lower than research questions that address current condition and future trajectories.

3.1.3 Spatial Scope

The wording of the Section 78 Notice is slightly ambiguous when it comes to the spatial extent to be covered by the Plan. On one hand "....... the surrounding environment that has been impacted by groundwater pumping at Barwon Downs" could be interpreted to mean all groundwater-dependent ecosystems in the region that have been impacted by pumping. Alternatively, because Boundary Creek and Big Swamp are the only geographical locations that are named implies that the scope of works needs to be restricted to the immediate vicinity in, and around Boundary Creek. Given the timelines outlined in the Section 78 Notice for the formulation of the Plan, it would not be practicable adopt the broader spatial definition of all groundwater dependent ecosystems. Therefore, the research activities that would constitute the 'scope of works' required by the Section 78 Notice have been limited to Boundary Creek, Big Swamp and the reach of the Barwon Riven downstream of the confluence with Boundary Creek that has been impacted by acid or metal pulses that came from Boundary Creek.[13]

3.2. Prioritising Research Questions

Question 1: Is 'McDonalds Dam' a net sink for surface water from late spring to early autumn?
Priority: High
Rationale: McDonalds Dam is a significant regulating structure on Boundary Creek and impacts on the hydrology of the creek and Big Swamp.
Activities to be included in the Scope of Works: Works have been already implemented to answer this question.

Question 2: *Is Reach 2 net losing?*
Priority: High
Rationale: This is an important aspect of the hydrology and hydrogeology of Boundary Creek and Big Swamp.
Activities to be included in the Scope of works: Ongoing monitoring of flows downstream of McDonalds Dam and at Bores TB2 and 109131 and instillation of V-notch weirs on Boundary Creek at the eastern and western ends of Big Swamp.

Question 3: Can surface water alone sustain the ecological condition of the Damplands?
Priority: High
Rationale: The Damplands are locally ecologically important and their condition needs to be maintained.
Activities to be included in Scope of Works: Continuation of on-going vegetation monitoring of the Damplands and Big Swamp. Instillation of photo-points in the Damplands.

Question 4*:* Is there a hydraulic connection between Big Swamp and the Lower Tertiary Aquifer?
Priority: Low
Rationale: Addressing this question offers no additional benefit for the future remediation of Big Swamp.
Activities to be included in Scope of Works: Potential contamination of the LTA by acid and/or metals presents an an-going concern. However, this issue can be addressed by

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[13] Noting that sites on the Barwon River upstream of the confluence with Boundary Creek may be included as 'Control" sites.

routine water quality monitoring of adjacent, already extant, bores and comparing the water quality in the bores with long-term water quality elsewhere in the LTA.

<u>Question 5</u>: Are there preferential surface or subsurface flow paths in Big Swamp?
Priority: High
Rationale: This will add to an understanding of the hydrogeology of the area of interest. In addition, material recovered during the drilling of the bores can be used to address Questions 6 -10, 11 and 13.
Activities to be included in Scope of Works: Following a feasibility study to determine the best way to drill bores in Big Swamp, install a series of piezometers in the swamp.

<u>Question 6:</u> How much actual and potential acidity is currently stored in Big Swamp?
Priority: High
Rationale: Understanding current acidity levels is currently in Big Swamp is critical for remediation planning and would be important component of Item 2.5(a) reporting (soil chemistry and peat profile).
Activities to be included in Scope of Works: Analyse material collected from cores collected during the installation of the piezometers (described at Question 5) for the suite of analytes recommended in the new Australian Acid Sulfate Soils Guidelines - S_{Cr}, KCl extractable pH, TAA, net acid soluble sulfur, and acid neutralising capacity.

<u>Question 7:</u> How much sulfate remains in the sediment profile in the swamp?
Priority: High
Rationale: Understanding the current sulfur levels currently in Big Swamp is critical for remediation planning and would be important component of Item 2.5(a) reporting (soil chemistry and peat profile).
Activities to be included in Scope of Works: In addition to the analytes measured for Question 6, include analysis of sulfate.

<u>Question 8:</u> How much bioavailable carbon is currently stored in Big Swamp that can be used to promote biogeochemical processes?
Priority: High
Rationale: Generation of biogeochemical processes to create alkalinity requires a source of carbon that is relatively bioavailable for use by the microbes that drive biogeochemical processes. If that carbon isn't present then the remediation process would need to include supplementing the swamp with an alternate source of bioavailable carbon. Needed for Item 2.5 (a) reporting (incubation tests)
Activities to be included in Scope of Works: Incubation studies that measure the loss of oxygen and/or generation of carbon dioxide on rewetted soil samples collected for Question 5.

<u>Question 9:</u> Will re-inundation lead to the onset of sulfate reduction to a sufficient extent to generate sufficient alkalinity to buffer the actual acidity in the swamp?
Priority: High
Rationale: One option for the remediation of the acidity currently stored in Big Swamp is the re-introduction of sulfate reduction. This would be an important element of Item 2.5 (a) reporting (incubation tests).

Activities to be included in Scope of Works: Undertake a series of incubation tests, in parallel with test outlined at Question 8, using samples collected for Question 5. The nature of the tests would be similar to that outlined in Section 2.2.3 (above).

Question 10: Is it feasible to generate alkalinity in Big Swamp by promoting other anaerobic reactions?
Priority: High
Rationale: If sulfate-reduction cannot be re-instated in Big Swamp then instigating alternate biogeochemical reactions may be feasible. This would be an important element of Item 2.5 (a) reporting (incubation tests).
Activities to be included in Scope of Works: Undertake a series of incubation tests, in parallel with test outlined at Question 8 and 9, using samples collected for Question 5. The nature of the tests would be similar to that outlined in Section 2.2.3 (above).

Question 11: Is it necessary to directly introduce alkalinity (in the form of lime or other ameliorants) directly into the swamp?
Priority: High
Rationale: If alkalinity cannot be generated in-situ (addressed by Questions 8-10) then it may be necessary to directly introduce alkalinity into swamp soils as part of the remediation process.
Activities to be included in Scope of Works: The question would be answered by exploring the results from the studies outlined for Questions, 6, 9 and 10, possible in conjunction with biogeochemical modelling (see Section 3.3. - below).

Question 12: Is it possible to scale outcomes observed in laboratory experiments outlined in Question to the field?
Priority: Medium
Rationale: This is a second order question and will rely on the outcomes of the incubation tests suggested to address Questions 8 - 10.
Activities to be included in Scope of Works: None at this stage, but in consultation with SRW, the Scope of Works may need to be amended.

Question 13: How extensive is fire damage to the peat in Big Swamp?
Priority: High
Rationale: Burnt peat will have substantially different biogeochemical responses to inundation than unburnt peat. Understanding the spatial extent of burning will help in the translation of the incubation studies to the on-going remediation of Boundary Creek and Big Swamp. This would be included in Section 2.5 (a) reporting (peat profile)
Activities to be included in Scope of Works: In addition to the analyses undertaken to address Questions 5 and 7, analyses soil samples for one or more of the following: total carbon, charcoal content or magnetic susceptibility.

Question 14: Has drying or fire affected the physical properties of the peat?
Priority: Low
Rationale: There are no additional benefit in the remediation of Boundary Creek and Big Swamp by addressing this question. Biogeochemical responses of burnt peat should be

captured at questions 6 - 11, if sufficient areas of burnt peat are included in the sampling program (Question 5).
Activities to be included in Scope of Works: None.

Question 15: How has drying and fire affected the overall geomorphology of the swamp?
Priority: High
Rationale: LIDAR mapping of Big Swamp is specifically included for reporting under Item 2.5(a).
Activities to be included in Scope of Works: Undertake a LIDAR survey of Big Swamp to the same or better resolution as the survey undertaken in 2006/06.

Question 16: What is an appropriate target for restoring the vegetation community structure of Big Swamp?
Priority: Low
Rationale: One of the objectives of the Section 78 notice is to improve the ecological condition of Big Swamp, not necessarily to restore it to a previous condition. While it would be beneficial to know the previous trajectory of vegetation community structure in the swamp in the past, it is not essential.
Activities to be included in the Scope of Works: None.

Question 17: If attempts to restore the conditions in Big Swamp are unsuccessful, what are the options for restoring Reach 3 to its prior (post -European) ecological condition?
Priority: Medium
Rationale: This is a second order question. If remediation actions can restore water quality and quantity entering Reach 3 of Boundary Creek from Big Swamp, the ecological condition of this reach should improve. If results from the incubation studies and soil quality studies indicate that alkalinity generation is not feasible in the swamp, then intervention in Reach 3 may be warranted.
Activities to be included in Scope of Works: None at this stage, but in consultation with SRW, the Scope of Works may need to be amended.

Question 18: Is installation of a liming station on Boundary Creek downstream of Big Swamp a feasible option for managing periodic acidification in Reach 3 and the Barwon River?
Priority: Medium
Rationale: This is a second order question. If remediation actions can restore water quality and quantity entering Reach 3 of Boundary Creek from Big Swamp, the ecological condition of this reach should improve. If results from the incubation studies and soil quality studies indicate that alkalinity generation is not feasible in the swamp, then intervention in Reach 3 may be warranted.
Activities to be included in Scope of Works: None at this stage, but in consultation with SRW, the Scope of Works may need to be amended.

Question 19: Have inflows from Boundary Creek negatively impacted on sediment quality in the Barwon River?
Priority: High
Rationale: The Barwon River is a regionally important water course that has, at times, been negatively impacted by inflows from Boundary Creek. Understanding the current ecological

condition of the river reach immediately downstream of the confluence with Boundary Creek will serve as a baseline to assess the success or otherwise of the remediation strategy developed for Boundary Creek and Big Swamp.
Activities to be included in Scope of Works: Undertake a sediment sampling program as outlined at Section 2.2.5

Question 20: Have inflows from Boundary Creek impacted on the ecological condition of the Barwon River?
Priority: High
Rationale: The Barwon River is a regionally important water course that has, at times, been negatively impacted by inflows from Boundary Creek. Understanding the current ecological condition of the river reach immediately downstream of the confluence with Boundary Creek will serve as a baseline to assess the success or otherwise of the remediation strategy developed for Boundary Creek and Big Swamp.
Activities to be included in Scope of Works: Undertake a sediment sampling program as outlined at Section 2.2.5 (above).

Question 21. What has been the impact on the Big Swamp of lowering the hydraulic head of the LTA from metres above the swamp to metres below?
Priority: Low
Rationale: While addressing this question would inform strategies for the rehabilitation, or even restoration, of Big Swamp, there is little additional benefit in addressing this question for the design of a remediation program as outlined under the Section 78 Notice.
Activities to be included in Scope of Works: None under the Section 78 Notice, but should be addressed under a separate file note.

Question 22. What was the pre-groundwater extraction levels of this head in relation to Big Swamp?
Priority: Low
Rationale: While addressing this question would inform strategies for the rehabilitation, or even restoration, of Big Swamp, there is little additional benefit in addressing this question for the design of a remediation program as outlined under the Section 78 Notice.
Activities to be included in Scope of Works: None under the Section 78 Notice, but should be addressed under a separate file note.

Question 23. Would Boundary Creek have dried up, losing its summer base flows despite climate change, if groundwater extraction had not taken place?
Priority: Low
Rationale: While addressing this question would inform strategies for the rehabilitation, or even restoration, of Big Swamp, there is little additional benefit in addressing this question for the design of a remediation program as outlined under the Section 78 Notice.

Activities to be included in Scope of Works: None under the Section 78 Notice, but should be addressed under a separate file note.

3.3. Summary of activities to be included in Scope of Works grouped by the headings in Item 2.5(a) of the Section 78 Notice

Hydrogeological Condition

12. On-going water level monitoring of existing bores
13. Regular (6 monthly) monitoring of water quality (pH, sulfate and heavy metals) in bores that intersect the LTA near Boundary Creek (Question 4).
14. Instillation of up to 18 shallow groundwater monitoring bores in Big Swamp (Question 5). The soil collected during drilling will be used for subsequent chemical analysis and incubations - see below

Hydrology

15. On-going monitoring of surface water flows, including below McDonalds Dam (Question 1).
16. Instillation of v-notch weirs in Boundary Creek at the eastern and western edges of Big Swamp (Question 2).

Ecological Assessment

17. Continue on-going vegetation monitoring in the Damplands and Big Swamp (Question 3)
18. Assessment of sediment quality in the Barwon River downstream of Boundary Creek (Question 19)
19. Assessment of macro-invertebrate community structure in Boundary Creek and the Barwon River downstream of the confluence (Question 20).

LIDAR Topographic Mapping

20. Undertake a LIDAR survey of Big Swam (Question 15).

Results of Soil Sampling

21. Using the soil collected for Question 5 determine S_{Cr}, KCl extractable pH, TAA, net acid soluble sulfur, and acid neutralising capacity (Question 6), sulfate (Question 7) and at least one of total carbon, charcoal density or magnetic susceptibility (Question 13).
22. Using the soil collected for Question 5 undertake lab incubation studies to determine the amount of bioavailable carbon in Big Swamp (question 8), whether or not it is possible to re-instate sulfate reduction in the wetland (Question 9) and whether or not other biogeochemical processes can lead to an increase in alkalinity (Question 10).

Furthermore, it is anticipated that the biogeochemistry of Big Swamp will be linked to the hydrology and hydrogeology of Boundary Creek and the LTA through a modelling exercise.

At its simplest this could take the form of conceptual models, but, if warranted, could be extended to predictive mathematical models.

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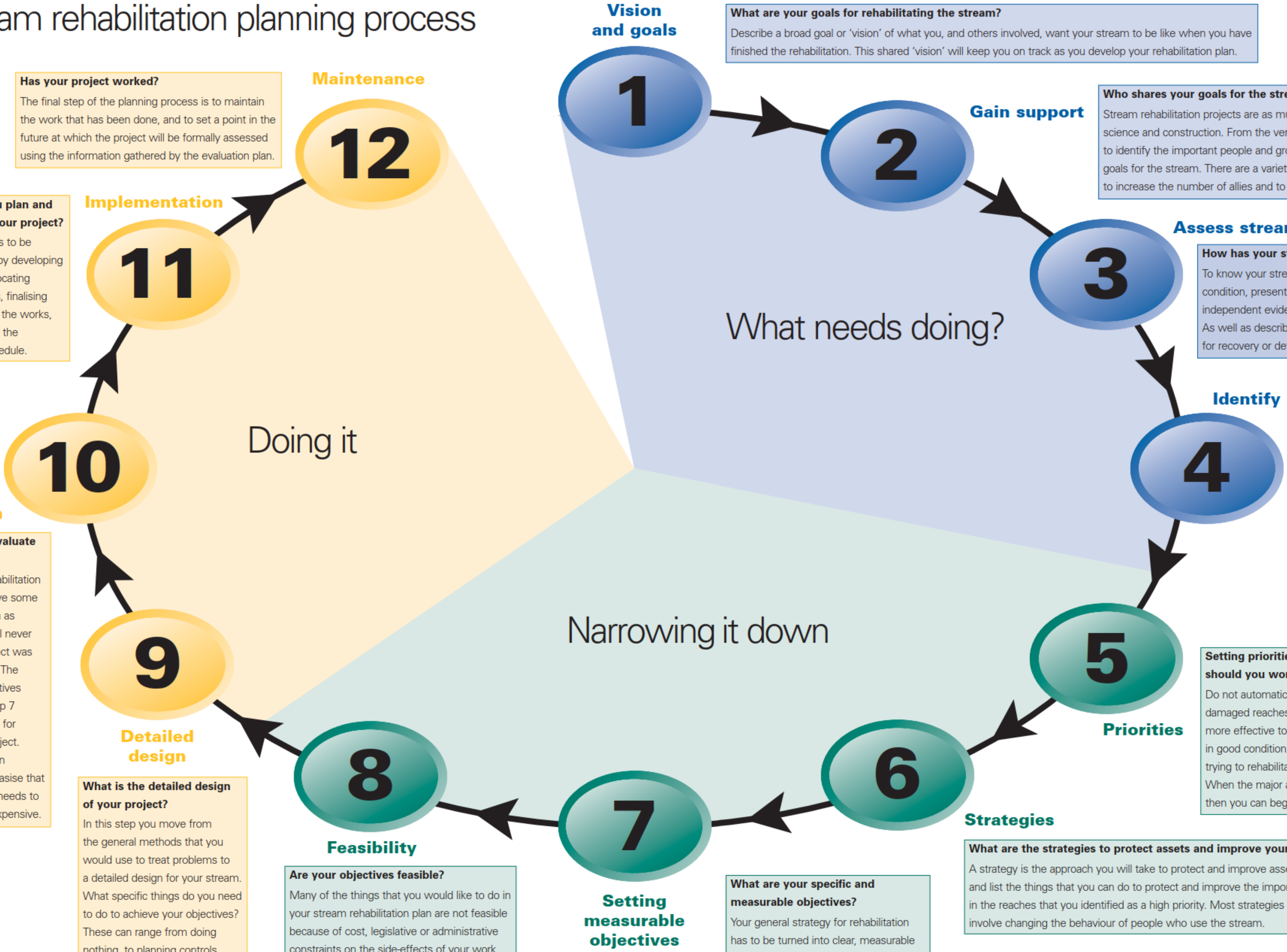
Appendix D

A stream rehabilitation planning process



1 Vision and goals

What are your goals for rehabilitating the stream?

Describe a broad goal or 'vision' of what you, and others involved, want your stream to be like when you have finished the rehabilitation. This shared 'vision' will keep you on track as you develop your rehabilitation plan.

2 Gain support

Who shares your goals for the stream?

Stream rehabilitation projects are as much about people as they are about science and construction. From the very beginning of a project you need to identify the important people and groups who support or oppose your goals for the stream. There are a variety of techniques that you can use to increase the number of allies and to resist or convert the opponents.

3 Assess stream conditions

How has your stream changed since European settlement?

To know your stream you need to describe its pre-disturbance condition, present condition and rate of change. Look for independent evidence, anecdotal and historical information. As well as describing the present condition, estimate the potential for recovery or deterioration of the stream.

4 Identify problems and assets

What are your stream's main natural assets and problems?

Rehabilitation is about protecting natural stream assets and improving or creating other assets. An asset is any aspect of the stream already in good enough condition to meet your goal. Many stream assets are threatened or have already been degraded. In this step, you identify the main assets, degraded assets and problems impacting on your stream.

5 Priorities

Setting priorities: which reaches and problems should you work on first?

Do not automatically start rehabilitation at the most damaged reaches. In terms of stream health, it is usually more effective to protect reaches of stream that remain in good condition, than to spend large amounts of money trying to rehabilitate reaches that are already damaged. When the major assets of the stream have been protected, then you can begin to improve the stream condition.

6 Strategies

What are the strategies to protect assets and improve your stream?

A strategy is the approach you will take to protect and improve assets. Identify and list the things that you can do to protect and improve the important assets in the reaches that you identified as a high priority. Most strategies will also involve changing the behaviour of people who use the stream.

7 Setting measurable objectives

What are your specific and measurable objectives?

Your general strategy for rehabilitation has to be turned into clear, measurable objectives that specify what you want to achieve in your rehabilitation project. These objectives will become the core of your stream rehabilitation plan.

8 Feasibility

Are your objectives feasible?

Many of the things that you would like to do in your stream rehabilitation plan are not feasible because of cost, legislative or administrative constraints or the side-effects of your work. By examining each of your objectives to check whether or not they are feasible, you will arrive at a final list of problems to treat.

9 Detailed design

What is the detailed design of your project?

In this step you move from the general methods that you would use to treat problems to a detailed design for your stream. What specific things do you need to do to achieve your objectives? These can range from doing nothing, to planning controls, flow manipulation, or complete channel reconstruction.

10 Evaluation

How will you evaluate your project?

Every stream rehabilitation project should have some form of evaluation as without it, you will never know if your project was worth the bother. The measurable objectives worked out in Step 7 become the basis for evaluating the project. Practical evaluation procedures emphasise that not all evaluation needs to be detailed and expensive.

11 Implementation

How will you plan and implement your project?

The plan needs to be implemented by developing a time line, allocating responsibilities, finalising funding, doing the works, and organising the evaluation schedule.

12 Maintenance

Has your project worked?

The final step of the planning process is to maintain the work that has been done, and to set a point in the future at which the project will be formally assessed using the information gathered by the evaluation plan.