Barwon Water

# Boundary Creek and Big Swamp remediation: Options assessment

13 December 2019

CDM Smith

# Executive Summary

This report details the results of a Remediation Options Assessment (ROA) for identification of preferred remediation options to address ASS impacts to Big Swamp and Boundary Creek, in response of a Section 78 Notice issued to Barwon Water.

The framework developed to identify the preferred remediation option for management of ASS impacts at the site comprised:

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

A risk assessment was also performed on the selected practically achievable remediation options to identify potential risks and required management measures associated with implementation of each option, in accordance with one of the requirements of the Section 78 Notice.

Inputs and feedback from the RWG technical experts and the community were sought at various stages of the process to assist with development of key aspects of the ROA.

Results of the weighted scoring from the detailed assessment of the options retained after preliminary screening provides the following ranking:

1. Managed Groundwater Levels and Wetland Flooding
2. Aerial liming
3. In-stream treatment
4. Aerobic wetland
5. Soil Mixing
6. RAPS
7. Excavation and disposal

These results, being the outcome of a multi-parameter assessment, provide an indication of the remediation options that, overall, are likely to achieve the best outcomes for the project.

The 'managed groundwater levels and wetland flooding' remediation option is considered to be the preferred remediation option being the one that, overall, has the highest likelihood of achieving the project objectives. Other remediation options considered as part of the ROA can be retained either to integrate with the preferred remediation option or as contingency measures.

The outcomes of the risk assessment process indicate that the risks associated with the practical remediation measures can be adequately managed through implementation of mitigation measures. The risk mitigation measures generally include collection of additional data to improve understanding and assessment of risks, undertaking monitoring activities to confirm if the identified risks are present and implementation of contingency measures to treat unacceptable risks.

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# Section 1 **Introduction**

## 1.1 Background

Barwon Water has engaged CDM Smith Australia Pty Ltd (CDM Smith) to undertake a Remediation Options Assessment (ROA) for management of acid sulfate soils (ASS) issues at Big Swamp and Boundary Creek, in response to a Ministerial Notice (the notice) issued by Southern Rural Water (SRW) under Section 78 of the Water Act 1989 (the Act).

The works supporting preparation of this ROA have been prepared in general accordance to our proposal 001238-PRP dated 20 September 2019.

## 1.2 Description of the issues

Big Swamp is a peat swamp along Boundary Creek, a tributary of the Barwon River, in the Otway Ranges of Victoria, Australia. Sediments in Big Swamp contain significant amounts of pyrite ($FeS_2$), one of the iron sulfides commonly associated with ASS.

A combination of drier climate conditions, anthropogenic modifications to the Boundary Creek catchment and pumping from the Barwon Downs borefield by Barwon Water has caused several environmental impacts, including:

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

## 1.3 Identification of the Areas for Remediation

To assist with identification of the areas to be covered by the Remediation Plan required by the Section 78 Notice, Barwon Water has conducted a risk assessment on the whole extent of the Lower Tertiary Aquifer (LTA) system potentially affected by historical pumping activities from the Barwon Downs borefield.

The results of the risk assessment (Barwon Water, 2019) indicate the following:

- Big Swamp and Boundary Creek are two areas of potential 'high risk' where impacts have been confirmed by the results of monitoring activities, and/or high value groundwater dependent ecosystems are known to exist.
- Other areas of potential 'high risk' have been identified, however for these areas, impacts have not been confirmed.

Based on these results, Barwon Water has adopted the following prioritisation approach for preparation of the Remediation Plan:

- Priority for remediation is on the areas of potential 'high risk' where impacts have been confirmed by monitoring and high value GDEs are known to exist, including:
  - Boundary Creek reaches 2 and 3
  - Vegetation in Boundary Creek in reaches 2 and 3
  - Big Swamp

According to this prioritised approach and the requirements of the Section 78 Notice, this ROA has been prepared to support development of a remediation strategy for Big Swamp and Boundary Creek.

## 1.4 Objectives

The objectives of the ROA are to:

- Develop a vision and identify objectives for the Big Swamp and Boundary Creek remediation project (the project).
- Identify potential technologies that could be applicable to achieve the project objectives.
- Prepare a framework to support transparent and independent assessment of the identified remediation options, based on a range of performance criteria and indicators.
- Provide a concept for an integrated approach to remediation by combining the most suitable ('preferred') remediation options resulting from the assessment.

## 1.5 Scope of Works

The following scope of works was undertaken to support development of the ROA:

- Review of relevant information and technical reports related to the site, including results of surface water groundwater modelling (Jacobs, 2019b), geochemical modelling (GHD, 2019), ecological study (Eco Logical, 2019), and surface water quality assessment (Austral, 2019) and incubation testing (Monash University, 2019).
- Participation in two technical workshops and two remediation working group (RWG) meetings to assist in development of the ROA.
- Review of available guidance for the preparation of remediation option assessment, including the framework outlined in EPA Victoria Publication 840.2 *The Cleanup and Management of Contaminated Groundwater* (April 2016) and the guidelines developed by CRC Care Pty Ltd as part of the National Remediation Framework initiative.
- A comprehensive literature review on ASS management practices and technologies, including the National guidance for the management of acid sulfate soils in inland aquatic ecosystems (Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council, 2011).
- A preliminary screening of a broad range of potentially applicable remediation options for management or treatment of ASS impacts and selection of options to be retained for detailed assessment.
- Detailed assessment of the retained options and scoring of these options based on a technical, logistical, financial, timing, regulatory, community and sustainability considerations.
- Identification of options presenting the highest scores ('preferred options') and development of a remediation strategy (using one or a combination of the preferred options as required) aimed at meeting the project objectives and vision.
- Undertaking a risk assessment of practical remediation measures that could be adopted at the site.
- Preparation of this report outlining the results of the ROA.

## 1.6 Supporting Information

The supporting information used to develop the ROA are referenced in Section 11. The ROA has also considered relevant feedback from technical and community working groups received during the workshops and meetings held to support development of the remediation process.

# Section 2 **Remediation Process Overview**

## 2.1 12-Step Remediation Process

The 12-Steps planning procedure from the Rehabilitation Manual for Australian Streams (Cooperative Research Centre for Catchment Hydrology Land and Water Resources Research and Development Corporation (LWRRDC and CRCCH), 2000) was adopted to assist in developing the remediation strategy for the Boundary Creek and Big Swamp Remediation Plan (Figure 2-1).


**Figure 2-1 12-Steps Stream Rehabilitation Process adopted for the remediation strategy.**

In Figure 2-1, the blue arrows represent movement between steps, and the grey arrows represent the reassessment of past steps as a result of reality checks and community feedback.

## 2.2 Collaborative Approach

As recommended in the 12-Steps Rehabilitation process ('Share the Vision'), a collaborative approach was adopted to assist in developing project visions and objectives that were relevant to the community, aligned with the requirements of the Section 78 notice and technically sound.

To assist this engagement and consultation process, the Boundary Creek and Big Swamp RWG was established in May 2018, providing an opportunity to interested community stakeholders to actively engage with Barwon Water in the design of the remediation plan for Boundary Creek and Big Swamp.

The RWG nominated three technical experts to provide independent advice on various aspects of the remediation concept as needed by the working group, as follows.

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

This previous work provided the basis for development of the project vision and objectives, which were discussed and developed as part of the following workshops and meetings:

- Technical workshop held at Barwon Water offices in Geelong on 10 October 2019. The workshop was attended by the RWG technical experts (Darren Baldwin and Richard Bush), Monash University Professor Perran Cook and a range of consultants providing advice on surface water, groundwater, ecology, geochemistry and remediation.
- RWG meeting held in Colac on 23 October 2019. The meeting was attended by representatives from Barwon Water, SRW, CDM Smith and the RWG (including technical experts Darren Baldwin, Richard Bush and Vanessa Wong).

## 2.3 Project Vision

The project vision, which describes the intended end point of the remediation efforts, was developed in consideration of the requirements of the Section 78 notice, inputs from the technical workshop and community aspirations.

The following vision was presented and discussed and agreed during the RWG meeting:

To implement a **practical** remediation strategy that achieves an **improvement to the environment and the community**, so that:

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

## 2.4 Project Objectives

To assist in realising the project vision, **six project objectives** were developed and agreed during the first technical workshop and RWG meeting:

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

## 2.5 Role of the Remediation Option Assessment

As discussed, the project vision provides a statement of an aspirational goal for the remediation project, where a recognisable project endpoint is described at a relatively high level.

While the project vision is largely aspirational and may be not achievable (LWRRDC and CRCCH, 2000) the project objectives provide a set of more detailed, measurable and specific indicators that can be used to assess on how the remediation project is progressing. The objectives should be developed so that they are instrumental to achieve the project vision.

The ROA is equivalent to the 'feasibility' step of the 12-Steps rehabilitation process, where potentially applicable remediation option (identified as part of the 'strategy' step) are assessed by undertaking 5 tasks (LWRRDC and CRCCH, 2000):

- Financial cost evaluation
- Regulatory approval evaluation
- Assessment of environmental gains and potential side effects
- Assessment on the ability to meet project objectives
- Weighted feasibility

The approach followed for the Big Swamp and Boundary Creek ROA has been conducted in general accordance to the above principles as well as other relevant guidelines related to site remediation and assessment, as described in more details in Section 5.

# Section 3 **Remediation Conceptual Model**

This section presents a remediation conceptual model (RCM) of key site properties and acid generation, neutralisation and transport mechanisms that are considered relevant for development of the ROA. Additional technical details on these concepts are provided in the Jacobs, GHD, Eco Logical and Monash University reports, which have provided the basis for development of the RCM.

## 3.1 Catchment Description

Land use around Big Swamp and Boundary Creek is a mixture of cleared agriculture land and state forest that has been extensively modified since European settlement.

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

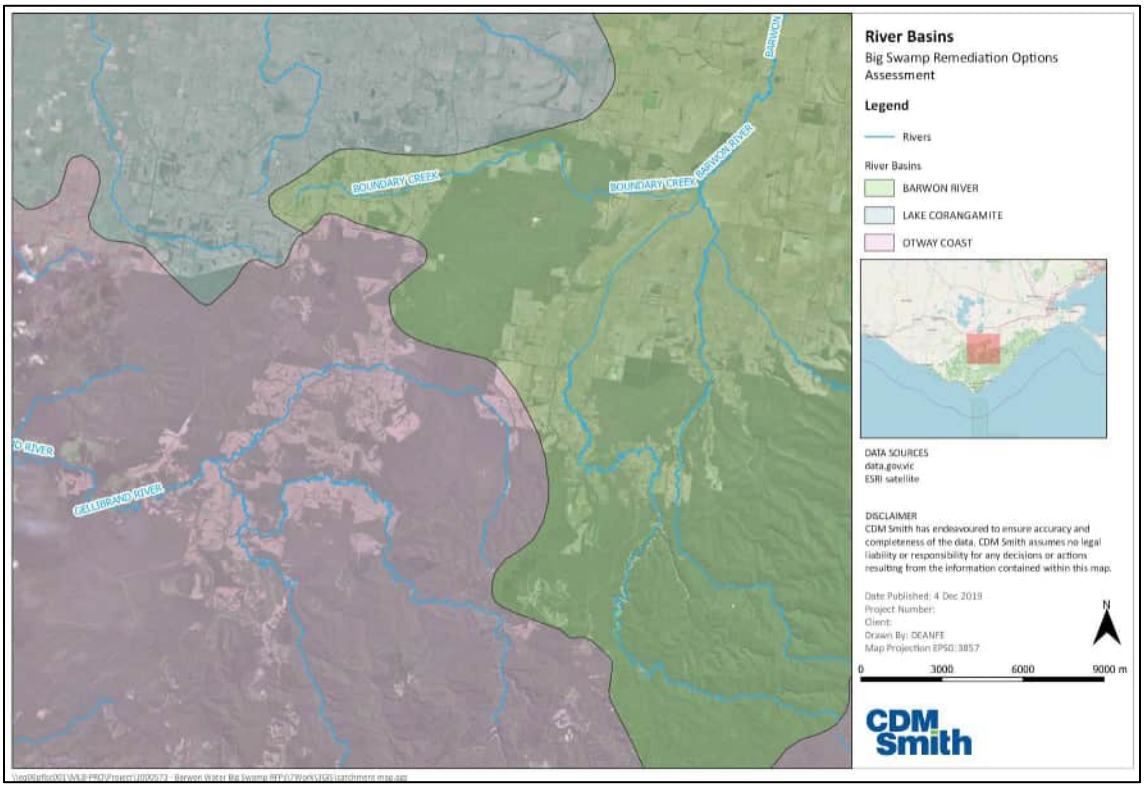


**Figure 3-1 Catchment Identification**

The Barwon River and its tributaries rise in the Otway Ranges and flow north through Forrest and Birregurra, draining the southern part of the catchment. The Barwon River East Branch and West Branch join just upstream of the confluence with Boundary Creek. Boundary Creek flows for approximately 18 km in an easterly direction across the Barongarook High and joins the Barwon River around Yeodene.

The Gellibrand River is in the Otways Coast catchment, rises near Upper Gellibrand and flows in a westerly direction toward Gellibrand. It discharges into the ocean at Princetown.

The Barwon Downs borefield is located approximately 30 km south east of Colac and taps into the Lower Tertiary Aquifer (LTA) at depths up to 600 m at the borefield. The LTA covers an area of approximately 500 $km^2$ below the surface and it outcrops at the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment (near Gellibrand).

## 3.2 Climate

Climate conditions in the Boundary Creek catchment are summarised in Figure 3-2 (Jacobs, 2018a) and Figure 3-3 (Jacobs, 2019b)

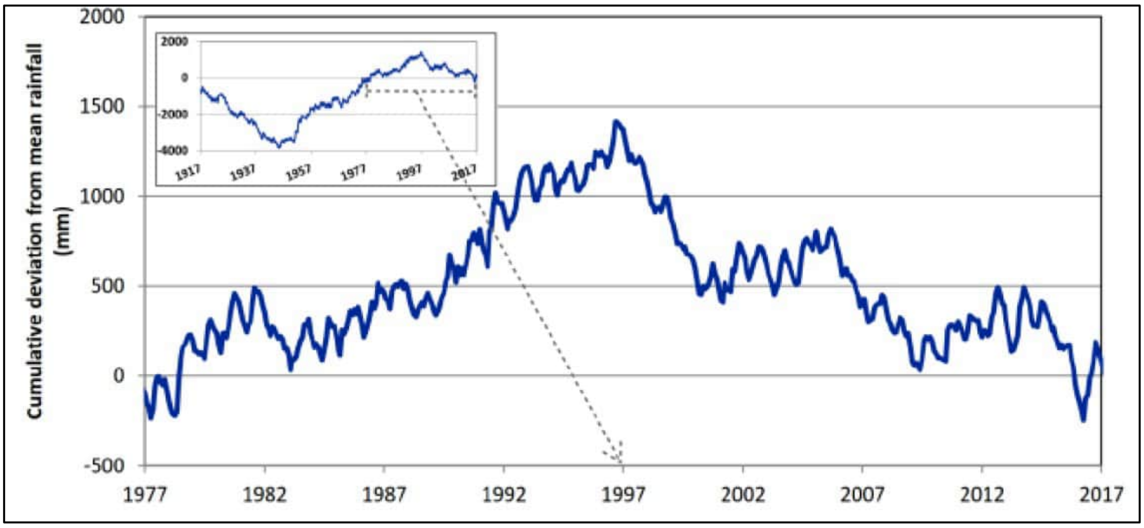


**Figure 3-2 Cumulative deviation from mean annual rainfall at Forest State gauge (BOM gauge 090040)**

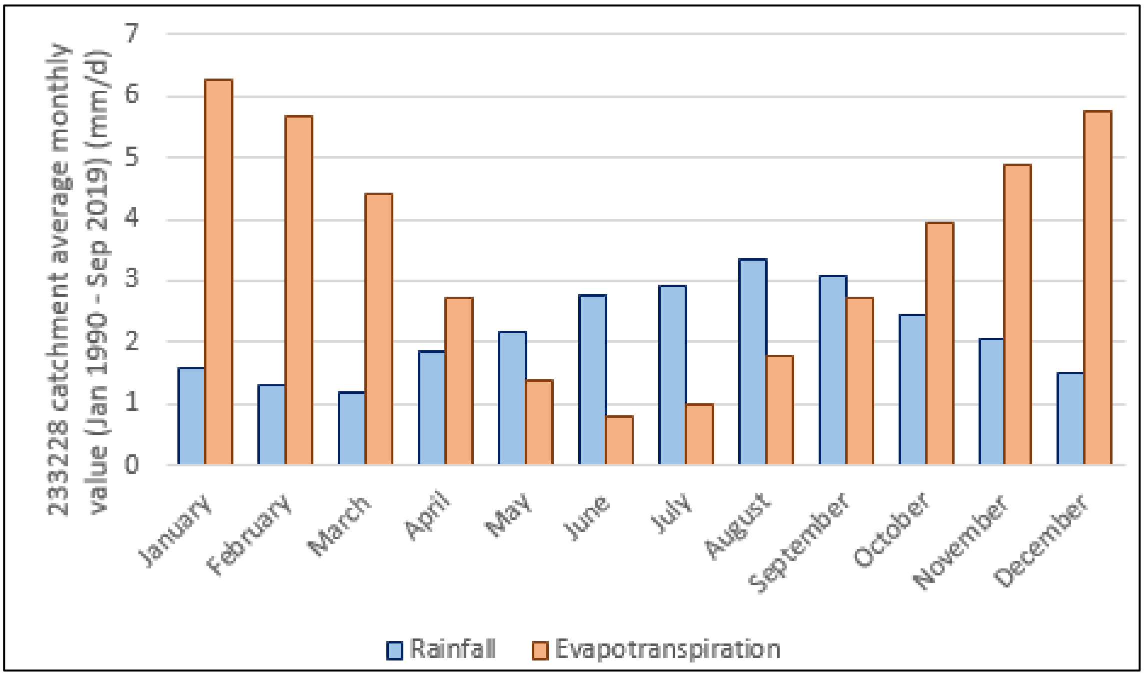


**Figure 3-3 Monthly average rainfall and evapotranspiration (mm/d) which falls over the Boundary Creek catchment upstream of the Yeodene township (233229) between 1990 – Sep 2019**

Figure 3-2 (presenting rainfall as cumulative departure from the mean) indicates periods of drought (i.e. a declining trend in the graph) between 1900-1955, 1995-2010 (millennium drought) and 2014-2017.

Figure 3-3 (presenting average rainfall and Morton's wet areal potential evapotranspiration for the Boundary Creek Catchment) indicates that rainfall is higher than evapotranspiration between May and September.

Future climate projections for the Barwon River catchment (DELWP, 2016), indicate between 5%-20% reduction in rainfall, between 4%-5% increase of evapotranspiration and between 2%-5% reduction in runoff by 2040 (median projected model outputs, highest greenhouse gas concentration scenario).

Overall, these predictions indicate that future climate conditions or the Barwon River catchment are expected to be hotter and drier, with increased demand for water for public, domestic, commercial and agricultural use.

## 3.3 Surface Water (Boundary Creek)

### 3.3.1 Catchment Description

For the purpose of this RCM, Boundary Creek can be divided in three reaches (Jacobs, 2018a and 2018b), as described below (Figure 3-4):

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

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

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

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

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

  - Reach 2a, a likely artificial channelised section immediately downstream of McDonalds Dam.
  - Reach 2b, a densely vegetated and marshy area known as the ‘damplands’ characterised by highly braided flow pathways and waterlogged conditions.
  - Reach 2c, corresponding to Big Swamp, a large peat swamp covering an area of approximately 11 ha (Section 3.4)

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

Figure 3-4 also indicates presence of shallow Quaternary Alluvium sediments that are interpreted to occur locally along the Boundary Creel flow path, overlying the regional formations. Quaternary Alluvium includes the deposits and acid sulfate soils that occur throughout Big Swamp.

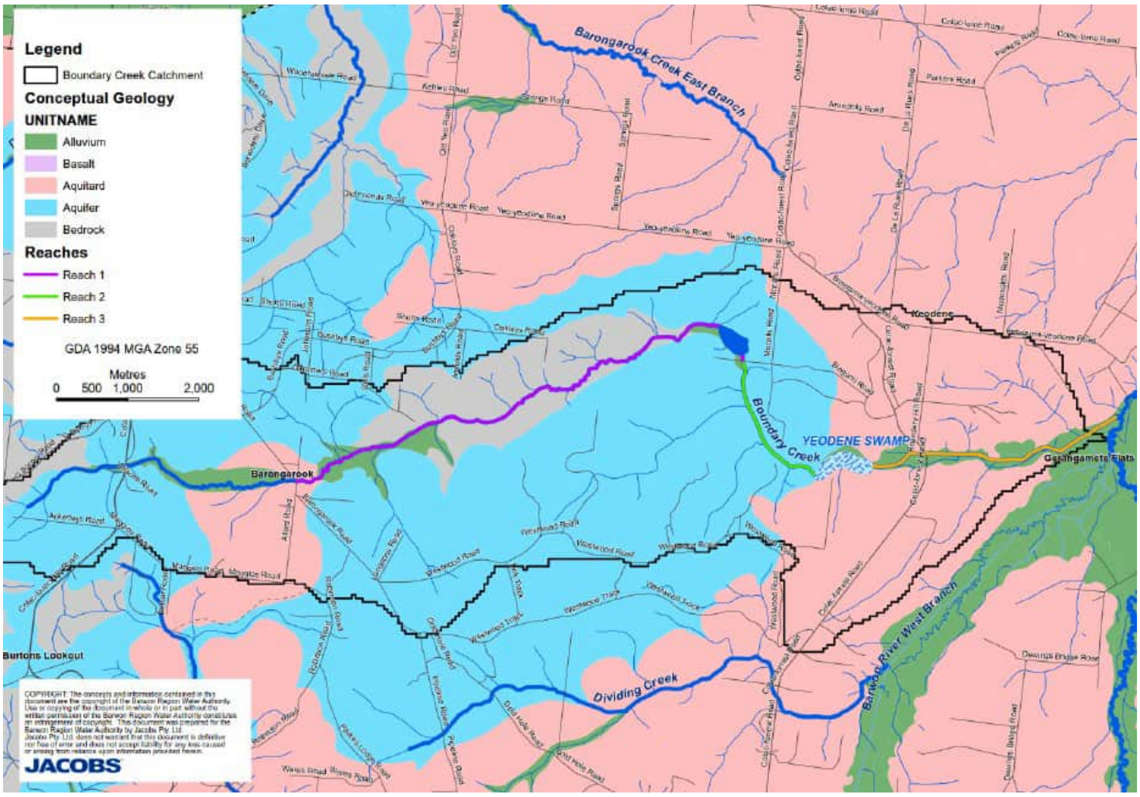


**Figure 3-4 Simplified geology of the Boundary Creek catchment (Jacobs, 2018b)**

### 3.3.2 Streamflow

Location of streamflow gauges along Boundary Creek and availability of flow data are summarised in Figure 3-5 and Figure 3-12 (Jacobs, 2019b).

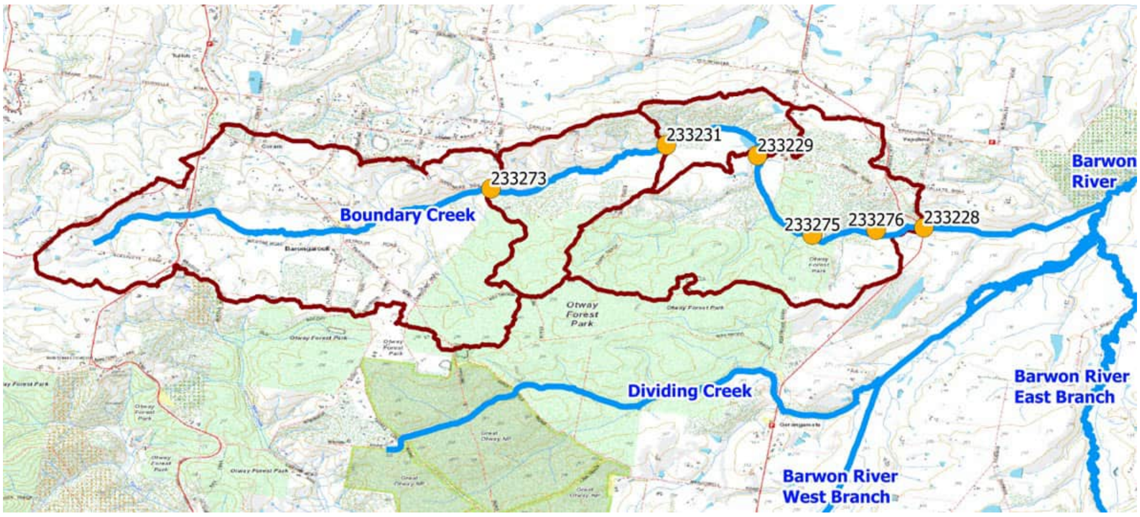


**Figure 3-5 Flow gauge locations along Boundary Creek (Jacobs, 2019b). Streamflow gauge ME763 (not in figure) located along Boundary Creek at Yeodene**

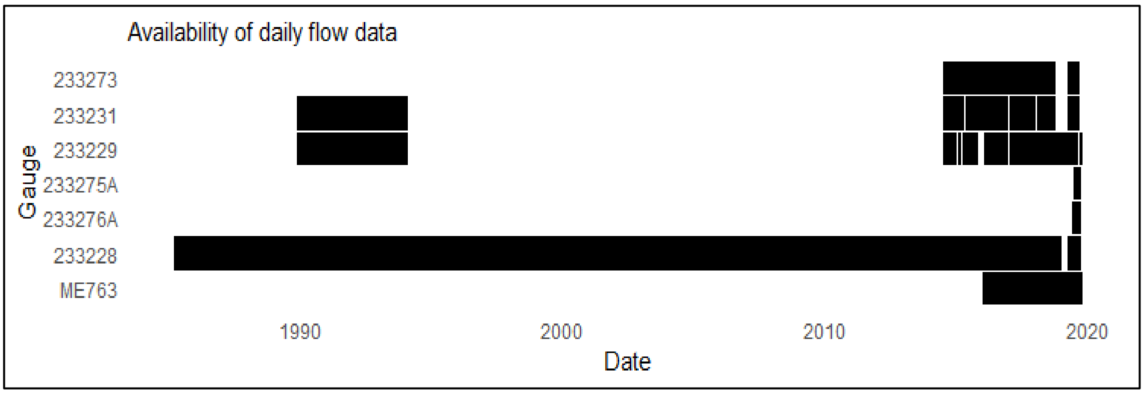


**Figure 3-6 Timeline of available streamflow data (Jacobs, 2019b)**

Analysis of historical average monthly flow in Boundary Creek at the Yeodene streamflow gauge (233228) are provided in Figure 3-7. The data indicates that Boundary Creek streamflow is lower in summer than in winter because of annual rainfall variability. In addition to seasonal variability, the figure indicates a decline in streamflow from approximately 1999, characterised by lower winter flows and periods of no flow during summer.

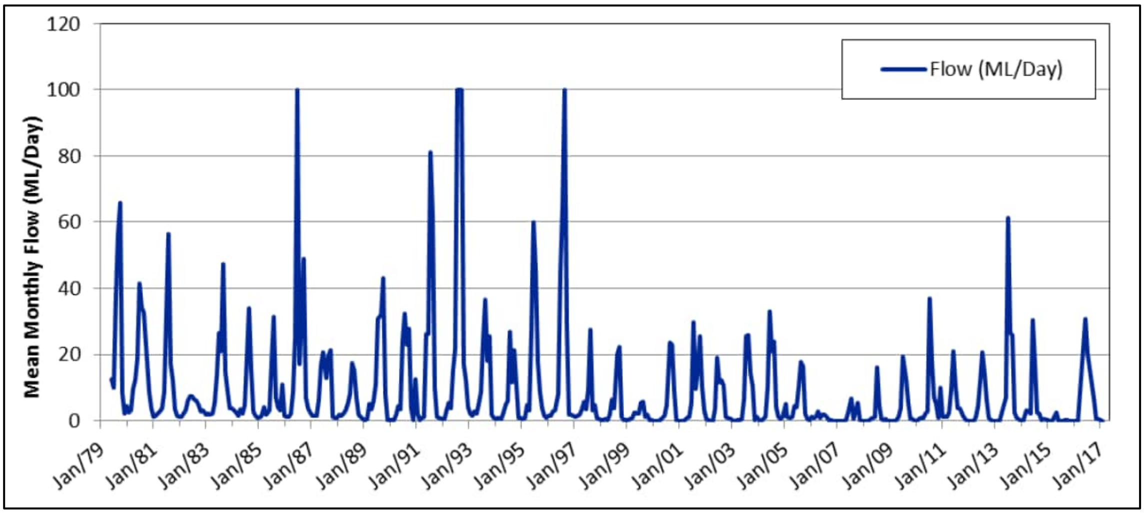


**Figure 3-7 Average monthly flow in Boundary Creek at Yeodene (Jacobs, 2018b)**

The average daily flow at the Yeodene flow gauge over the monitoring period (March 1985 to October 2019) is 7.5 ML/day, with pre 1999 average monthly flow at 10.3 ML/day and post 1999 average monthly flow at 5.6 ML/day (WMIS, 2019). The average monthly flow during the low flow period (defined by Jacobs as December to March) for the entire flow record is 1.1 ML/day. Prior to 1999 this low flow average monthly flow was 1.7 ML/day, dropping to 0.6 ML/day for the post 1999 period.

The cause of reduced streamflow in Boundary Creek at Yeodene have been investigated by Jacobs, and identified as the combination of the following main contributing factors (Jacobs, 2018b):

- Groundwater extraction from the Barwon Down borefield and associated decline in groundwater levels in the LTA.
- Periods of droughts.
- The construction of McDonalds Dam.
- Failure to fully release the 2 ML/d supplementary flows supplied by Barwon Water downstream of McDonalds Dam.

- Drainage from agricultural channels historically realised in the area are, more recently, the fire trenches constructed by the Country Fire Authority (CFA) to control t peat fires in Big Swamp.

### 3.3.3 Loss Analysis

Streamflow data from gauge 233229 (Boundary Creek downstream of McDonalds Dam) and gauge 233228 (Boundary Creek at Yeodene) were analysed to estimate Boundary Creek gain/losses between these two streamflow gauges (Jacobs, 2019b). The results of this analysis (performed using recorded streamflow data in the period 2015-2018 and inputs from the Jacobs surface water model to infill missing streamflow data where required) are summarised in Figure 3-8.

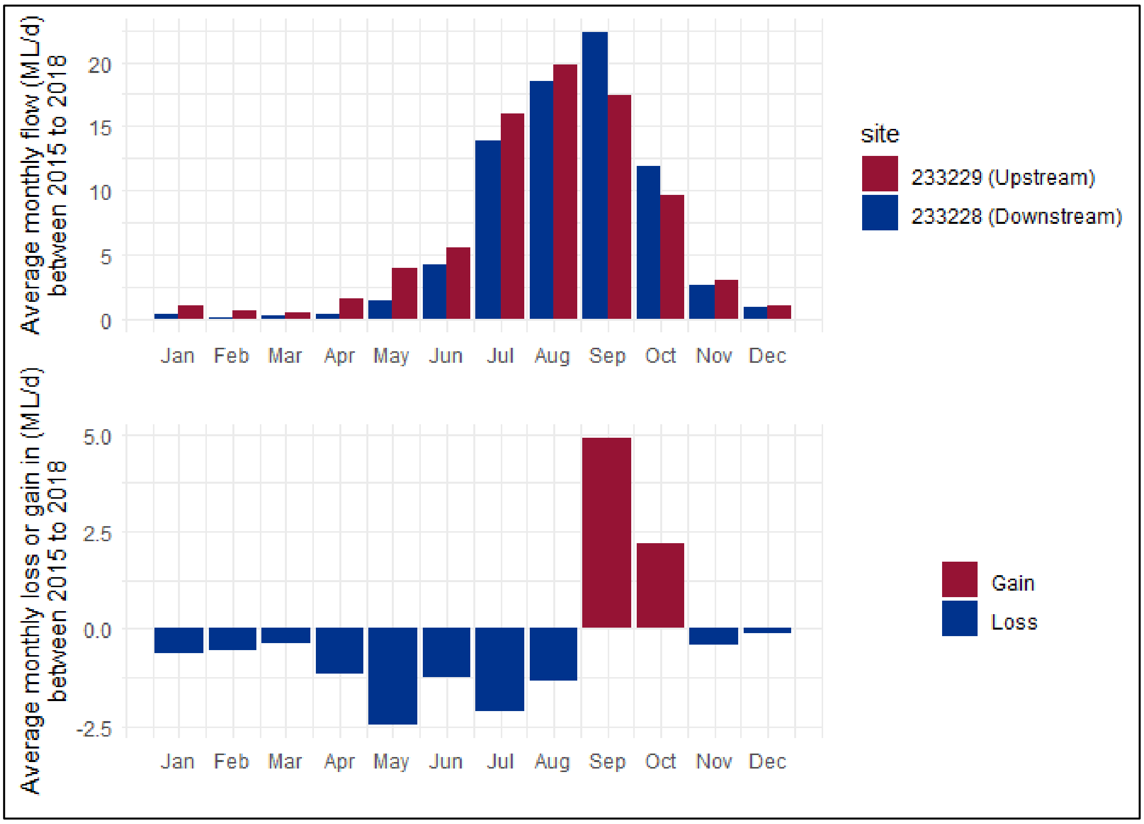


**Figure 3-8 Boundary Creek average monthly gains/losses (Jacobs, 2019b)**

The results indicate that Boundary Creek is gaining in September and October and losing the remainder of the years. The losses, that are assumed to represent infiltration to groundwater, are in the range of 0.5 ML/d to 2.5 ML/d.

### 3.3.4 Surface Water Quality

The following sources of surface water quality data have informed this assessment:

- Electrical conductivity and pH data monitored at the Yeodene stream gauge at monthly intervals since 1985 (Jacobs, 2018b).
- Surface water sampling collected in May and August 2017 at selected sites along Boundary Creek (Jacobs, 2018b).
- Results of Austral surface water sampling as part of the investigation into sediments and macroinvertebrates in the Upper Barwon River (Austral, 2019).

#### 3.3.4.1 Yeodene gauge data (Jacobs, 2018b)

Jacobs analysed the water quality data recorded at the Yeodene gauge, specifically pH versus stream flow. The overview of this data indicates:

- Prior to 1990 the median pH was 6.5 although readings below pH 5 were recorded when flows were reduced in some summers and autumns.
- Between 1990 and 1992 the median pH was 5.1 with readings below 4 recorded in the reduced flow periods of summer and autumn.
- Between 1992 and 1999 the median pH was 5.9, with only two readings below 4.
- From 1999 onwards, the median pH dropped to 3.8, with rare readings above 5.

Cease to flow days in the creek were compared to the measured pH (Figure 3-9), which suggests a correlation between cease to flow events and a progressive lowering in pH values. Cease to flow events have occurred annually since 1999 and over this time pH has fallen and not recovered.

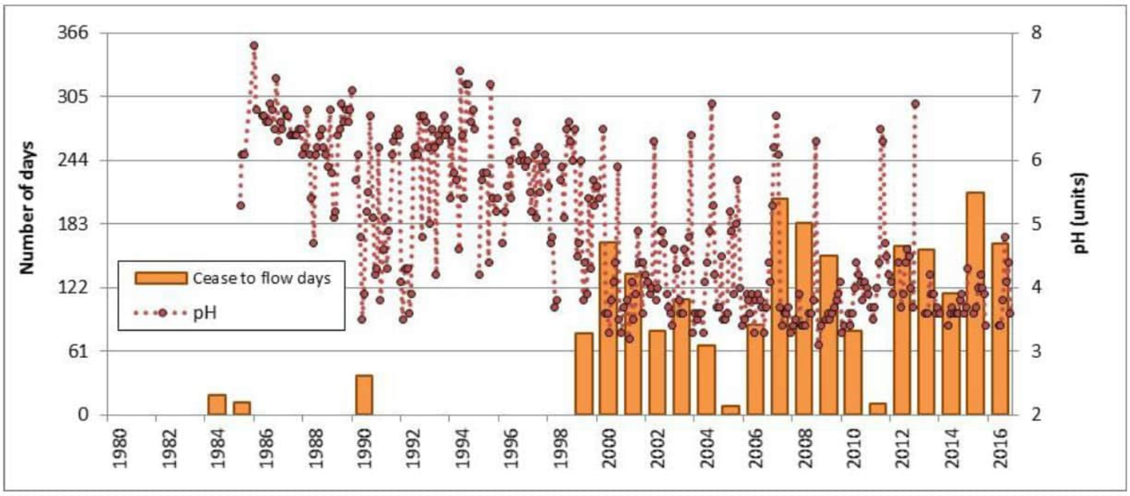


**Figure 3-9 Number of cease to flow days in Boundary Creek at Yeodene gauge vs monthly pH readings at Yeodene gauge (Jacobs, 2018b)**

#### 3.3.4.2 Surface water sampling (Jacobs, 2018b)

Two surface water sampling events in May and August 2017 (Jacobs, 2018b) were conducted at locations shown in Figure 3-10 and summarised below:

- The most significant changes in surface water quality along Boundary Creek occur through Big Swamp.
- The changes in water quality include reduced pH, increased salinity and increased concentration of dissolved metals and sulfate, consistent with the effects of acid sulfate soil impact.
- The higher winter flows of more than 15 ML/day did not significantly impact the concentrations of dissolved metals or acidity levels.

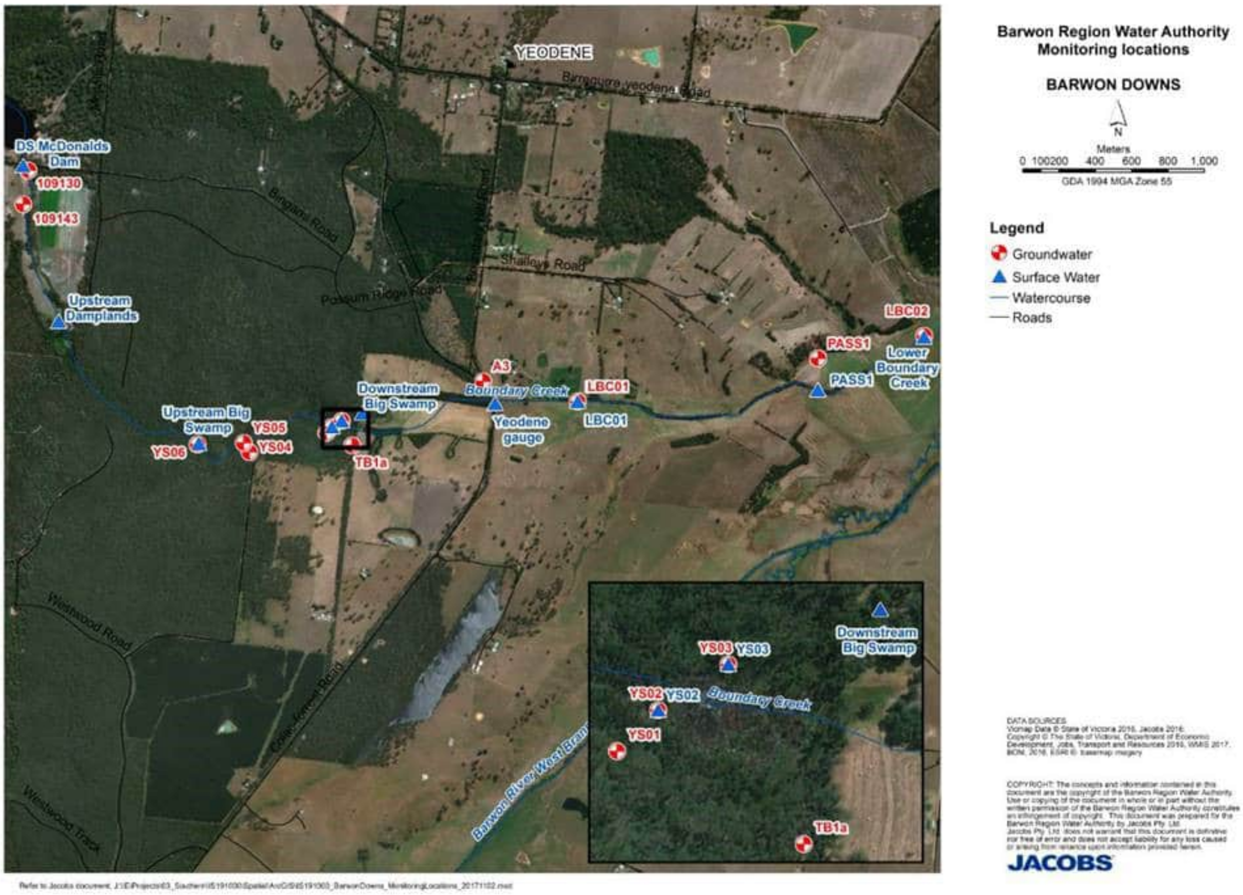


**Figure 3-10 Location of groundwater and surface water monitoring locations (Jacobs, 2018b)**

### 3.3.4.3 Austral Study (Austral, 2019)

Austral undertook an investigation of sediments, water quality and macroinvertebrates in the Upper Barwon River at selected survey sites in October 2019. The sampling locations are shown in Figure 3-11.

The results of the in-situ water quality and metals laboratory analyses for water indicate the following:

- At the time of sampling, pH was low in the East and West branches of the Barwon River, although by Site 4 (just upstream of the Boundary Creek confluence) the pH was neutral (7.4).
- Boundary Creek downstream of the swamp has a low pH (3.94 at the Colac-Forest Road crossing) and remains low pH to the Barwon River confluence (5.55 just upstream of the confluence with the Barwon River).
- The drop in pH in the Barwon River between upstream of the Boundary Creek confluence and downstream of the confluence is just 0.6 pH units (7.4 to 7.34), and by Site 7 (3 km downstream of the confluence) pH is 7.9. Downstream of Site 7 the pH remains constant between 7.8 and 8.0.
- These samples represent springtime conditions. Sampling in the autumn is recommended to provide a more thorough understanding of seasonable water quality and stream health.

Sediment samples were also taken (0 to 20 cm and 20 to 40 cm) and analysed for metal concentrations. The results of the sediment sampling indicate the following:

- There is an impact in the Barwon River from the Boundary Creek confluence to Site 8, with no impact discernible by Site 9, approximately 20 km downstream of the Boundary Creek confluence.

- Historical (both shallow and deep samples) metal concentrations in Boundary Creek (Site 5) show high concentrations of aluminium, arsenic and chromium, suggesting that the concentration of these metals has not varied significantly due to changes at the swamp.
- For iron, lead and zinc in Boundary Creek (Site 5), the concentrations are higher in the shallow sediments than the deep, suggesting that the concentrations of these metals have increased more recently due to the drying and rewetting of the swamp.
- There is a spike in metals such as arsenic at Site 10, suggesting other catchment activities may be impacting the Barwon River.

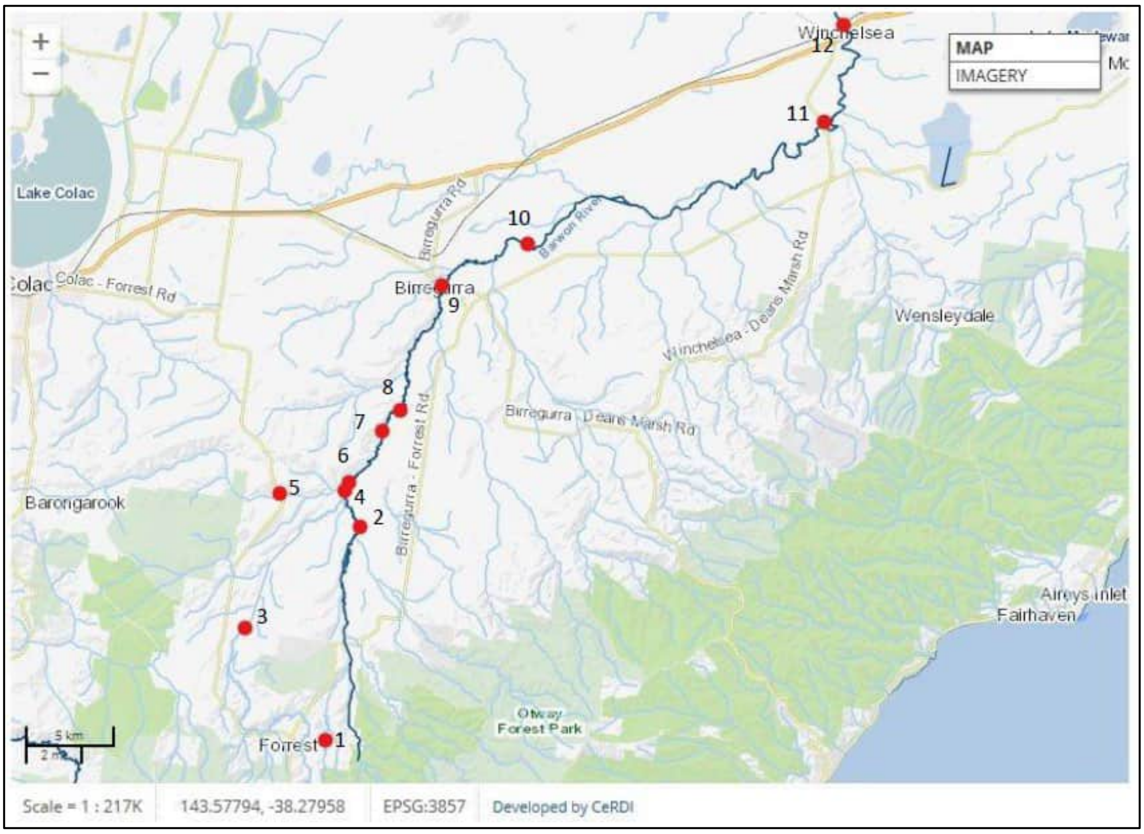


**Figure 3-11 Barwon River and Boundary Creek sampling locations (Austral, 2019)**

## 3.4 Big Swamp

Big Swamp is an approximately 11 ha peat swamp of quaternary alluvial sediments presenting a dominance of clays and silts with sparse intervals of sand. A conceptual model showing Boundary Creek Reaches 2, Big Swamp and Boundary Creek Reach 3 (Jacobs, 2018a) is presented in Figure 3-12.

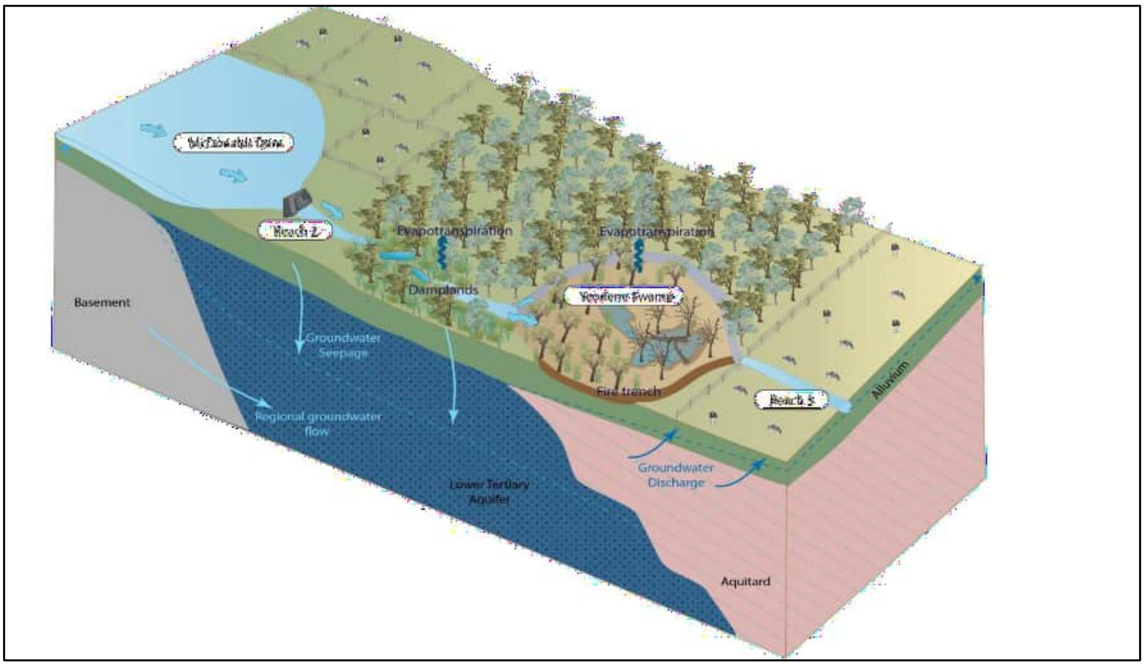


**Figure 3-12 Boundary Creek and Big Swamp Conceptual Model (Jacobs, 2018a)**

As indicated in Figure 3-12, the Swamp is located at the transition between the LTA aquifer and the MTD aquitard, however this transition has not been delineated. Quaternary alluvial sediments locally overly the LTA and the MTD and act as a localised aquifer that is inferred to be likely disconnected from the LTA (Jacobs, 2019a).

Two major fire events occurred at Big Swamp, reportedly in 1998 and 2010, causing major loss of vegetation across the swamp and ignition and ongoing smouldering of the peat. In 2010, the CFA excavated a fire trench (approximately 2 m wide, 2 m deep and 1 km long) along the southern and eastern boundaries of the swamp to contain the peat fire (Figure 3-13). The underground fire is also interpreted to have caused removal of organic content within the swamp and loss of soil structure, with signs of settlement evident across the area.

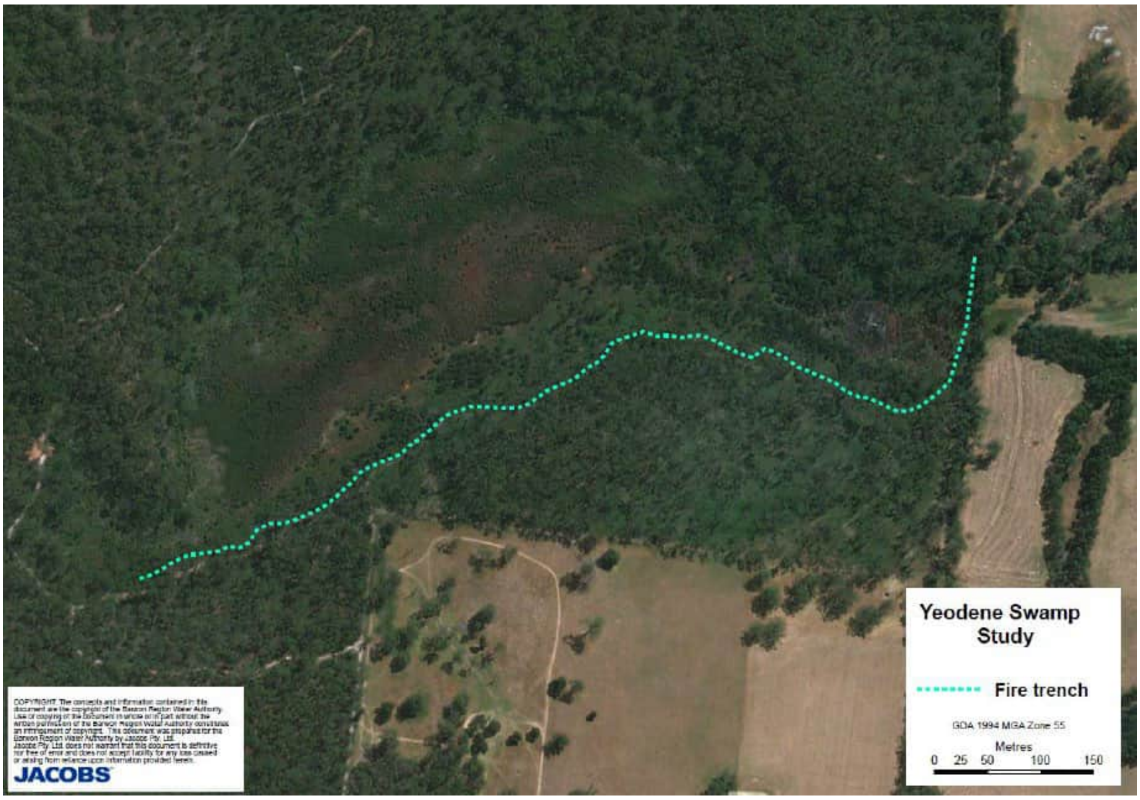


**Figure 3-13 Approximate Extent of Fire Trench (Jacobs, 2018b)**

Surface flows through Big Swamp appears to primarily develop through a defined channel along the northern boundary and, depending of flow rates, a series of channels mostly localised the central portion of the swamp (Figure 3-14). These channels seem to converge towards the northern channel towards the eastern end of the swamp.

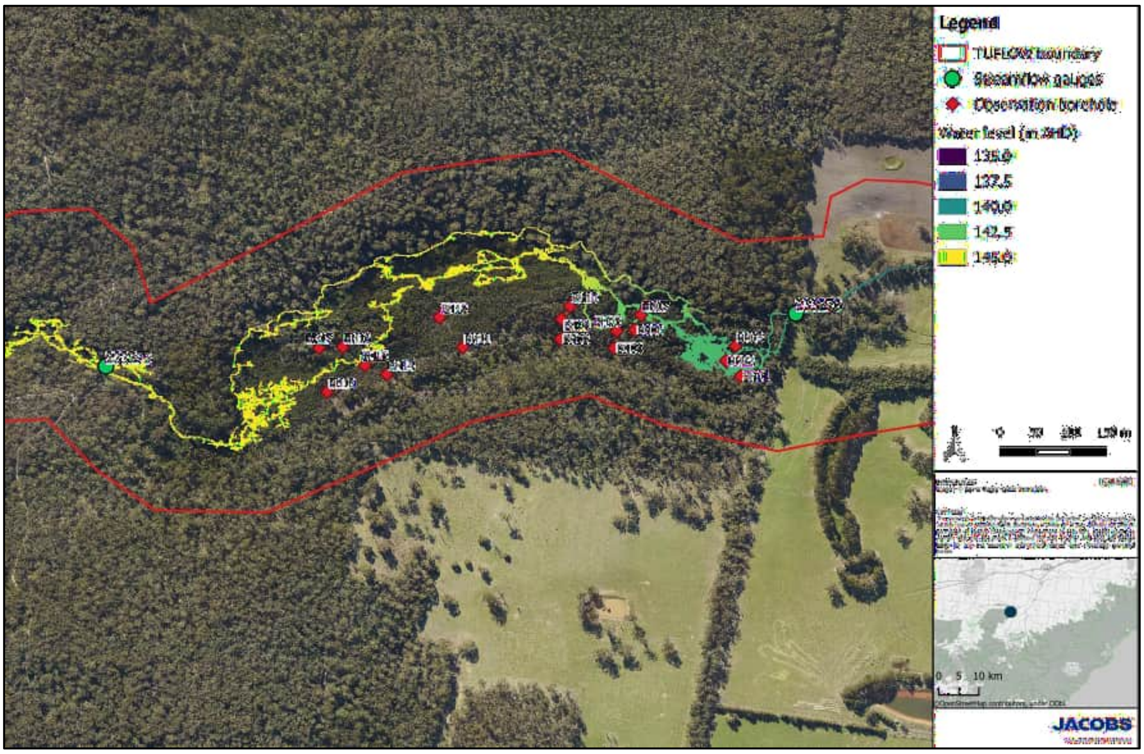


**Figure 3-14 Modelled surface water flow paths (5 ML/d steady state flow released upstream of McDonalds Dam) (Jacobs, 2019b)**

According to Eco Logical (2019), the current channels have been scoured and deepened by high rates of erosion in the swamp following the fires. Prior to the fire and before the current dry conditions, Eco Logical infers that surface water flow across the eastern and central sections would have occurred through a series of finer, more braided channels compared to the limited number of channels presently observed.

Because of high concentrations of iron sulphide minerals (predominantly pyrite, $FeS_2$) and limited buffering capacity, the alluvial sediments in Big Swamp are also described as ASS. Recent soil investigations by Jacobs (2019a) comprised collection of 181 soil samples from 18 boreholes installed across Big Swamp (Figure 3-15).

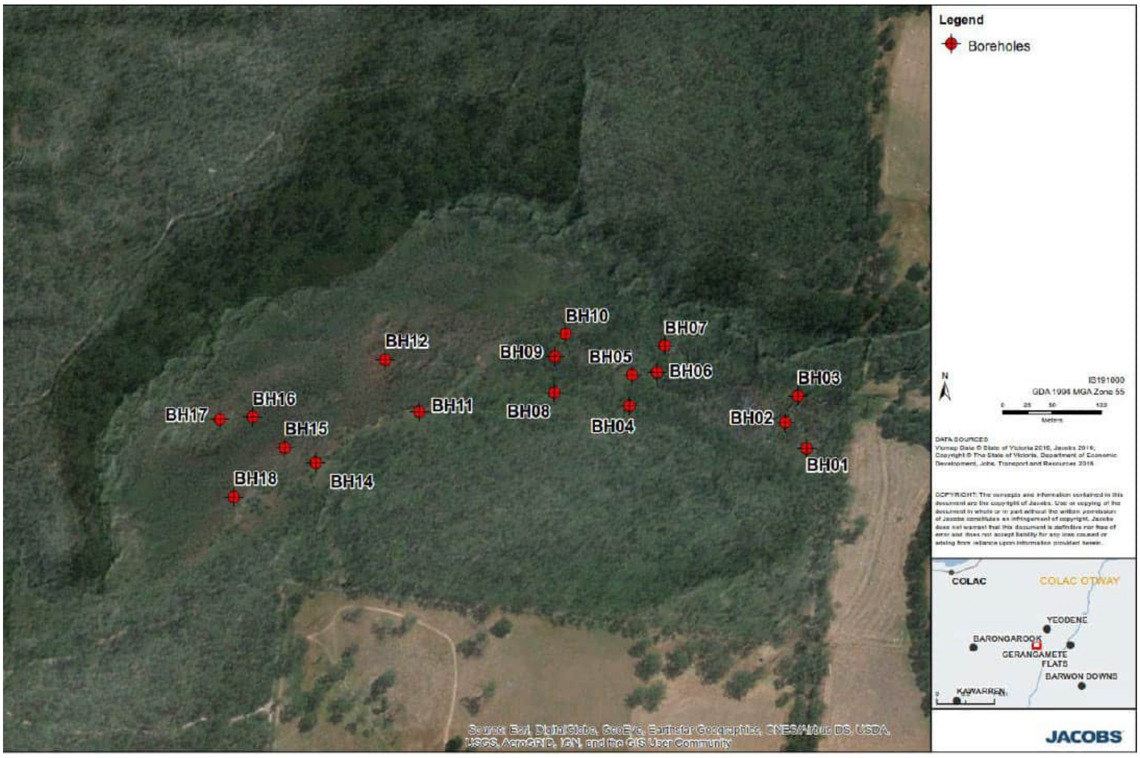


**Figure 3-15 Borehole Locations (Jacobs, 2019a)**

Results of static geochemical testing within each soil core indicate significant concentration of existing and potential acidity at all borehole locations, from near surface to the maximum investigations depths of 6 m below ground level (bgl). It has been interpreted (GHD, 2019) that dryer conditions and lowering of groundwater levels across Big Swamp have caused oxidation of ASS with consequent reduction of pH and increase of sulfate and metal concentrations.

These findings are summarised in the following figures:

- Figure 3-16 (Jacobs, 2019a), showing trends in potential and existing acidity with depth from 0.5 m soil aggregate samples.
- Figure 3-17 (GHD, 2019), showing interpreted net acidity distribution between borehole locations.

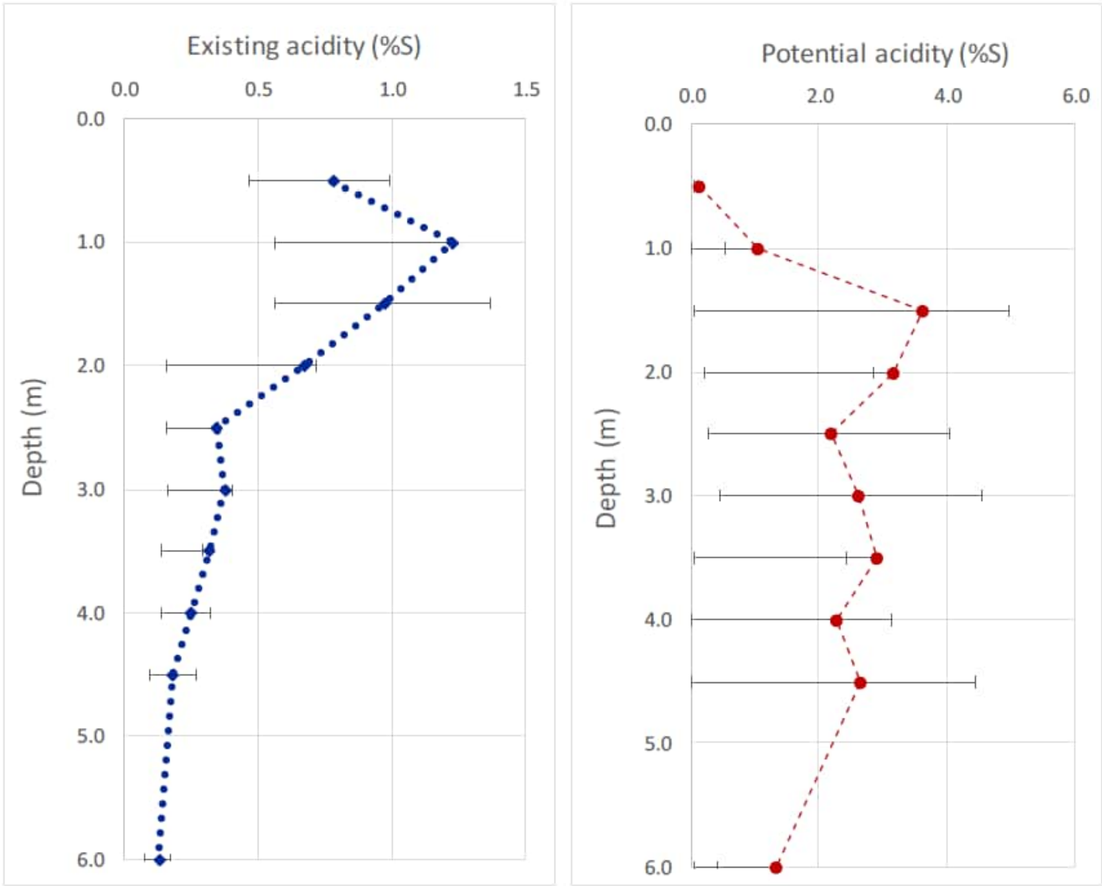


**Figure 3-16 Average, 25th and 75th percentile (show as error bars) of existing and potential acidity with depth (aggregate from 0.5 m intervals) (Jacobs, 2019a)**

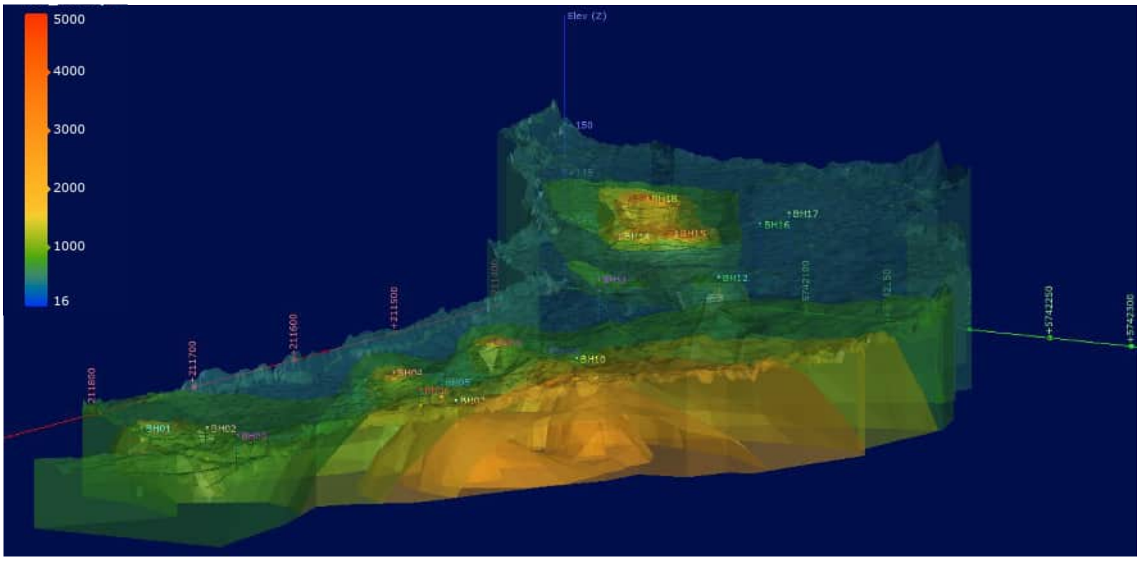


**Figure 3-17 Net Acidity 3D model (GHD, 2019)**

## 3.5 Groundwater

### 3.5.1 Groundwater levels and flow direction

Groundwater in the quaternary alluvium aquifer beneath Big Swamp is monitored by a network of 16 groundwater monitoring wells installed at locations depicted in Figure 3-15 (no monitoring well is installed at location BH13).

Data from a June 2019 gauging round indicate depth of between 1.4 m bgl and -0.1 m bgl (i.e. artesian conditions) across the groundwater monitoring network.

Interpreted groundwater elevations depicted in Figure 3-18 (Jacobs, 2019a) indicate a steep hydraulic gradient towards the swamp from the north and a gentler hydraulic gradient towards the swamp from the south. The hydraulic gradient through the swamp trends to the east in a broadly similar direction to the flow path of Boundary Creek.

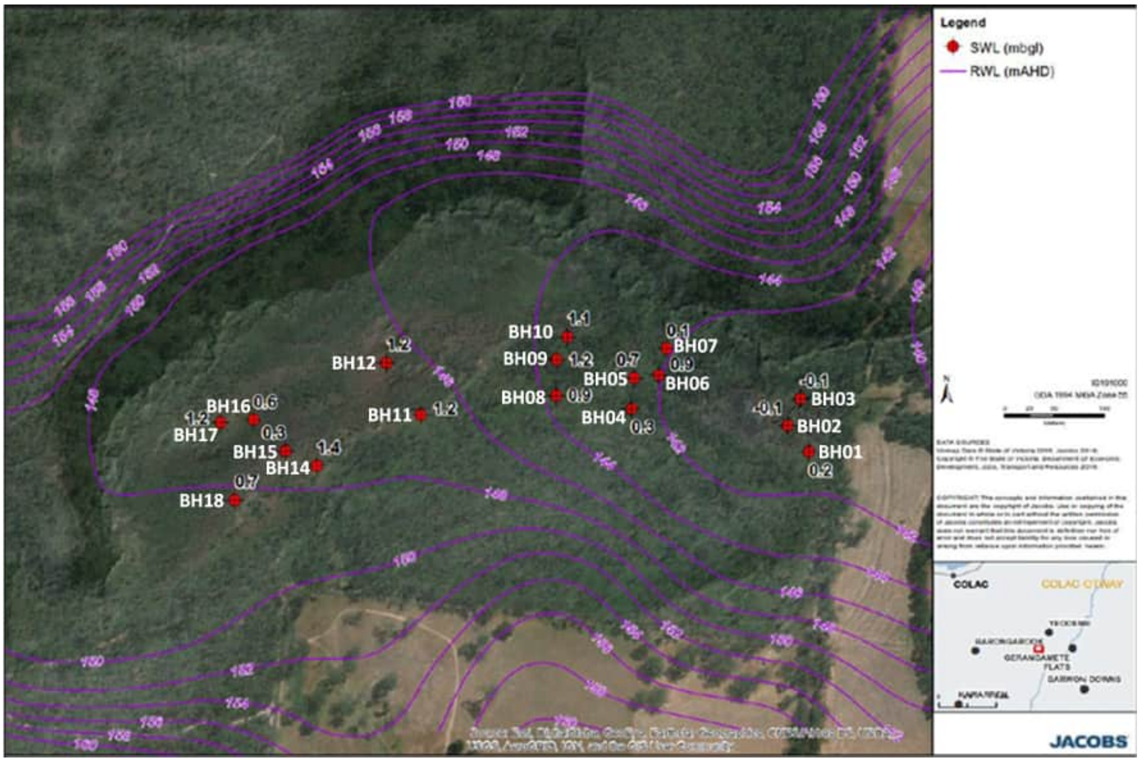


**Figure 3-18 Depth to water table and groundwater elevation (Jacobs, 2019a)**

Groundwater modelling outputs (Jacobs, 2019b) suggest a more pronounced seasonal changes in groundwater elevation across the western part of the swamp (i.e. in the range of 2.5 m for boreholes BH14 to BH18) compared to the eastern end of the swamp (i.e. less than 0.5 m for boreholes BH01 to BH03). The implication of this interpretation is that there is a higher potential to desaturate and activate ASS within the alluvium aquifer within the western end of Big Swamp. Based on interpretation of actual acidity distribution along three transect across Big Swamp (Figure 3-19), there appears to be a correlation between areas of higher actual acidity (lower pH) and areas where there modelled changes of groundwater levels are more pronounced.

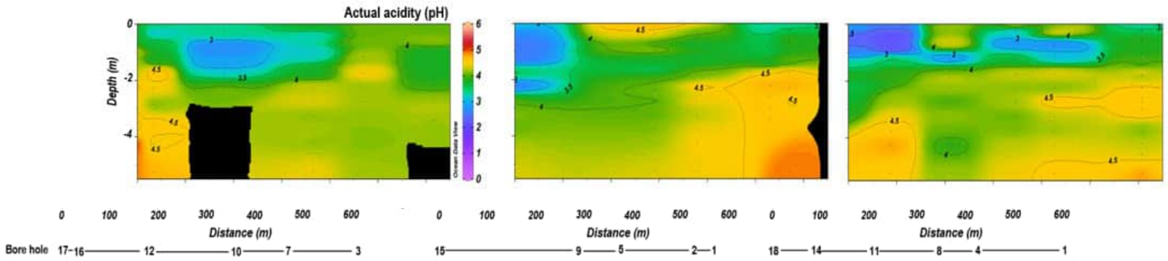


**Figure 3-19 Distribution of actual acidity along three transects across Big Swamp (Monash University, 2019)**

### 3.5.2 Groundwater quality

Groundwater quality is described in the Yeodene Swamp Study (Jacobs, 2018b) and summarised in the following points:

- Reach 1 (basement) – electrical conductivity between 4,000 and 6,000 µS/cm and slightly acidic (between 5.5 and 7.0 pH units). The slight acidity observed in this unit is not interpreted to be related to acidic event in the Big Swamp as groundwater is often slightly acidic.
- Reach 2 (lower tertiary aquifer) – typically fresh with electrical conductivity between 220 and 890 µS/cm and slightly acidic (between 5.5 and 7.0 pH units) and dissolved major ions are dominated by Cl and Na, consistent with rainfall recharge.
- Reach 3 – electrical conductivity between 1,300 and 2,500 µS/cm and ranging between slightly acidic and slightly basic (between 5.5 and 7.6 pH).

Groundwater quality in the shallow alluvial aquifer was monitored in May and August 2017 (Jacobs, 2018b) and can be summarised as follows:

- The pH indicates that the shallow alluvial aquifer has been affected by acid sulfate soils, with groundwater at YS01, YS03 and YS05 the most affected (ranging between 1.58 and 2.72 in May 2017 and 2.59 and 3.80 in August 2017), followed by locations A3 and TB1a downstream of Big Swamp (Figure 3-10). The groundwater upstream and downstream of the swamp does not appear to be affected by acid sulfate soils, with the pH consistent with regional groundwater pH.
- The impact of acid sulfate soils is also evident in the concentration of sulfate and chloride in the groundwater samples, with a higher proportion of sulfate relative to chloride in the groundwater with lower pH values, as is typical of groundwater affected by acid sulfate soils.
- The dissolved metal analysis also shows elevated dissolved metal concentrations (aluminium and zinc) coincident with lower pH groundwater related to the acidic leaching of metals from soils.

## 3.6 Groundwater/Surface Water Interactions

The nature of groundwater and surface water interaction in the Boundary Creek catchment is complex and changes spatially and temporally. The Yeodene Swamp Study (Jacobs, 2018b) summarises these interactions as follows:

- In Reach 1 of Boundary Creek the creek receives groundwater discharge from the basement, however, due to the low permeability of the basement rock, groundwater inflow volumes in this reach are small.
- In Reach 2 the groundwater elevations in the Lower Tertiary Aquifer have fallen to below the base of the creek and this reach of the creek has transitioned from a gaining stream to a losing stream (creek water is now lost to the aquifer via seepage).

- In Reach 3, where Boundary Creek intersects the aquitard, groundwater levels are above the streambed, indicating that Boundary Creek is a gaining stream through this reach. The low permeability of the aquitard limits the volumes of groundwater discharge in this reach.

Measurements of groundwater and surface water levels collected in May and August 2017 indicate that the Damplands and Yeodene Swamp were losing during May 2017 and that the lower reaches of Boundary creek were gaining. In August 2017 the Damplands and the upper parts of the swamp were losing but in some of the lower parts of the swamp the groundwater levels were equal to surface water levels, indicating a neutral hydraulic gradient and a zero net water exchange (e.g. at YS02). The lower parts of Boundary Creek were gaining in August 2017.

The groundwater-surface water modelling (Jacobs, 2019b) includes an analysis of surface water losses (described in more detail in Section 3.3.3). The results indicate that between McDonalds Dam and the Yeodene gauge, Boundary Creek is gaining in September and October, and losing the remainder of the months. The losses, that are assumed to represent infiltration to groundwater, are in the range of 0.5 ML/d to 2.5 ML/d.

## 3.7 Geochemical Characterisation Acidity Generation Processes

This section summarises key concepts from the conceptual geochemical model (GHD, 2019).

### 3.7.1 Terminology

The following generalised terms are generally used to describe the complex acidity associated with ASS:

- **Actual Acidity**: the soluble and exchangeable acidity already present in the soil and readily available for reaction, including pore waters containing metal species capable of hydrolysis (e.g. $Fe^{2+}$, $Fe^{3+}$ or $Al^{3+}$ ions). It is this acidity that is typically be mobilised and discharged following a rainfall event.
- **Retained Acidity**: the less available acidity retained from sparingly soluble and insoluble sulfur compounds (other than sulfides) that slowly produce acid (e.g. jarosite and natrojarosite).
- **Existing Acidity**: collective term that includes actual and retained acidity.
- **Potential Acidity**: The latent acidity in ASS that will be released if the sulfide minerals they contain (i.e. pyrite) are fully oxidised.
- **Net Acidity**: The result obtained when the acid neutralising capacity is subtracted from the sum of existing and potential acidity.

### 3.7.2 Acidity Source Formation

Big Swamp can be described as an inland acid sulfate soil (ASS) system where oxidisable sulfide mineral (mostly pyrite, $FeS_2$) formed through reduction of available iron and sulfate under reducing conditions promoted by decomposition of organic matter.

In addition, generation of monosulfidic black oozes (MBOs), the precursors to pyrite, can also form. MBOs are characterised by a gel-like consistence, ultra-fine grain size and high reactivity (with respect to oxidation). MBOs can form as thick accumulations (i.e. >1 m thickness) in drains, waterways and other waterlogged setting. If mobilised or resuspended during runoff events (i.e. following high rainfalls), they can oxidise readily once exposed to oxygen and can cause severe acidification and/or deoxygenation of receiving surface water environments.

### 3.7.3 Acidity Generation Processes

ASS sulfidic minerals (of which the most prevalent is pyrite, $FeS_2$) are stable under waterlogged, anaerobic conditions, where the water quality is consistent with low inputs of any oxidised components such as iron or nitrate.

Sulfidic soils are termed potential acid sulfate soils (PASS), as they hold the potential to generate acidity from the sulphides they contain. PASS will tend to have a pH ≥4 as this is the pH above which active bacterial sulfate reduction, the process generating the sulfides, can occur.

However, disturbances of ASS (i.e. drought, excavation, dewatering or surcharging activities) causing exposure to air (oxygen) can lead to of the release of this potential acidity to generate acidic conditions (these soils are defined as actual acid sulfate soils (AASS), tend to have a pH ≤4).

Simplified geochemical reactions relevant to the processes involved in the release of acidity from soils include:

- $FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} 2SO_4^{2-} + 2H^+$ (1)

  (Conversion of pyrite to ferrous iron, sulfate and acid.)

- $Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2\ H_2O$ (2)

  (Oxidation of ferrous iron to ferric iron, consuming acid.)

- $Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 \downarrow + 3H^+$ (3)

  (Precipitation of ferric hydroxide and acid generation, at pH>4.)

- $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO4^{2-} + 16H^+$ (4)

  (Microbially mediated oxidation of pyrite by ferric iron, and production of soluble ferrous iron and acid, at pH<4.)

The soluble ferrous iron produced by reactions (1) or (4) can be transported at significant distances downstream of the ASS source, where it can be oxidised to form insoluble iron oxy-hydroxides consuming oxygen and producing acid:

- $Fe^{2+} + 1/4O_2 + 3/2H_2O \rightarrow FeO.OH \downarrow + 2H^+$ (5)

  (Oxidation of ferrous iron and precipitation of goethite).

Other precipitates associated with iron oxidation include jarosite, natrojarosite and schwertmannite. Jarosite is a yellow mineral that is formed under strongly oxidising and highly acidic conditions (a pH of less than 3.7 units is required).

These minerals slowly decompose (usually by hydrolysis) leading to formation of iron precipitates, sulfate and acid. For example, in the case of jarosite:

- $KFe_3(SO4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3 \downarrow + 2SO4^{2-} + 3H^+ + K^+$ (6)

Similar reactions occur during oxidation of MBOs (FeS):

- $FeS + 2O_2 \rightarrow Fe^{2+} + SO_4^{2-}$ (7)

  (MBO oxidation consuming oxygen and releasing sulfate and acidity as ferrous iron; ferrous iron has then the potential to oxidise to ferric iron (reaction (2)) and hydrolyse (reaction (3)), generating acid)

The various acid sources and acidification reactions described above are summarised in Figure 3-20 (GHD, 2019), where a distinction is also made between primary and secondary acidification processes.

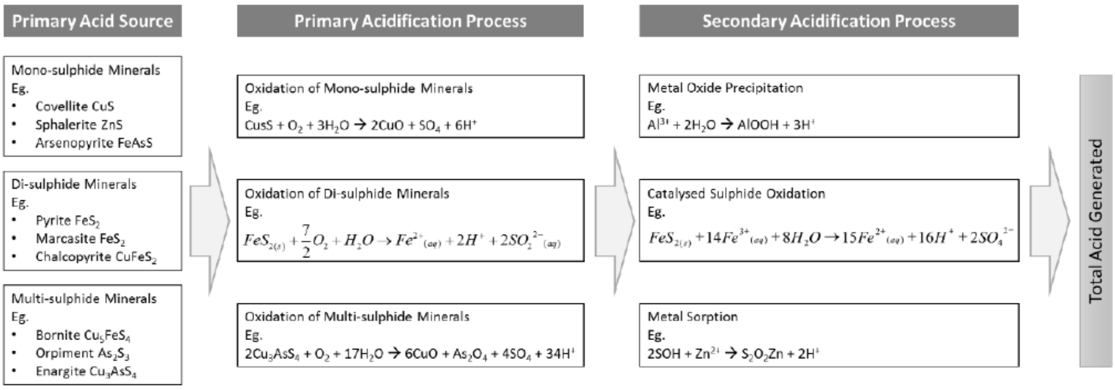


**Figure 3-20 Potential acid sources and primary and secondary acidification processes (GHD, 2019)**

It is important to mention that cations in aqueous solution behave as acids (Lewis acids), and thus for any acidity budget estimates, consideration should be given to other metals other than Fe.

A summary on the potential occurrence of acid generation processes at Big Swamp and Boundary Creek, based on a review of available surface water and groundwater quality data, is provided below (GHD, 2019):

- The primary acidification process in Big Swamp is oxidation of iron sulfide minerals, with pyrite being the main acid source mineral.
- Secondary acidification processes (i.e. pyrite oxidation by ferric iron and hydrolysis of jarosite) are also considered to have the potential to be periodically occurring in Big Swamp, however the data are considered insufficient by GHD to confirm these trends.
- There is limited evidence to suggest that any primary acid source minerals are present in Reach 3 of Boundary Creek.
- Elevated concentration of ferrous and ferric iron in Reach 3 of Boundary Creek indicates an export of acidity from Big Swamp and the potential for secondary acidification processes though oxidation of ferrous iron to ferric iron and then precipitation of ferric hydroxides.

### 3.7.4 Effects of ASS Oxidation

The effects of ASS oxidation include acidification of soil, surface water and groundwater; mobilisation of metals (i.e. aluminium, arsenic and iron); formation of precipitates in connected water systems which can affect both the flora and fauna through coating the leaves and gills causing suffocation and corrosion of steel and concrete structures.

### 3.7.5 Acidity Neutralisation Processes

The acid neutralising capacity (ANC) is a measure of the soil's intrinsic ability to buffer acidity and resist lowering of pH. ANC can be provided by dissolution of calcium and/or magnesium carbonates (typically sourced from invertebrate shells), cation exchange reactions, and by reaction with the organic and clay fractions.

Addition of finely crushed limestone ($CaCO_3$) is commonly used as a management strategy for mitigation of ASS impacts, according to the following reactions:

- $CaCO_{3(s)} + H^+_{(aq)} \rightarrow Ca^{2+}_{(aq)} + HCO^{3-}_{(aq)}$ (8)
- $HCO^{3-}_{(aq)} + H^+_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)}$ (9)

(Dissolution of calcite with neutralisation of acid and production of alkalinity.)

Other neutralising agents can also be used, based on project specific considerations.

Another approach to manage ASS issues is to permanently flood acidified ASS sediments, which can stop further pyrite oxidation and promote iron and sulfate reducing conditions:

- $4Fe(OH)_3 + CH_2O + 8H^+ \rightarrow 4Fe^{2+}$ $11H_2O + CO_2$ (10)

  (iron reduction)
- $2CH_2O + SO_4^{2-} + 4H^+ \rightarrow 2CO_2 + H_2S + 2H_2O$ (11)

  (sulfate reduction)
- $M^{2+} + H_2S + 2HCO^{3-} \rightarrow MS + 2H_2O + 2CO_2$ (12)

  (reaction of a generic reduced metal, $M^{2+}$, with $H_2S$ to form insoluble metal monosulphide.)

These reactions illustrate that bacteria use organic matter ($CH_2O$) as electron donor and iron oxide ($Fe(OH)_3$) and sulfate ($SO_4^{2-}$) as electron acceptors for their metabolism. In this process, they consume acid ($H^+$) and produce carbon dioxide ($CO_2$), reduced iron ($Fe^{2+}$), sulfur ($H_2S$) and water (H2O).

These two reactions occur sequentially, with iron reduction taking place first and sulfate reduction then taking place once all the iron oxide is consumed. Once sulfate reduction commences, the $H_2S$ produced will react with $Fe^{2+}$ produced from iron reduction to form reduced inorganic sulfur compounds such as iron monosulfide, which then converts to pyrite over time.

The availability of a carbon source is an important consideration in maintaining the stability of the metal sulphides (if formed) so that:

- Reducing condition are maintained
- Alkalinity is provided to buffer acid that may be generated by the sulphide oxidation.

In general, inland ASS soils are characterised by high organic matter content, high sulfide mineral content and low or absence of readily weathered minerals to provide buffering, resulting in significant decreases in pH in response to sulfide mineral oxidation. This general process was described by GHD in response to the review of available data on the Big Swamp sediments, which appear to have limited buffering capacity because of insignificant amounts of soluble carbonate minerals and slow kinetic reactions for the reduction of dissolved sulfate to sulfide and precipitation as of sulfide minerals (GHD, 2019).

## 3.8 Key Fate and Transport Mechanisms

The key fate and transport mechanisms that are likely to occur at Big Swamp include:

- Accumulation of actual and retained acidity in the soil profile as a result of ASS oxidation (i.e. including exposure to air). Where groundwater is shallow, capillary rise of mobile acidity products through the soil profile could also occur.
- Mobilisation and transport of actual and retained acidity by interaction of surface water or overland flow with shallow oxidised sediments.
- Mobilisation of and transport of actual and retained acidity by groundwater interacting with deeper oxidised sediments, with potential discharge into a surface water body (i.e. Boundary Creek). The significance of acidic discharges from groundwater into a surface water depends on groundwater level elevations compared to surface water elevation, hydraulic conductivity of the aquifer and hydraulic gradients.

## 3.9 Vegetation

An ecological assessment of Big Swamp was undertaken by Eco Logical covering the wetland and riparian extent of Big Swamp. This assessment identifies the following vegetation communities (Figure 3-21):

- Riparian Fern Scrub (EVC A120) throughout much of the swamp plain in the western and central sections of the swamp.
- Swampy Riparian Woodland (EVC 83) along the main channel and adjacent terraces of Boundary Creek.
- Wet Verge Sedgeland (EVC 932) at the western end of the swamp in a small patch adjacent to the main channel.
- Damp Sands Herb-rich Woodland (EVC 3) on the lower slopes to the south and east of the swamp plain.
- Lowland Forest (EVC 16) on the slopes surrounding Big Swamp, upslope from areas historically effected by water-logging or inundation.

Eco Logical identified three ecohydrological zones:

- Swamp plain – previously experienced near-continuous waterlogging with periods of inundation, however in recent years this part of the swamp has experienced significant drying. The dry conditions present throughout much of the swamp plain are unlikely to support a Riparian Fern Scrub community in the long term, leading to a gradual shift to a terrestrial damp woodland community over time.
- Main channel – surface flow modelling indicates that even under relatively low flows (e.g. 2ML / day) water persists in the channel. As a result, communities in this zone are likely to be more tolerant of long-term reductions in surface flows and the associated reduction in water tables within the swamp.
- Damp woodlands – unlikely to have experienced inundation in normal years, however, species would still have been heavily dependent on ground water with near-constant access to water within the root zone of mature trees and shrubs.

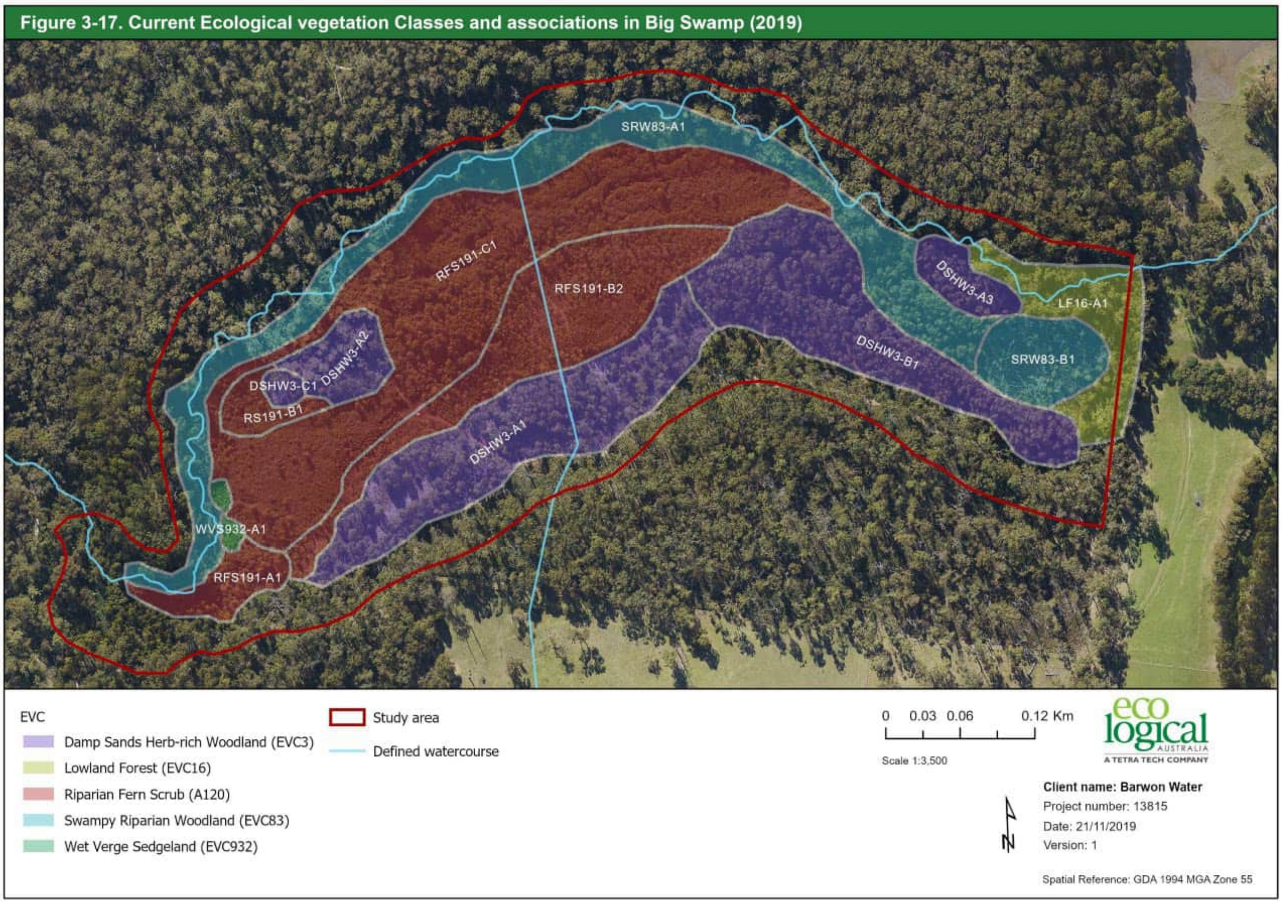


**Figure 3-21 Current ecological vegetation classes and associations in Big Swamp (Eco Logical, 2019)**

# Section 4 **Overview of ASS Remediation Strategies**

## 4.1 Available Guidance

Several sources of information related to the management and remediation of ASS impacts have been reviewed to support preparation of this ROA, including:

- National and interstate best practice guidance on the management of ASS issues in inland and coastal landscapes.
- Technical publications describing technologies for the treatment of acid mine drainage, which presents several similarities with ASS issues.
- Selected papers presenting case studies and technology performance reviews.
- Online resources, such as the Interstate Technology and Regulatory Council (ITRC) Mining Waste Treatment Technology Selection (www.itrcweb.org/miningwaste-guidance/) and the Global Acid Rock Drainage (GARD) Guide (www.gardguide.com).

## 4.2 ASS Management Principles

According to the *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*, the hierarchy of an ASS management strategy is:

1. Minimising the formation of ASS in inland aquatic ecosystems.
2. Preventing oxidation of ASS, if they are already present in quantities of concern; or controlled oxidation to remove ASS if levels are a concern but the water and soil has adequate neutralising capacity.
3. Controlling or treating acidification if oxidation of ASS does occur.
4. Protecting connected aquatic ecosystems/other parts of the environment if treatment of the directly affected aquatic ecosystem is not feasible.
5. Limited further intervention.

The above guidance is generally aligned with EPA Victoria Publication 655.1 *Acid Sulfate Soil and Rock* (July 2000), which indicates the following hierarchy of management:

1. Avoid disturbance
2. Minimise disturbance
3. Prevent oxidation
4. Treat to reduce or neutralise acidity
5. Off-site reuse or disposal.

The following sections provide a brief overview of common approaches for management of ASS. In most cases, several management strategies are required in order to effectively control ASS issues.

## 4.3 Minimise or Prevent Further Oxidation

The simplest way to minimise or prevent further oxidation is to adopt water table management strategies to ensure that ASS materials remain under sufficient depth of water. This strategy provides two benefits:

- The low solubility of oxygen in water provides a limiting factor to development of primary oxidation processes in previously oxidised ASS sediments.

- Elevating the water table minimises the risks of deeper un-oxidised ASS sediments being exposed to oxygen and initiating acid forming reactions.

This strategy is most effective when there is a plentiful and reliable supply of water. However, in cases where water is limited, artificial structures can be installed so that water levels are maintained across critical areas with highest potential for generation of acidity.

## 4.4 Inundation of Acidified Areas

Permanent inundation (or reflooding) of drained, acidified areas is a management strategy that has several benefits, including:

- prevent further ASS oxidation;
- contain acidity in the landscape/decreasing acid export;
- assist with ecological restoration; and,
- neutralise in situ acidity within the wetland by reversing key geochemical processes.

The last point relates to the potential for inundated areas to encourage natural microbial sulfate and iron reduction processes to neutralise acidity, generate alkalinity and precipitate metals. If organic matter ($2CH_2O$) is available in the inundated areas, sulfate reducing bacteria can use ferric iron ($Fe^{3+}$) and sulfate ($SO_4^{2-}$) as terminal electron acceptors, consuming protons and generating bicarbonate alkalinity ($HCO_3^-$):

- $CH_2O + 4Fe(OH)_3 + 8H^+ \rightarrow 4Fe^{2+} + CO_2 + 11H_2O$
- $2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^-$

The reduction of sulfate is an important mechanism for removing reduced metals (which may otherwise re-oxidise and release acidity), because formation of highly insoluble sulfides is enacted. For example:

- $Fe^{2+} + H_2S \rightarrow FeS + 2H^+$

It is noted that this strategy in most effective when the following conditions occur:

- Reduced metals can be effectively precipitated and retained in the system, minimising the potential for acidity to be exported outside of the system.
- The alkalinity generated by iron and sulfate reduction can be retained in the system to neutralise acidity in the system.
- The system is maintained in an anoxic saturated state preventing re-oxidation of metals and associated generation of acidity.

## 4.5 Isolation of Impacted Areas

If it is not feasible to restore an ASS impacted ecosystem, the focus will then be on protecting connected ecosystems from potential adverse effects caused by transport of acidification by-products though surface water, groundwater or overland flow.

Physical isolation of ASS sediments is a potentially effective method for protecting connected ecosystems; however, should only be considered when the benefits are greater than the negative effects of isolation.

Isolation can have negative effects on aquatic ecosystems, increased ASS oxidation rates and potential risks of mobilisation of acidification by products (i.e. wind erosion of dry ASS sediments or high flow events breaching the integrity of the isolation barrier).

Isolation techniques include diverting flow of creek across impacted areas, construction of impermeable barriers or flow regulators.

## 4.6 Dilution of Acidic Discharge

Dilution is a management approach that relies on mixing poor quality water with high quality water to reduce impacts on the receiving environments.

However, because of the relatively large volume of water required for effective dilution of acidic waters (up to 100 to 1000 times the volume of the system, depending on the inherent buffering capacity, or alkalinity, of the dilution water), coupled with the cost and sustainability consideration of using high quality water for management of impacts, dilution as a mitigation option in inland aquatic ecosystems may be useful in only a few cases.

## 4.7 Soil Neutralisation

These technologies can be broadly described as addition of acid neutralising compounds to raise pH and increase alkalinity of the soil. Under these conditions, the aqueous solubility of most metals is reduced, and they tend to precipitate out of solution.

Technical consideration for implementation of soil neutralisation technologies include the selection of the neutralising agent to be employed, method of application and application rates.

### 4.7.1 Neutralising Compounds

There are many types of neutralising compounds available for the treatment of ASS, which differ on their theoretical neutralising capacity, pH, solubility, moisture content, purity, particle size distribution, suitable application methods and health and safety considerations.

Commercially available products include calcium carbonate ($CaCO_3$) in the form of finely crushed limestone ('aglime'), dolomite (a rock comprising varying proportions of calcium carbonate and magnesium carbonate ($MgCO_3$), magnesite ($MgCO_3$), quick lime ($CaO$), hydrated lime ($Ca(OH)_2$), burnt magnesia ($MgO$), burnt dolomite ($CaO/MgO$), soda ash ($Na_2CO_3$) and sodium bicarbonate ($NaHCO_3$).

Industry by-products with neutralising capacity can also be used in some applications and tend to be considered for their generally lower costs and sustainability considerations. Some examples include by-products of the cement manufacturing industry such as fly ash, and bauxite residues.

### 4.7.2 Application Methods

#### 4.7.2.1 Surface

Surface applications involve spreading the neutralising compound over all or a part of the ASS affected catchment.

The aim of surface applications is to neutralise the acidity of the water draining from the catchment and improve surface soil conditions as the neutralising compounds slowly penetrate through the profile (depending on soil properties, precipitation and surface application rates).

Depending on the area requiring treatment and access constraints, surface application can be undertaken using truck mounted devices, specialised spreading equipment (i.e. pressurised slurries) or by air (i.e. fixed wing aeroplane or helicopter).

#### 4.7.2.2 Mechanical

Mechanical applications involve incorporation of the neutralising compound into the soil requiring treatment using conventional earth moving equipment or large diameter mixing devices.

In the first case, the soil is typically excavated, and incorporation of the neutralising compound is carried out on a specifically built treatment pad. In the second case (usually referred to as 'deep soil mixing'), the neutralising compound is added directly to the in-situ soil with no need for excavation.

#### 4.7.2.3 Injection

Injection applications involve injection of specifically formulated mixtures of neutralising agents and other compounds (slurries) that are injected under pressure in the subsurface with the aim of achieving a uniform distribution in the volume of soil requiring treatment.

### 4.7.3 Application Rates

For surface applications using lime (either granular or in a pelletised form), rates in the range of 2.5-5.0 t/ha are generally reported. For mechanical and injection applications, the mass of neutralising agent required is usually evaluated based on the acid-forming properties of the materials to be neutralised, which is determined from laboratory results.

Depending on the complexity of the project, required application rates can be also assessed using pilot trials, use of geochemical modelling tools or development of trial/error procedures.

## 4.8 Passive Systems for Treatment of ASS Impacted Water

### 4.8.1 In-stream Limestone Sand

This technology is based on placing piles of limestone sand directly in the streambed of high gradient streams. The piles are washed downstream during high flow events, with the limestone increasing pH and alkalinity of the streams as it progressively dissolves in the water.

**Figure 4-1 Limestone sand placed along a polluted stream**

Coating of limestone particles with Fe hydroxides (armouring) can occur, but the energy of the water in the stream causes agitation and scouring of limestone to keep fresh limestone surfaces available for reaction.

Selection of the locations of piles is based on access constraints and water quality objectives along various reaches of the stream. Application rates are calculated using empirical formulas, which consider the annual acid load into the stream.

### 4.8.2 Limestone Diversion Wells

Limestone diversion wells (LDWs) consist of in-ground wells (1.5-1.8 m in diameter and 2.0-2.5 m in depth) containing crushed limestone aggregates into which part of a fast-flowing stream flow is diverted, usually via a pipeline.

The turbulence caused by the water flowing into the well enhances dissolution of limestone, as wells as minimising the potential for armouring of the limestone surfaces.


**Figure 4-2 Limestone diversion well**

The water leaving the diversion well, with increased pH/alkalinity and carrying limestone particles abraded from the well, is then reintroduced into the stream where further pH neutralisation and metal precipitation occurs.

LDWs are generally employed at sites with suitable topographic fall between the stream diversion point and the intake of the well (minimum of 10 m vertical change), so that enough hydraulic force is applied to the limestone, promoting abrasion and grinding of the aggregate.

LDWs are maintenance intensive systems (i.e. require frequent re-filling of limestone, cleaning of leaves and debris, etc.) and are not generally suitable for sites that are remote or difficult to access. In addition, aluminium and other metals may precipitate in the receiving stream as a result of increase pH and alkalinity.

### 4.8.3 Open Limestone Drains

Open limestone drains (OLDs) are open channels containing coarse limestone aggregate (15-30 cm diameter) used to increase pH and alkalinity of the waters requiring treatment. A typical OLD may have 0.3 m to 1 m of limestone at the bottom and 1 m to 3 m of water with a residence time of at least 14 hours (Figure 4-3).

**Figure 4-3 Example of an OLD**

To minimise reduction of treatment efficiency caused by formation of Fe and Al precipitates on the surface of the aggregate (armouring), OLD are constructed with high gradients (>20%) if site conditions allow. One of the drawbacks of steep OLDs is that they require additional aggregate volume to achieve the required residence time.

Depending on the characteristic of incoming water, a properly designed OLD can raise pH to 6-8 and generate alkalinity in the range of 40-60 mg/L $CaCO_3$. A settling pond is usually required after the OLD to retain the metal precipitates, prior to final discharge of the treated water in the environment.

### 4.8.4 Anoxic Limestone Drains

Anoxic limestone drains (ALDs) are buried trenches lined with an impermeable material, backfilled with coarse limestone aggregate (15-30 cm diameter) and buried under clay (Figure 4-4). The ALD is then filled with the water requiring treatment and maintained in a saturated condition so that ingress of oxygen is prevented and armouring of the limestone is minimised.

**Figure 4-4 ALD under construction (Skousen, 2005)**

Dissolution of limestone within the ALD increases pH and alkalinity of the water requiring treatment, creating favourable conditions for metal precipitation. Typically, an ALD is followed by an aerobic treatment unit (such as an aerobic wetland or settling pond) where dissolved metals are oxidised, precipitated and retained prior to final discharge of the treated water in the environment.

ALDs are typically constructed to achieve residence times of approximately 14 hours, increase of water pH to 6-8 and alkalinity generation in the range of 250-300 mg/L $CaCO_3$.

For best performances, ALDs should receive incoming water with low concentrations of dissolved oxygen (<1 mg/L), aluminium (<1 mg/L), ferric iron ($Fe^{3+}$) and sulfate (<1,500 mg/L). If these conditions are not met, precipitation of iron oxide/hydroxides, aluminium hydroxide hydrate and gypsum is likely to occur, causing armouring of the limestone and plugging of the void spaces within the drain.

### 4.8.5 Constructed Wetlands

Constructed wetlands are a form of passive system for treatment of acidic discharges that relies on a combination of physical, chemical, microbial and plant-mediated processes for amelioration of water quality. These include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms.

The key considerations when determining the type and size of a constructed wetland include:

- The influent water acidity load, pH and redox state.
- Water flow rates (including assessment of seasonal variability) and retention times.
- The area available for a wetland.
- Access requirements for ongoing monitoring and maintenance.

The main types of constructed wetlands are discussed in the following sections.

#### 4.8.5.1 Aerobic Wetlands

The main process undertaken within constructed aerobic wetlands is aeration of the water requiring treatment, which encourages dissolved iron to oxidise, precipitate and settle (Figure 4-5).

**Figure 4-5 Aerobic Wetland**

Aerobic wetlands can be described as shallow excavations (lined or unlined) filled with 300-900 mm of soil where shallow water (depths in the range of 100-300 mm) flows horizontally through planted vegetation. Plants are an important component of the wetland because they increase water retention time by preventing channelised flow, increase dissolved oxygen concentrations and have the potential to uptake some of the metals in the incoming waters.

Aerobic wetlands are usually designed with variable water depths to encourage plant community diversity and with a series of ponds (containing no plants) to allow settling of metal precipitates.

Because of the acidity generated by the hydrolysis of iron ($Fe^{3+} + 3\ H_2O \dashrightarrow Fe\ (OH)_3 + 3\ H^+$) and the increased toxicity associated with metal precipitates retained in the wetland, these systems are usually suited for treatment of mildly acidic or net alkaline waters with pH greater than 4.5 and low to moderate concentration of iron and other metals. Aerobic wetlands are often included as a final step in treatment processes containing other technologies, such as OLD or ALD, where they act as oxidation stages and/or settling ponds.

The size of the wetland is an important factor in the success of water treatment. Design must consider total acidity loads and water flow rates. General design criteria indicate iron removal rates of 10-20 g of $Fe/m^2/d$ and 0.5-1.0 g of $Mn/m^2/d$.

Because of large area requirements and limitations associated with available space, aerobic wetlands are often undersized, leading to inadequate retention times and poor effluent water quality.

#### 4.8.5.2 Anaerobic Wetlands

Anaerobic wetlands (also referred to as compost wetlands) have shallow water depths (in the range of 100 mm) and a thick permeable anoxic substrate (≥ 300 mm) comprising various forms of organic matter (Figure 4-6).

**Figure 4-6 Anaerobic Wetland**

As the water moves horizontally through the substrates, several microbial processes are enacted to neutralise acidity, generate alkalinity and remove metals from solution. These processes can be summarised in the following equations:

- $2CH_2O + SO_4^{2-} + 2H^+ \rightarrow 2\ CO_2 + H_2S + 2H_2O$

  (Reduction of sulphate to hydrogen sulphide, consuming protons i.e. acidity.)

- $2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO^{3-.}$

  (Reduction of sulphate to form hydron sulphide ($H_2S$), with generation of bicarbonate alkalinity.)

- $M^{2+} + H_2S + 2HCO^{3-} \rightarrow MS + 2H_2O + 2CO_2$

  (Reaction of a generic metal, $M^{2+}$, with $H_2S$ to form insoluble metal monosulphide.)

Wetland plants are usually incorporated in the wetland design, since they stimulate microbial processes and act as an organic carbon source; however, they may not survive in highly acidic environments. Limestone can be also be mixed with the organic material to increase generation of alkalinity. The presence of anaerobic conditions prevents or mitigates metal precipitation and armouring of the limestone.

Aluminium dissolved in the water entering the anaerobic wetland is poorly soluble at pH above 4.5 and generally precipitates on the top of the organic layer due to the increase of pH via sulfate reduction and limestone dissolution.

Because the effluent from an anaerobic wetland has low dissolved oxygen and potentially soluble metals in the reduced form, it is normal practice to add further treatment steps such as an aeration/settling pond or an aerobic wetland to oxygenate the water and remove residual iron concentrations. The acidity released by metal hydrolysis is compensated by the alkalinity added in the anaerobic wetland.

Since anaerobic wetlands produce alkalinity, they can be used to treat waters with net acidity (300-500 mg/L), low pH (around 4.0), high dissolved oxygen (> 2 mg/L) and moderate to high metal concentrations. Typical sizing guidelines for anaerobic wetlands are 3.5-7 $g/m^2\ d^{-1}$ (acidity) and 10 $g/m^2\ d^{-1}$ (iron).

#### 4.8.5.3 Reducing and Alkalinity Producing Systems

Reducing and alkalinity producing systems (RAPS) combine the benefits of ALDs and anaerobic wetlands. While many design variations are possible (i.e. vertical flow wetland, vertical flow ponds and vertical flow reactors), the basic concepts of RAPS are common and can be summarised as follows:

- Use mixtures of limestone and organic matter, combining organic and inorganic approaches to water treatment.
- Rely on alkalinity generation by dissolution of limestone and sulfate reducing bacteria activity.
- Promote reducing conditions in the water so that metal sulphide precipitation can occur and armouring of limestone is minimised.
- Provide sites for metal absorption in the organic matter layer.
- Raise the pH of water to near neutral conditions.

The type of RAPS selected for water treatment is generally dependent on site-specific conditions such as topography, available surface area for the treatment system, soils and geology, groundwater flows, etc., as well as the availability of resources for setting up and maintaining the treatment system. As a result, RAPS have been implemented in various forms, ranging from fully engineered constructions to relatively unmodified natural systems (Figure 4-7).

**Figure 4-7 Vertical flow wetland**

The main difference between a RAPS and an anaerobic wetland is that in a RAPS, water flows in a predominantly vertical manner, so that the interaction of water with organic matter and limestone is greatly increased. Underlying drainage pipes at the bottom of the RAPS convey the water into a settling pond or an aerobic wetland, where precipitation and sedimentation processes can take place before discharging the water to the receiving environment.

Because of the increased efficiency realised by vertical flow conditions, RAPS require less surface area compared to anaerobic wetlands (as little as 20% for the same degree of treatment). For influents containing significant quantities of ferric iron ($Fe^{3+}$) and/or sediment, vertical-flow systems should be preceded by either a settling pond or an aerobic wetland so as to limit accumulation of solids on the organic layer surface. For treating highly acidic discharges, several vertical flow cells can be placed in sequence, separated by settling ponds.

The drawback of RAPS is that the site must have sufficient natural relief to overcome the head losses associated with water flow across the organic layer and limestone (in the range of 1.5 m). Additionally, at least 1 m of freeboard is advisable on top of the organic layer (to guarantee sufficient driving head), so a minimum relief in order of 2.5 m is required to allow water flow without the need for active pumping.

General design guidelines for RAPS recommend limestone drainage layer thickness in the range of 60-100 cm, organic layer thickness in the range of 15-60 cm and loading rate of 25-30 $g/m^2 d^{-1}$ (acidity) with a 15 hours retention time in the limestone layer.

### 4.8.6 Aeration and Settling

Aeration (i.e. increase of dissolved oxygen concentration in water) and settling are used to collect treated or partially treated waters discharging from a range of passive treatment systems (such as OLDs, ALDs or RAPS) to promote oxidation, precipitation and settling of metals. In cases of net alkaline discharges containing high concentrations of iron where no further alkaline addition is needed, aeration and settling may be the only process required to achieve suitable treatment.

Aeration can be achieved by mechanical or chemical means. When topography and land availability allow, passive mechanical means (such as aeration cascades) are typically employed. Assuming aeration can achieve a dissolved iron concentration of 8 mg/L, a single aeration step is generally suitable for treatment of water with 30-50 mg/L of iron (based on stochiometric and efficiency considerations). If higher iron concentrations are present, successive aeration steps with settling units between them are required.

Settling for removal of metal precipitates can be achieved in settling ponds or clarifiers. Coagulants and flocculants may be required to assist the settling process in case of large flow rates and limitation of available land.

Available design recommendations for settling ponds include the following:

- Water residence time of 8-72 hours.
- The length-to-width ratio should be within the range 2:1 to 5:1, to help minimise possible streaming and short-circuiting.
- The depth of the pond should be in the range of 3 m to prevent resuspension of settled particles due to the horizontal velocity of water and / or wind.
- The most effective shape of ponds, from a hydraulic point of view, is rectilinear. However, amenity considerations may lead to less effective shapes requiring larger land area requirements than initial calculations would suggest.
- Sludge captured in the settling pond requires periodic removal (typically every few years) and is often a significant cost element in the long-term operation of this type of passive treatment system.

### 4.8.7 Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are subsurface structures filled with reactive material (i.e. organic matter/limestone or zero valent iron) that are designed to intercept and treat impacted groundwater (Figure 4-8). Organic material can promote bacterially mediated sulphate reduction, which results in generation of alkalinity and precipitation of dissolved metals in the form of sulfide precipitates within the barrier.

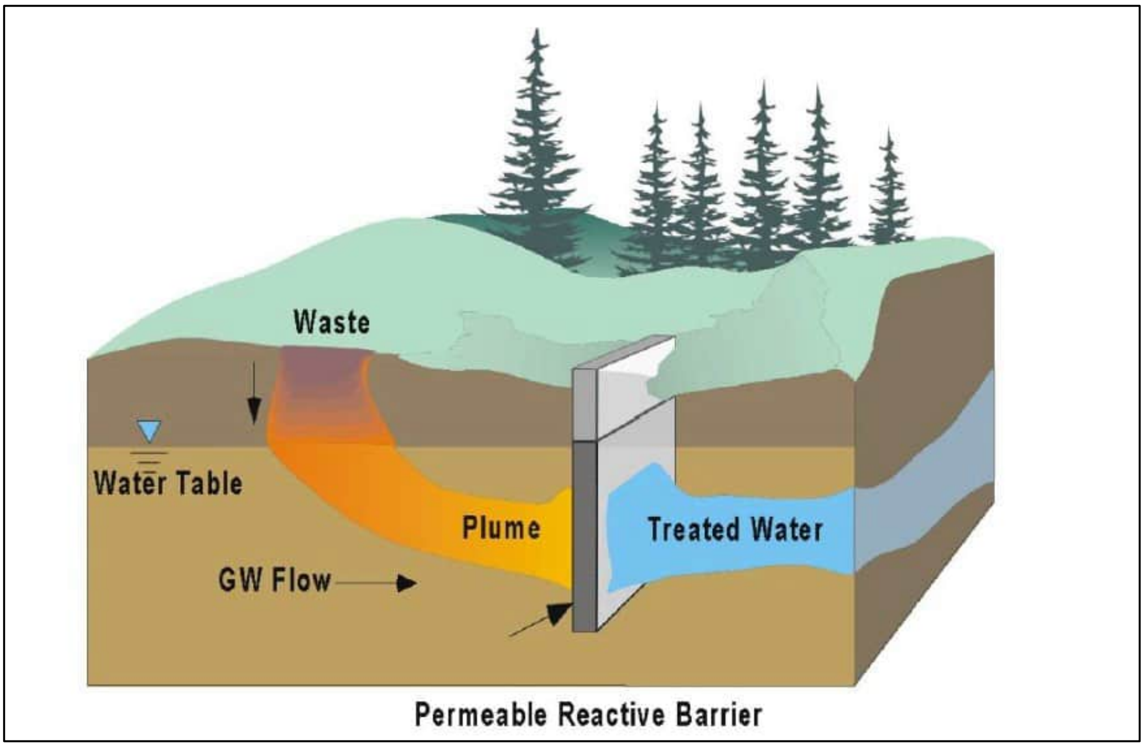


**Figure 4-8 PRB diagram (US EPA, 1998)**

The key factors that may limit the lifetime of PRBs are the mass of available reactive material and the available volume of pore spaces (and permeability) of the barrier. Metal precipitation and substrate compaction can result in a decrease in porosity and permeability of the barrier. Typical width of PRBs are between 1.4 – 4.0 m and residence times within 3 – 90 days.

## 4.9 Active Systems for Treatment of ASS Impacted Water

Active systems for treatment of acidic water discharges include physical, chemical and biological approaches that manage a broad range of influent characteristics, flow regimes and discharge criteria. The main processes employed by active systems include:

- pH control or precipitation.
- Electrochemical concentration.
- Biological mediation / redox control (sulphate reduction).
- Ion exchange / absorption or adsorption / flocculation and filtration.

Active systems can be classified as fixed plant (where the water requiring treatment is directed to a conventional water treatment plant) or in-stream (where portable active or passive systems perform the treatment within or adjacent to the affected water body).

### 4.9.1 Fixed Plant

For the purpose of this ROA, it is assumed that a fixed plant based on pH increase with inorganic alkaline amendments (calcium hydroxide or calcium oxide) followed by oxidation and sedimentation (by flocculation and clarification) would be used to treat water at the site. This general approach is one of the most widely applied for treatment of acid mine drainage worldwide because of its effectiveness and relatively low cost.

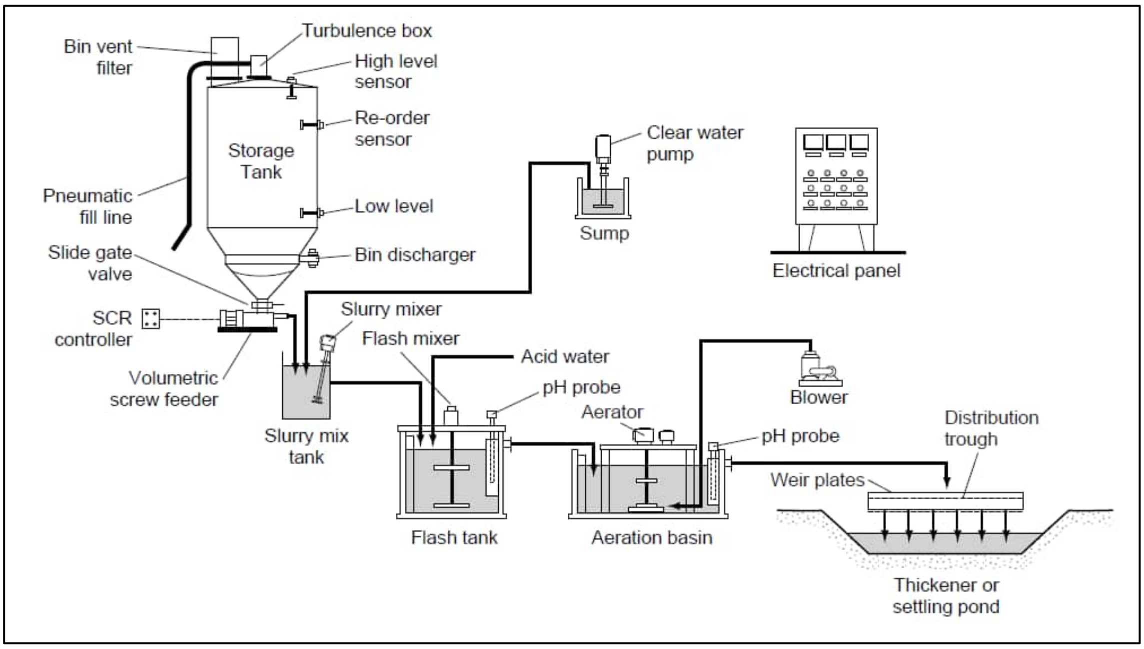


**Figure 4-9 Conventional water treatment utilizing lime. (Source: AMD Treat, US DoI)**

Despite the general concept behind the treatment process being relatively simple, numerous variations are possible depending on project-specific parameters and factors, including total suspended solids content, flow rate, iron/manganese concentrations, chemical costs, health and safety considerations and available land area.

### 4.9.2 In-stream Treatment

In-stream treatment systems generally use pH control/precipitation methods for the treatment of water by using small portable plants (manual, semi-automated or fully automated) with low capital costs. The common feature of these systems is the capability for storage and dispensing of alkaline reagents (such as calcium hydroxide or calcium oxide) in the water body requiring treatment (Figure 4-10).

Figure 4-10 In-stream dosing system

The main advantages of these systems are the limited requirements for power, reduced operation and maintenance intensity and flexible implementation. One of the main disadvantages is that direct dosing of alkaline reagents in streams or channels has the potential to transport metal precipitates downstream of the treatment location.

For the above reasons, in-stream treatment is generally only suitable for the following circumstances:

- Emergency response or other short-term treatment applications, where a large quantity of reagent needs to be dosed into a water body or stream over a short period of time.
- Long-term treatment applications, where a relatively low dose rate is required over an extended period.

## 4.10 Limiting Further Intervention

Limiting further intervention or adopting a range of targeted contingency measures may be an acceptable management strategy in particular cases.

The decision of limiting intervention and/or deferring broad scale management strategies is usually supported by a suitable set of monitoring data and a properly developed risk assessment process.

When a strategy of limited further intervention is being considered, the following steps should be undertaken to support the decision:

- Engage the stakeholders and community to explain the rationale behind the limited further intervention strategy.
- If necessary, refine the assessments of the risk to both adjacent ecosystems and landholders as a consequence of the decision not to take further action.

- Implement a monitoring and reporting regime to enable periodic review of the quality of affected aquatic ecosystem and connected waters.

## 4.11 General Considerations for Options Assessment

### 4.11.1 Active vs. Passive Systems

Advantages and disadvantages of active and passive treatment systems are summarised in Table 4-1

**Table 4-1 Comparison of Active and Passive Systems**

| System Type | Advantages | Disadvantages |
|---|---|---|
| Active | • Ability to meet high and variable flow rates<br>• Effective removal of contaminants from water<br>• Precise process control, such that they can be engineered and operated to produce a specific water chemistry<br>• Suitability in locations where only a small land area is available (however sludge capture may still require large land areas) | • High capital cost<br>• High ongoing O&M costs<br>• Power and other infrastructure requirements<br>• Loss of amenity values |
| Passive | • Overall treatment costs are less compared to an equivalent active system<br>• Less requirement for specialised operators<br>• Can enhance amenity values | • Relatively new technologies and lack of understanding of some relevant processes (i.e. sulfate reduction) and experience of long-term application<br>• Precise adjustment to change of influent quality and flow rates is not possible<br>• Performance of passive systems is subject to seasonal and other variations |

### 4.11.2 Inflow Water Characteristics

Figure 4-11 depicts acid load guidelines for selecting effective active and passive treatment systems. Contours shown are for acid loads in tonne $CaCO_3$/d.

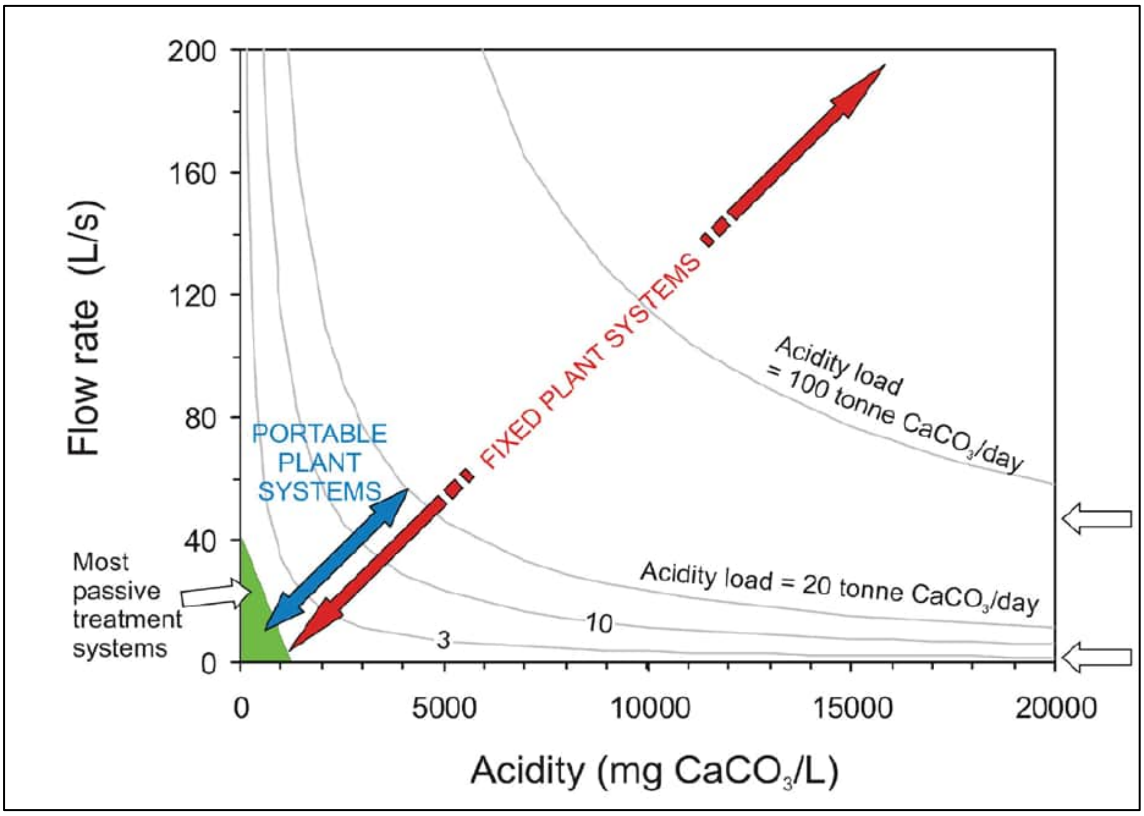


**Figure 4-11 Applicability Range of Active and Passive Systems (Taylor et al., 2005)**

The guideline indicates that passive systems are best suited to the treatment of waters with low acidity (<800 mg $CaCO_3$/L) and low acidity loads (100–150 kg $CaCO_3$ per day).

# Section 5 **Remediation Option Assessment Framework**

The framework for identification of the most suitable remediation option (or combination of options) for management of ASS impacts at the site has been developed in general accordance with the guidelines provided in the following publications:

- Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), National Remediation Framework, *Guideline on performing remediation options assessment,* Version 0.1 (August 2018).
- CRC CARE National Remediation Framework, *Guideline on performing cost-benefit and sustainability analysis of remediation options,* Version 0.1 (August 2018).
- EPA Victoria, Publication 840.2, *The cleanup and management of polluted groundwater*, February 2014.
- Government of Western Australia, Department of Environment Regulation, Contaminated Sites Guidelines. *Assessment and management of contaminated sites* (December 2014).
- UK Environment Agency, Contaminated Land Report 11, *Model Procedures for the Management of Land Contamination* (September 2004).
- Battelle Memorial Institute, *Guidance for Optimizing Remedy Evaluation, Selection, and Design*, (March 2010).
- Interstate Technology & Regulatory Council (ITRC), *Remediation Management of Complex Sites*, (2017).

## 5.1 Technology Identification

This task involved a comprehensive literature review for initial identification of a broad spectrum of available options for remediation of ASS impacts, based on CDM Smith's experience, published technology performance data and guidance from national and international sources.

The outcome of this task was identification of 17 remediation options (Section 5.1). Included in the identified options are the six remediation options previously identified in the Yeodene Swamp Study (Jacobs, 2018b), which are presented in this ROA with some modifications to their original inception to reflect the outcomes of the technical workshop, community meeting and feedback from the RWG Expert Panel.

## 5.2 Preliminary Screening

The purpose of this task is to restrict more detailed and site-specific assessment only to those options considered to be potentially feasible for the site. The preliminary screening was therefore conducted at a relatively high level considering the following parameters:

- Suitability of the technology to treat the ASS impacts at the site (i.e. consideration of relevant soil, surface water and groundwater parameters).
- Potential constraints associated with site morphology (i.e. presence or absence of steep inclines, land availability, etc.) and requirement for technology implementation.
- Assessment of likelihood of regulatory or community acceptance to the technology.

As part of preliminary screening, information on technology application, governing principles, typical performances, advantages and limitations were also collected and summarised to provide the basis for relative ranking of technologies performed as part of detailed assessment.

Following preliminary screening, seven remediation options were retained for detailed assessment.

## 5.3 Detailed Assessment

To support detailed assessment of the shortlisted technologies, the following steps were performed:

- Development of a high-level concept design for each retained option, using a range of site-specific data or general assumptions.
- Estimate of **relative cost** of each technology using publicly available data and software (AMDTreat v5.0.2 Plus) developed by the Pennsylvania Department of Environmental Protection, the West Virginia Department of Environmental Protection, the U.S. Geological Survey's (USGS) and the Office of Surface Mining Reclamation and Enforcement (OSMRE).
- Liaison with other technical consultants working on the project (Jacobs, GHD and Monash University) to obtain site-specific information on expected design requirements, performances and risks associated with each remediation option.
- Review of application national and international guidance for selection of suitable project-specific categories for the assessment of each option. The following set of six categories was considered to enable a broad assessment of the various facets associated with each option:
  - Technical
  - Logistical
  - Financial
  - Stakeholders
  - Timing
  - Sustainability
- Development of indicators for each category to assist with ranking the merits of each option. Ranking ranged from 1 (low/least preferable) to 5 (high/most preferable), according to the general guidelines provided in Table 5-1.

**Table 5-1 Ranking Guidelines**

| Category | Description | 1 | 3 | 5 |
|---|---|---|---|---|
| A – Technical | Ability of the technology to achieve the remediation objectives, considering nature, distribution and concentration of the contaminants and the site-specific geological and hydrogeological setting. | Not proven or outside recommended ranges for chemicals to be treated. Site specific conditions preventing or limiting effective implementation. | Proven effectiveness and within recommended ranges for chemicals to be treated. Several pilot scale trials required to develop detailed design. | Proven effectiveness and within recommended ranges for chemicals to be treated. Minimal pilot scale trials required prior to implementation. |
| B – Logistical | Practical considerations associated with implementation of the technology at the site. | Large footprint (>2 ha), complex access/organizational issues requiring engineering and administrative controls and high O&M intensity. | Medium footprint (<2 ha), access/organizational issues requiring administrative controls and medium O&M intensity. | Small footprint (<1 ha), limited access/organizational issues and low O&M intensity. |
| C – Financial | Relative cost of implementing the technology for a nominal 10-year timeframe | Fixed costs > $5 M<br>Ongoing costs > $100k/yr | Fixed cost $1 to $5 M<br>Ongoing costs $50k/yr to $100/yr | Fixed costs < $1 M<br>Ongoing costs < $50k/yr |
| D – Stakeholders | Likelihood of regulatory and community approval. | Unlikely to meet regulatory or stakeholder approval. | Standard level of permitting required and aligned with stakeholder's expectations. | Minimal permitting requirements and strongly supported by the community. |

| Category | Description | 1 | 3 | 5 |
|---|---|---|---|---|
| E – Timing | The envisaged timeframe required for the technology to meet the selected clean-up objectives. | More than 2-years for design and construction.<br>More than 5 years to realise relevant project objectives.<br>No source reduction, long treatment timeframes (>50 years) envisaged. | Between 1 and 2-years implementation time.<br>Between 1 and 5 years to realise relevant project objectives.<br>Some potential for source reduction potentially leading to shorter treatment timeframes (between 10 and 50 years). | Less than 1-year implementation time.<br>Less than 1 year to realise relevant project objectives.<br>Substantial source reduction short treatment timeframes (less than 10 years). |
| F - Sustainability | Includes consideration such as remediation hierarchy, use of resources, emissions and impacts on future generations. | High use of resources (chemical or natural), landfill space. High and/or non-recoverable impacts on the natural environment. | Moderate use of resources (chemical or natural), landfill space. Moderate impacts on the natural environment, likely to be recoverable. | Low use of resources (chemical or natural), landfill space. Low impacts on the natural environment. |

- Development of a weighting system to allow prioritisation of more categories that were considered more important for the project.
- Discussion on the proposed categories, indicators and weighting system as part of the 10 October 2019 workshop and the 23 October 2019 RWG meeting so that feedback from technical and community stakeholders could be incorporated in the ROA framework.
- Ranking of the indicators and calculating scores for each category. The scores were normalised to remove the effect of different numbers of indicators defined for each category (i.e. all the categories have the same weight regardless of number of indicators).
- The normalised scores for each option were then weighted and summed to assist with identifying preferred options for the site. Various permutations using different weights were performed to account for feedback from the community and for sensitivity analysis.
- Based on the outcomes of the previous steps, the preferred options were integrated to develop a strategy aimed at meeting the project objectives and fulfil the project vision.

Results of the ROA are provided in the following sections.

# Section 6 **Preliminary Screening**

## 6.1 Identification of potentially applicable remediation options

Table 6-1 presents a summary of the 17 remediation options identified for preliminary screening and provides the following information:

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

**Table 6-1 Remediation Options Identified for Preliminary Screening (Options from Yeodene Swamp Study (Jacobs, 2018b) listed first)**

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O1 | True 'do nothing' | Limited further intervention | This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018b).<br>During the first technical workshop, it was agreed that a true 'do nothing' approach should reflect historical conditions and management practises at the site, which include the following:<br>• Supplementary flow not passed entirely at McDonalds Dam<br>• Continued presence of existing drainage channels across Big Swamp<br>• Water users along Reach 3 of Boundary Creek unable to access water allocation during periods of 'no flow'<br>• Unlikely recovery of groundwater levels in the LTA aquifer to pre-pumping conditions in the short term (i.e. 5 years) | • Lowest financial cost | • High socio-environmental cost<br>• Does not satisfy notice requirements. | • It is unlikely that a 'do nothing' approach will meet any of the project objectives. |
| O2 | Implementation of contingency measures | Limited further intervention | This is a slightly modified version of the original 'do nothing' option presented in the Yeodene Swamp Study (Jacobs, 2018b).<br>During the first technical workshop, it was recognised that a range of contingency measures have been identified to ameliorate some of the issues associated with historical conditions at the site. These contingency measures include:<br>• Minimum supplementary flow of 2 ML/d passed entirely at McDonalds Dam (already implemented)<br>• Infilling of existing drainage channels across Big Swamp (potentially applicable)<br>• Construction of a water pipeline to provide water to users along Reach 3 of Boundary Creek (to be implemented)<br>• No interim pumping from the LTA until the s78 notice is lifted. | • Low financial cost<br>• Provides water security to water users downstream of Big Swamp. | • High socio-environmental cost<br>• Does not satisfy notice requirements. | • It is unlikely implementation of the planned contingency measures will meet all of the project objectives.<br>• The aim of considering this option is to provide a baseline assessment of future trajectory of environmental outcomes for the Big Swamp, Boundary Creek and Barwon River in consideration of a range of existing/potential contingency measures implemented or to be potentially implemented at the site (i.e. in addition to the remediation options). |

| | | | | | | |
|---|---|---|---|---|---|---|
| O3 | Direct treatment of soils with neutralising agents (wetland liming) | Treatment to neutralise acidity (soil and water) | This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages spreading of agricultural lime (or other suitable neutralising agent) over all or a part of Big Swamp to neutralise acidity of the upper soil profile as wells as increasing pH and alkalinity of the water leaving Big Swamp and discharging into Boundary Creek.<br>Once the areas requiring treatment and the treatment rate (expressed as mass of neutralising agent per unit area) have been evaluated, a variety of implementation methods are possible, including terrestrial and aerial applications. | • Effective duration longer compared to in-stream liming methods; in some cases, effects last 10 to 20 years.<br>• Lower amount of metals including aluminium is expected to be exported to streams. Also expected to result in less aluminium precipitate on stream bottom compared to other stream liming methods. | • Clearing of vegetation for construction of access tracks in case of terrestrial application over the entire swamp area.<br>• Impacts of the neutralising agent on the terrestrial and aquatic ecosystems sensitive to rapid pH change from direct application to plant (i.e. leaf scorching) or indirectly through soil and pore water chemistry changes.<br>• Grain diameter of the neutralising agent must be evaluated to minimise potential for downstream transport during high rainfall events, which may cause uneven coverage of the treatment area.<br>• Metal precipitation in Boundary Creek associated with increased surface water pH. | • Terrestrial applications (i.e. using truck mounted equipment, pressure hose for slurry applications or manual spreading) are likely to be challenging because of access constraints and soft consistency of the soil across Big Swamp.<br>• Aerial application by helicopter is likely to overcome some of the logistical constraints related to terrestrial applications, however, will incur increased costs and results in less control on application to understorey leading to increased risk of damage to vegetation.<br>• This technology is generally more effective when application of the neutralising agent is targeted at water discharge areas (i.e. areas of high groundwater levels during periods of high rainfall) compared to uniform application over the entire swamp area.<br>• Compared to surface water liming, this technology generally provides more sustained treatment timeframes, requiring less frequent applications.<br>• Because dissolution and penetration of the neutralising agent is associated with rainfall (amongst other factors), this method is generally less suitable for dry and severely acidified environments. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O4 | Oxic (aerobic) limestone drain (OLD) | Treatment to neutralise acidity (water) | This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages construction of an open drain channel filled with limestone (or other suitable material) downstream of Big Swamp to improve quality of Boundary Creek water (i.e. increase pH/alkalinity and decrease dissolved metals concentration).<br>Key design parameters of OLDs are mass and size of the limestone aggregate, slope of the drain and water residence time (in the range of several hours).<br>The slope of the drain is inversely proportional to residence time, however higher slopes increase OLDs' efficiencies by limiting the potential for metal precipitation on the surface of the aggregate (armouring). Armouring reduces limestone pore space and surface area, decreasing the limestone dissolution rate and acid neutralising capacity. | • Low cost<br>• Simple implementation | • Armouring of the alkaline materials caused by metal precipitation has the potential to be detrimental to efficiency and longevity of the limestone drain.<br>• Ongoing maintenance is required to ensure treatment efficiency is maintained over time.<br>• Depending on quality (i.e. pH, metal and anion/cation concentrations) of the water leaving the OLD, a settling pond may be required for collection of precipitates prior to discharge in Boundary Creek. | • Construction of an OLD (and potentially settling pond) with adequate slope and residence time to treat Boundary Creek water is likely to impact on the following:<br>– Hydrological and hydrogeological regime of Boundary Creek (Reach 2/Reach 3) and Big Swamp.<br>– Amenity and natural environment of Big Swamp and Reach 3 of Boundary Creek.<br>• Large excavations required for construction may disturb ASS |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O5 | Dilution of acidic discharge | Treatment to neutralise acidity (water) | This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages provision of additional water volumes (i.e. in addition to the supplementary flow of 2 ML/d released upstream of McDonalds Dam as part of the contingency measures) to improve water quality in Boundary Creek.<br>Implementation of this option will require construction of a dedicated water infrastructure and identification of a sustainable source to supply water in the long term (this option does not address generation of acidity in Big Swamp, which will continue).<br>The Yeodene Swamp Study (Jacobs, 2018b) assumes that the additional water volumes will be delivered through McDonalds Dam. However, to increase effectiveness and minimise potential side effects to natural environments downstream of the release point, the additional water volumes could also be delivered downstream of Big Swamp (i.e. in the upper reaches of Reach 3 of Boundary Creek).<br>While not mentioned in the Yeodene Swamp Study (Jacobs, 2018b), the additional water may also be amended with neutralising agent to increase pH/alkalinity and therefore volumetric requirements. | • Relatively simple implementation<br>• Can be readily implemented and used as seasonal relief to downstream water quality in Boundary Creek particularly during higher acid loads times or events. | • Geochemical modelling conducted as part of the Yeodene Swamp Study (Jacobs, 2018b) indicates that, using low alkalinity additional water, significant volumes are required to improve the quality (i.e. reduction of metal concentration and increase of pH) of Boundary Creek water.<br>• The water volumes required to achieve dilution of acidic discharge are not available in the region and could potentially trigger water management issues in other parts of Victoria.<br>• Deliveri of significant volumes of additional water is likely to have significant impacts on the hydrology, hydrogeology and natural environments downstream of the delivery point, which will require detailed assessment to support detailed design and implementation of this option. | • Addition of neutralising agents to the additional water (by construction of an automated dosing station) is likely to reduce the volumes of water required to improve water quality at Boundary Creek.<br>• A settling pond will be needed downstream of the water delivery point to capture metal precipitates. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O6 | Water flow diversion and Big Swamp isolation | Reduce export of existing acidity | This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages isolation of Big Swamp (source of acidity) and diversion of Boundary Creek flow so that the swamp is by-passed and transport of acid drainage to Reach 3 of Boundary Creek is minimised.<br><br>Implementation of this option would require building a channel so that water flowing into Boundary Creek does not disperse into Big Swamp, as well as construction of a series of impermeable structures to prevent groundwater within the alluvial swamp sediment to discharge into Reach 3 of Boundary Creek.<br><br>Additional water retention structures may be also required to minimise risks of acid flushes from Big Swamp into Reach 3 of Boundary Creek. | • This option could be effective in improving water quality in Boundary Creek by breaking the pathway between source (Big Swamp) and downstream environments. | • This option is likely to have significant impacts on the hydrology, hydrogeology and natural environments of Boundary Creek (Reach /Reach 3) and Big Swamp, which will require detailed assessment to support detailed design and implementation of this option.<br>• Implementation of this option, in the absence of contingency measures, has the potential to worsen intensity of 'acid flushes' associated with drying and wetting cycles.<br>• Dryer conditions across Big Swamp will also increase fire risks. | • This option is likely to severely impact on the natural environment of Big Swamp, which is likely to dry out further and continue to generate acidity. It is therefore considered that this option is unlikely to gain stakeholder's approval unless:<br>– A water retention system and artificial water recharge are implemented so that surface water and groundwater levels can be maintained at acceptable conditions across Big Swamp;<br>– It is demonstrated to be the only alternative to manage acid discharges to Boundary Creek and Barwon River;<br>– The community agrees that Boundary Creek and Barwon River are of higher value compared to Big Swamp. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O7 | Flooding of Big Swamp (natural anaerobic wetland) and managed groundwater levels | Treatment to neutralise acidity (water) and prevent (further) oxidation | This option was included in the Yeodene Swamp Study (Jacobs, 2018b) and envisages flooding of Big Swamp to create permanently waterlogged areas where microbially mediated iron reducing and sulfate reducing reactions have the potential to increase alkalinity, raise pH and remove dissolved metals by precipitation.<br>For sulfate reduction reactions to occur, the following conditions must be realised in the re-flooded portions of Big Swamp:<br>• A permanent water coverage having enough depth to maintain generally anaerobic conditions within the water column.<br>• Presence of a bioavailable organic carbon source (electron donor).<br>• pH between 5 and 8.<br>• Presence of sulfate and low concentration of competing electron acceptors such as nitrate ($NO_3^-$), manganese ($Mn^{4+}$) and ferric iron ($Fe^{3+}$).<br>Implementation of this option envisages the following steps:<br>• construction of water retention structures (likely to be located at the downstream side of Big Swamp) to realise a permanent water coverage across a significant portion of Big Swamp.<br>• infilling of existing drainage channels across Big Swamp to assist with water retention.<br>• supply of additional water volumes to achieve the required permanent water coverage.<br>• supply of additional organic carbon source (and potentially sulfate) in case of deficiencies of these elements in the natural environment.<br>In addition to promoting favourable geochemical conditions to neutralise acidity, this option would aim to maintain or increase groundwater levels in the Big Swamp alluvium aquifer to prevent or minimise further oxidation of ASS sediments. | • Reversal of iron sulfides oxidation processes.<br>• Minimise further oxidation.<br>• Relatively low cost.<br>• Barrier installation is a proven technology and can be supported by adequate modelling. | • The delivery of supplementary flow to maintain waterlogged conditions and higher groundwater levels will result in increased surface water flow in Big Swamp, which has the potential to enhance mobilisation and downstream transport of acidification by-products accumulated in near-surface sediments.<br>• Preliminary results from laboratory incubation work from Monash University and GHD geochemical modelling suggest that there is a risk that the soluble ferrous iron generated under reducing conditions will not precipitate in Big Swamp and will be transported downstream in Boundary Creek (refer to Section 7.3.6.3.2 for additional details).<br>• Visual amenity will be impacted because vegetation not tolerant to higher groundwater levels or permanently waterlogged conditions is likely to retreat or die following inundation of Big Swamp. | • Groundwater and surface water modelling are required to assist in assessment of the following technical aspects associated with this option:<br>– availability of additional water volumes to be delivered to Big Swamp to achieve the required minimum groundwater levels.<br>– extent and location of the water retention structures required to maintain groundwater at the desired levels.<br>– potential impacts to hydrological and hydrogeological regime of Boundary Creek upstream and downstream of Big Swamp.<br>• Geochemical modelling is required to assist with assessment of nature and rate of reactions that may be triggered by inundation of Big Swamp and the potential for mobilisation of acidity (both existing and as a consequence of iron reduction). |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O8 | Soil excavation/ treatment and rehabilitation | Treatment to neutralise acidity (soil) | This option involves excavation and removal of the oxidised ASS sediments within Big Swamp, which are treated (or disposed) according to EPA Victoria ASS management guidelines.<br>Construction of access tracks and significant removal of vegetation will be required to implement this option. The excavation is likely to be progressed as separate cells to minimise potential exposure of non-oxidised sediments to oxygen.<br>Following removal of the oxidised sediments, lime would be added at the base of the excavations to neutralise potential future acidity generation and then the excavation would be backfilled with suitable imported fill.<br>After remediation and backfilling, the site would be landscaped and revegetated to resemble the original character of Big Swamp. | • Could effectively remove the source of acidic discharges into Boundary Creek and Barwon River<br>• The extent of excavation areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed.<br>• Based on a comparison of aerial images captured since 2010 (when the majority of Big Swamp vegetation was severely affected by a fire), it appears that low lying vegetation would re-establish within 3 to 5 years after re-planting. | • The soft consistency of the soil across Big Swamp is likely to pose significant logistical constraints to implementation of this option.<br>• Irrespective of the extent of excavations, implementation of this option will severely impact on the natural environment of Big Swamp and the hydrological/ hydrogeological regime of Boundary Creek.<br>• This option is the less likely to achieve rehabilitation of the site to its original values. However, removal of acid generating sediments within Big Swamp is likely to be an effective solution to reduce acid impacts to the waters of Boundary Creek and Barwon River.<br>• | • This option is the least preferred approach based on EPA Victoria ASS management hierarchy.<br>• It is considered that this option is unlikely to gain stakeholders approval, **unless**:<br>– It is demonstrated that removal of oxidised sediments is the only alternative to manage acid discharges to Boundary Creek and Barwon River;<br>– The community agrees that Boundary Creek and Barwon River are of higher value compared to Big Swamp;<br>– Remediation of Big Swamp to a satisfactory 'engineered end-point' as opposed to rehabilitation to some of its original values is an acceptable outcome for the project. |
| O9 | Soil mixing | Treatment to neutralise acidity (soil) | This option involves the use of a large diameter (one to three metres) hollow-flight auger fitted with special mixing 'paddles' (or other suitable device) to achieve mixing of a neutralising agent with the oxidised sediments in Big Swamp.<br>Construction of access tracks and significant removal of vegetation will be required to implement this option.<br>Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require to be rehabilitated through landscaping and planting of vegetation. | • Compared to surface liming, this option has the potential to achieve effective neutralisation of oxidised ASS sediments at depth.<br>• The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed. | • The soft consistency of the soil across Big Swamp is likely to pose significant logistical constraints to implementation of this options. | • If applied on a large scale, this option will severely impact on the natural environment of Big Swamp although would be less than Option 8. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O10 | Alkaline slurry injection | Prevent (further) oxidation and treatment to neutralise acidity (soil) | This option involves injection of a slurry composed of alkaline and impermeable materials to minimise oxygen infiltration and neutralise acidity. Depth of application would be typically to the top of the unoxidized ASS in Big Swamp.<br>Construction of access tracks and significant removal of vegetation will be required to implement this option.<br>Following treatment of the oxidised sediments, the disturbed sections of Big Swamp will require rehabilitation through landscaping and planting of vegetation. | • Compared to surface liming, this option has the potential to achieve effective neutralisation of oxidised ASS sediments at depth.<br>• The extent of treatment areas could be minimised by developing a high-resolution characterisation of the spatial extent of oxidised sediments within Big Swamp, so that a more targeted approach can be developed. | • Same considerations as Option 9 'Deep soil mixing'.<br>• Additionally, soil heterogeneity could limit the ability to achieve uniform distribution of the injected amendments. | • If applied on a large scale, this option will severely impact on the natural environment of Big Swamp, although would be relatively less than Option 8 and Option 9. |
| O11 | In-stream limestone sand | Treatment to neutralise acidity (water) | This option involves placement of limestone sand (or other suitable neutralising agent) directly in the streambed of Boundary Creek.<br>The sand is carried into the stream during high flow periods where it dissolves releasing alkalinity and increasing pH. | • No maintenance, simple, and relatively inexpensive. | • Water quality improvement may be inconsistent.<br>• Effectiveness diminishes with time. Limestone sand must be applied repeatedly, usually at least once per year.<br>• Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH. | • Unlikely to be effective, considering the limited flow and gentle slopes of Boundary Creek, limiting the potential for downstream transport of the neutralising sand. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O12 | Active treatment system | Treatment to neutralise acidity (water) | This option involves installation of an active treatment system to treat water quality in Reach 3 of Boundary Creek.<br>The system would be installed at the downstream end of Big Swamp and will comprise a range of equipment (i.e. tanks, mixers, pumps) to dose dry or liquid chemicals in the Boundary Creek water to increase alkalinity/pH and remove metals (by precipitation and settling).<br>Depending on system configuration and design parameters, precipitation of metals could be achieved in a settling pond or above ground clarifiers. | • Compared to passive systems, active systems are better suited to manage high acid loads, high flows and variability in acid loads. They also require a smaller footprint compared to passive systems. | • Disadvantages of active systems include:<br>– higher capital and ongoing costs;<br>– infrastructure requirements (power, water, access roads, etc.);<br>– potential generation of large volumes of low-density sludges requiring management;<br>– potential acquisition of land to operate system;<br>– effects on amenity (noise, visual impacts, etc.). | • An in-stream systems could be used to treat Boundary Creek water, and off-set some of the disadvantages associated with fixed plant systems. |
| O13 | Limestone diversion wells | Treatment to neutralise acidity (water) | This option envisages that a portion of the flow in Boundary Creek downstream of Big Swamp is diverted into a series of limestone-filled wells to increase alkalinity/pH and precipitate metals.<br>Following treatment, the flow is diverted back into Boundary Creek. | • Typical pH increases are about ½ to 2 units during average flows.<br>• Multiple diversion wells can be installed to increase effectiveness. | • Typically, this option is suitable for treating small flows and likely to fail in cases when a stream has a variety of flow regimes during the year.<br>• High maintenance (weekly to biweekly) is required.<br>• Metals such as Al and Fe are likely to precipitate downstream of the application point because of the increased pH. | • Unlikely to be suited for site conditions. |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O14 | Anoxic limestone drains (ALD) and settling pond | Treatment to neutralise acidity (water) | This option envisages construction of a buried drain lined with impermeable material, filled with limestone (or other suitable neutralising agent) and covered by impermeable materials.<br>The water seeping downstream of Big Swamp is diverted into the limestone (to maintain saturated conditions and anoxic conditions) where dissolution of the limestone increases alkalinity and pH.<br>Low oxygen conditions in the ALD would prevent precipitation of metals and armouring issues.<br>The water leaving the ALD is then directed into an aerobic settling stage where metals are precipitated and removed from the water. Removal of metal precipitates (sludges) i required at periodic intervals. | • Increases efficiency of other treatment types. For example, anoxic limestone drains can be used to pre-treat water prior to entering a wetland system.<br>• ALDs can also be used as a post-treatment system to add additional alkalinity. | • Water pre-treatment may be required prior to the ALD to remove dissolved oxygen and generate reducing conditions to promote conversion of ferric iron ($Fe^{3+}$) to ferrous iron ($Fe^{2+}$).<br>• The infrastructure required for precipitation and settling of metals (i.e. settling tank, engineered section of Boundary Creek or settling pond) is likely to impact on the natural environment of Big Swamp and Reach 3.<br>• Anoxic condition in the drain are likely to reduce issues associated with iron armouring of alkaline materials.<br>• Variable alkalinity output.<br>• Effluent pH difficult to maintain over time.<br>• Treatable effluent limited to low oxidised metal concentrations (aluminium and ferrous iron) and low dissolved oxygen. | • High concentration of Al (i.e. >25 mg/L) in the water requiring treatment will form floc in the ALD, progressively reducing its permeability and efficiency.<br>• Large excavations required for construction may disturb ASS |

| ID | Technology | Principle | Site Implementation | Advantages | Disadvantages | Key Issues |
|---|---|---|---|---|---|---|
| O15 | Constructed aerobic wetland | Treatment to neutralise acidity (water) | Construction of an aerobic wetland to remove metals by oxidation and hydrolysis. | • Relatively inexpensive.<br>• Lower maintenance than active treatment systems.<br>• Can improve amenity. | • Metal removal efficiencies vary because pH is seldom constant.<br>• pH decreases as metals are removed.<br>• Land area required must be large.<br>• Limited useful life. Substrate becomes saturated with metals and must be replenished or replaced. Most are constructed within a 15-to 25-year lifetime. | • This option is generally suited for water streams that are slightly alkaline, with a pH greater than 5.5 pH units and contain low to moderate concentrations of metals.<br>• These conditions are unlikely to be realised by the Boundary Creek waters downstream of Big Swamp.<br>• Large excavations required for construction may disturb ASS |
| O16 | RAPS (reducing and alkalinity producing systems) | Treatment to neutralise acidity (water) | Construction of a vertical flow anaerobic wetland to increase alkalinity, raise pH and remove metals by precipitation of insoluble hydroxides, carbonates and sulfides.<br>The anaerobic wetland comprises an organic-rich substrate at the top, a layer of limestone at the bottom and a drainage system. The wetland is constructed within a watertight basin and water flowing from the top across the organic layer and the limestone layer is collected by the drainage system and released into an aerobic settling pond.<br>Alkalinity is generated by microbial process in the organic layer (if sulfate is available) and through dissolution of the limestone.<br>An aeration and settling stage may be required prior to discharge to increase oxygen and promote precipitation of residual dissolved metals. | • Area required for RAPS is relatively small compared to other passive systems.<br>• Treat poorer quality water compared to passive systems. | • Drainage system limited by high concentrations of aluminium and ferric iron.<br>• Noxious odour (hydrogen sulfide) produced in vicinity of the system.<br>• Risk of people or animal drowning. | • The construction of an anaerobic wetland is likely to impact on the natural environment of Big Swamp and Reach 3.<br>• Large excavations required for construction may disturb ASS |
| O17 | Permeable reactive barrier | Treatment to neutralise acidity (groundwater) | Construction of permeable reactive barriers in Big Swamp (perpendicular to groundwater flow direction) to intercept and treat acidic groundwater. | • Relatively low maintenance and installation costs.<br>• Ability to treat a range of contaminants. | • Construction of a permeable reactive barrier is likely to have some impact on the natural environment of Big Swamp.<br>• Clogging and periodic removal of barrier material will be required. | • The ability of permeable reactive barriers to ameliorate water quality in Boundary Creek depends on the acid load associated with groundwater.<br>• Excavations required for construction may disturb ASS |

## 6.2 Technology Screening

Based on the information presented in Table 6-1, the following remediation options **have not been carried forward** for detailed assessment:

- **O1 - Do nothing**. The main reasons for removing this remediation option is the likely inability of meeting any of the project objectives based on magnitude and inferred persistence of acid generating processes within Big Swamp. This option would also fail to meet the requirements of the Section 78 Notice.
- **O2 - Contingency measures**. This option comprises implementation of various contingency measures including efficient delivery of a supplementary flow of 2 ML/d to Boundary Creek downstream of McDonalds Dam, infilling of key drainage lines across Big Swamp and construction of a water pipeline to water users along Reach 3 of Boundary Creek. Because the contingency measure of most relevance to the ROA (i.e. provision of 2 ML/d supplementary flow) has already been implemented, this option is removed from detailed assessment and used as a baseline to compare the other options.
- **O4 - Oxic limestone drain.** This option was removed because the concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. Armouring of the limestone aggregate caused by metal precipitates is likely to impact on the long-term effectiveness of the OLD. The relatively gentle slopes of the site do not provide favourable conditions for installing the OLD with the recommended 20% gradient that is indicated as one of the main design factors to limit the severity of armouring issues. In addition, an OLD constructed in accordance to the recommended design water retention time of 3 hours, will require approximately 310 $m^3$ of limestone aggregate (assuming a porosity of 40%) for each ML/d of water requiring treatment, equivalent to an open channel 5 m wide, 1 m deep and 60 m long. It is considered that such a structure (refer to Figure 4-3 for an example of an actual OLD) will impact on the visual amenity of the area downstream of Big Swamp.
- **O5 - Dilution of acidic discharges.** This option is removed because of the large water volumes (estimated by Jacobs in the range of 60-250 ML/d depending on flow conditions) required to achieve effective dilution of acidity and acidity impacts in Boundary Creek. It is considered that sourcing and delivery of such volumes of dilution water would be impracticable, unlikely to be accepted by the authority (dilution for management of contamination is usually considered an unacceptable management practise by EPA Victoria) and a risk of impacting on water availability in other parts of Victoria.
- **O6 - Water flow diversion and Big Swamp isolation**. This option is removed because of the technical challenges associated with providing an effective hydraulic barrier to prevent acidic discharges from Big Swamp to the surrounding receiving environments and the additional impacts to Big Swamp caused by further declines of surface water and groundwater water levels that are likely to eventuate as a result of decreased inflows into the swamp. The progressive acidification of Big Swamp and the drier environment caused by hydraulic isolation will also increase fire risk and potential for episodic and high intensity ‘acid flushes’ in case the integrity of the barrier is compromised during high rainfall events. It is also unlikely that this option would gain regulatory approval and/or community support.
- **O10 – Alkaline slurry injection**. This option is removed because a generally equivalent option (soil mixing) has been retained for detailed assessment. Soil mixing was retained over slurry injection because it is considered to be easier to implement in consideration of the high liming rates required to neutralise ASS in Big Swamp, the low hydraulic conductivity of the majority of the alluvium sediments in Big Swamp and the potential for preferential pathways to affect homogeneity of treatment.
- **O10 - In-stream limestone sand**. This option has been removed because during periods of low flow the limestone sand is unlikely to be transported downstream in Boundary Creek, resulting in low consistency of this technology in managing water quality impacts. In addition, a generally equivalent option (active treatment) has been retained for detailed assessment which has the advantage of providing more consistent outcomes in terms of treatment efficient and water quality results.

- **O13 - Limestone diversion wells**. This option has been removed because the high concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. In addition, limestone diversion wells require a very high O&M intensity (i.e. weekly) to maintain system efficiency and replacement of the limestone aggregate.
- **O14 - Anoxic limestone drain.** This option has been removed because the concentrations of iron and aluminium in the water requiring treatment (Section 7.1) are outside of the recommended range for this technology to be suitable. In addition, the high retention times required for effective limestone dissolution (in the range of 13 hours) generally require construction of large structures. For example, an ALD designed to treat 4 ML/d of impacted water would typically be 1.5 m deep (1 m of limestone and 0.5 m of impermeable cover), 5 m wide and 1,000 m long (assuming limestone porosity of 40%). It is considered that construction and ongoing maintenance of such a structure downstream of Big Swamp would be impracticable.
- **O17 - Permeable reactive barrier.** This option has been removed because the surface water and groundwater modelling results provided by Jacobs appear to indicate that groundwater discharges into Reach 3 of Boundary Creek account only for a small proportion of the total flow (i.e. less than 0.3 ML/d, refer to Section 7.3.6.3.1) and therefore groundwater transport does not significantly contribute to acidic impact to Boundary Creek.

The following remediation options have been retained for detailed assessment:

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

Detailed assessment of the above remediation options is discussed in Section 7.

# Section 7 **Detailed Assessment**

## 7.1 Input Parameters

Input parameters supporting development of the retained remediation options are summarised in Table 7-1.

**Table 7-1 Summary of Input Parameters**

| Parameter | Adopted Value | Justification |
|---|---|---|
| **Soil parameters** | | |
| Wetland area | 11 ha | Based on review of aerial image. |
| Average soil net acidity | 5 % as S | Based on average existing and potential acidity results from borehole samples collected within Big Swamp (Figure 3-16) (Jacobs, 2019a). |
| Average depth of soil to be treated | 2 m | Based on measured depth to groundwater and average existing and potential acidity results from borehole samples collected within Big Swamp (Figure 3-16) (Jacobs 2019a). |
| **Water parameters** | | |
| Treatment flow rate | 4 ML/d | About half the average daily flow at Yeodene gauge (233228) (Jacobs, 2018b). |
| Acidity | 500 mg/L $CaCO_3$ | Based on May-17 and August-17 surface water quality data (Jacobs, 2018b). |
| Acidity load | 2,000 kg/d | Product of treatment flow rate and acidity. |
| Total Iron | 28 mg/L | Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b). |
| $Fe^{3+}$ / $Fe^{2+}$ | Variable | Both ferrous and ferric iron are soluble in water at low pH (<3.5). Relative proportion depending on water redox conditions, with reducing conditions leading to an increase of ferrous iron ($Fe^{2+}$) and oxidising conditions leading to an increase of ferric iron ($Fe^{3+}$). |
| Aluminium | 75 mg/L | Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b). |
| Sulfate as $SO_4$ | 700 mg/L | Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b). |
| Manganese | 0.15 mg/L | Based on May-17 surface water quality data (low flow period) (Jacobs, 2018b). |
| Dissolved oxygen | 7 mg/L | Based on Austral surface water monitoring results (site 5 and site 5.5, October 2019) (Austral, 2019). |
| pH | 4 units | Based on Jacobs' Big Swamp report (Jacobs, 2018b). |

## 7.2 Methodology for Estimate of Relative Costs

The methodology adopted to estimate relative costs of the preferred remediation options is summarised below.

- Use of the AMDTreat software (USA written) to assist in developing sizing parameters and cost estimate. The software uses a 3-step approach to calculate a treatment cost:
  - The user enters water quality and quantity data (Table 7-1)

  - The user enters an active and/or passive treatment system by selecting the applicable treatment components from the software menu. Cost components include capital costs, ancillary costs (i.e. settling ponds, roads, land access, engineering costs) and annual costs (i.e. sampling, maintenance, pumping, chemical and sludge removal).
  - The user customises each treatment system to site-specific conditions by controlling the size, quantity, and unit cost of treatment system components.
- Because only **relative cost estimates** are required for the purpose of the ROA, several cost unit rates were maintained as per software default values to maintain consistency. However, specific cost unit rates were adjusted to Australian conditions in case they represented a significant component of the total cost (for example sludge disposal costs).
- Cost unit rates not provided in the AMD treat software (i.e. soil disposal cost) were assumed based on our understanding of local market conditions.
- Engineering cost (typically including cost for detailed design) were assumed to be as 20% of capital costs and baseline O&M cost were assumed to be as 3.5 % of capital costs. Budgetary allocations in addition to baseline O&M allowance were also included for some remediation options (i.e. installation of an active groundwater system) where it was considered that additional O&M expenditures were likely to be required.
- Sampling costs were estimated only in relation to activities specifically associated with implementation of each remediation option (i.e. they did not include broader surface water and groundwater monitoring activities already being undertaken as part of the Section 78 Notice requirements).
- No estimate was included for additional works such as tendering, construction quality assurance/quality control, permitting and principal contracting.
- No cost estimate was included for provision of supplementary flows as part of contingency measures (2 ML/d), building of roads to improve access at the site and delivery of infrastructures (i.e. power, water, etc.).
- Additional specific cost assumptions and exclusions are detailed in the description of each of the preferred remediation options.
- An exchange rate of 1.45 USD/AUD (current as of 5 December 2019) was assumed to convert cost outputs from AMDTreat (provided in US dollars) to Australian dollars.

## 7.3 Concept Designs of Retained Options

The following sections provide additional detail on concept designs for the retained remediation options, including the following:

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

**The concept designs have been undertaken based on a range of assumptions and a review of draft reports from Jacobs, Monash University, GHD and Eco Logical. These reports are based on a limited set of soil, surface water and groundwater data, leading to use of conservative assumptions and considerable uncertainty in the predicted results, particularly with respect to temporal variability of the hydrogeochemical system.**

**Consequently, the information provided in the following sections should be used with caution and only to inform relative decisions on the preferred remediation options (or combination of options) required to achieve the project objectives. Planning, design and budgeting of the preferred remediation option (or combination of options) should be reviewed and updated as more relevant information on site conditions and technology performance are obtained.**

### 7.3.1 Wetland Liming

#### 7.3.1.1 Principles

The principles for surface application of pelletised lime ($CaCO_3$) to Big Swamp include the following:

- Neutralise acidity and increase alkalinity of surface water discharging from Big Swamp into Boundary Creek. This would be accomplished by dissolution of lime deposited in permanently wet areas of Big Swamp as well as dissolution of lime deposited on dry areas of Big Swamp during rain events (i.e. dissolution by runoff water).
- Neutralise acidity in the upper portion of the soil profile as alkalinity from lime is progressively dissolved and transported at increased depths. Depending on rates of precipitation, limestone dissolution rates and soil properties, alkalinity may migrate downwards in the soil profile at a rate of 5-10 cm every 2-3 years.

#### 7.3.1.2 Implementation

Implementation of this remediation option could be realised using a fixed wing aircraft or helicopter (Figure 7-1) to spread pelletised lime across the entire extent of Big Swamp (11 ha). This solution would overcome logistical issues associated with accessing highly vegetated portions of Big Swamp as well as reducing the impacts of heavy machinery typically required for land applications. Based on a literature review of watershed liming projects, a liming rate in the range of 3 t/ha has been adopted to develop the concept design and costing.

Figure 7-1 Helicopter application

#### 7.3.1.3 Expected Performance

Case studies indicate that a dosage of 5 t/ha applied to discharge areas was enough to produce stable pH levels above 6.0 in water quality control sites (Rotteveel, 2018). However, there also have been cases where the increase of pH in surface streams following liming was only marginal (i.e. <0.5 pH units).

Depending on liming rate, soil type and precipitation, improvements of water quality are reported by literature within the first year of liming application, with the effects lasting for several years (between 2 and 10 years) following application.

#### 7.3.1.4 Geochemical Considerations

Results from soil samples collected from Big Swamp (Jacobs, 2019a) indicate that high concentrations of existing and/or potential acidity are present in Big Swamp to maximum investigation depths of 6.0 m bgl.

Based on review of technology performance, it is considered unlikely that wetland liming would reach and neutralise significant portions of the actual or potential ASS at depths greater than 0.5 m below ground level, with ongoing production of acidity requiring multiple applications over time to maintain effectiveness.

The ability of the technology to reduce acid releases into Boundary Creek and improve water quality will depend on several factors, including the rate of lime dissolution compared to the rate of acid mobilisation/production, the potential for armouring of lime surfaces, rainfall patterns and the actual implementation (i.e. total lime mass, lime distribution, etc.) of each lime application.

#### 7.3.1.5 Cost Estimate

Design inputs, cost assumption and estimated costs (for a 10 year period) are summarised in Table 7-2 and Table 7-3.

**Table 7-2 Wetland Liming - Design Inputs and Cost Assumptions**

| Design inputs | Cost assumptions | O&M Assumptions |
|---|---|---|
| Area: 11 ha<br>Liming rate: 3t/ha<br>Pellet lime use | Fixed costs: $ 6,000<br>Spreading cost: $ 400/t<br>Pellet lime cost: $ 150/t<br>Spreading rate: 7/t hour | Annual vegetation survey: $ 5,000<br>Monthly water sampling, four samples per event<br>O&M cost 3.5% of capital cost for consistency with AMDTreat |

**Table 7-3 Wetland Liming - Cost Estimate (10 years operation)**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Capital | $ 25,000 | |
| Engineering | $ 5,000 | 20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| O&M per year | $ 6,000 | 3.5% of capital cost plus vegetation survey. |
| Sampling per year | $ 20,000 | |
| Total 10 years | $ 350,000 | Assumed three applications in total. |

#### 7.3.1.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low to Medium.**

The ability of the technology to reduce acid releases into Boundary Creek will depend on several factors, including the rate of lime dissolution compared to the rate of acid production, the potential for armouring of lime surfaces, rainfall patterns and the parameters (i.e. total mass, distribution, etc.) of each lime application.

When mobilisation of existing and retained acidity in the soil profile occurs at a higher rate than lime dissolution rate, pH increase in Boundary Creek surface waters is likely to be limited. However, as the existing and retained acidity are flushed from the system pH is likely to start to increase because the lime dissolution rate is likely to be higher than ASS oxidation rate (GHD, 2019).

- **Manage secondary precipitates: Potentially Worse.**

  Formation of iron/aluminium precipitates following pH increase is likely. These precipitates, if not captured within Big Swamp, have the potential to be carried downstream and settle in Boundary Creek and/or Barwon River.

- **Maintain Boundary Creek minimum flow: No effect**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: Not known.**

  The effect on vegetation is unknown, although it is possible that aerial application of lime could cause harm to vegetation that has adapted to acidic conditions.

- **Reduce fire risk in Big Swamp: No effect.**

  No effect on fire risk is expected from implementation of this technology.

### 7.3.2 Soil Mixing

#### 7.3.2.1 Principle

The principle of this remediation option is to achieve a thorough mixing of suitable alkaline materials into the soil, with the aim of reducing export of acid and acidification products downstream of Big Swamp. The amount of neutralising agent added must be sufficient to neutralise all existing acidity that may be present and all potential acidity that could be generated from complete oxidation of the sulfides over time. An appropriate safety factor must be also included in that amount.

#### 7.3.2.2 Implementation

Because of practical constraints and ecological considerations, it is considered that soil mixing would be typically implemented at the site for treatment of selected ‘hot spots’ rather than the entire extent of Big Swamp. The areas targeted for treatment are likely to be severely disturbed following remediation and will require work to rehabilitate vegetation and general amenity.

Two conventional 30 t excavators (instead of piling rigs) are proposed for transportation and mixing of fine agricultural lime with the in-situ ASS requiring treatment. The use of excavators compared to piling rigs is considered to be more suitable due to the difficult terrain and access conditions at the site.

To realise mixing of lime with the in-situ ASS, one of the excavators would be fitted with a ‘rotary blender’ attachment, which is capable of maximum treatment depths between 3 m (powder product such as agricultural lime) and 4 m (slurry product) (Figure 7-3).

For costing purposes, an ‘average’ liming rate for neutralisation has been calculated based on the following formula (Department of Environment Regulation, Western Australia Treatment and management of soil and water in acid sulfate soil landscapes, 2015)

- Lime (kg/tonne soil) = (Net acidity (%S x 30.59) x 1.022 x Safety Factor) / ENV

The resulting liming rate is 390 kg/t based on the following inputs parameters:

- Net acidity: 5% S
- Safety factor: 1.5
- Effective neutralising capacity (ENV): 60%
- Soil density: 1700 kg / m$^3$

Average liming rates estimated by GHD range between approximately 40 kg of lime per t of soil (low net acidity case) and 480 kg of lime per t of soil (high net acidity case) (GHD, 2019), which is supportive of the liming rate assumed in the ROA for costing purposes.

It is however noted that liming rates in the range of 1000 kg of lime per t of soil can be calculated when considering net acidity concentrations of individual borehole samples collected from the first 2 m of the soil profile rather than average net acidity estimates (Figure 7-2, Monash University, 2019). On-site mixing for application of such liming rates is expected to be practically difficult and would result in higher costs than currently estimated.

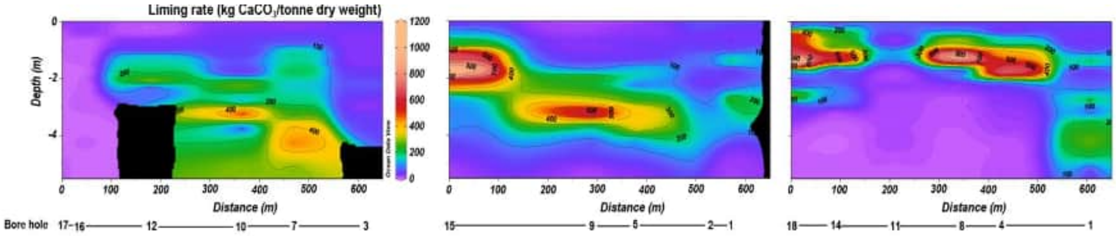


**Figure 7-2 Liming rate distribution along three east-west transects across Big Swamp (Monash University, 2019)**

In cases where treatment of deeper soil (> 3 m) is required, this remediation option would require the use of piling rigs equipped with specialised mixing devices or through subsurface injection of lime slurries.

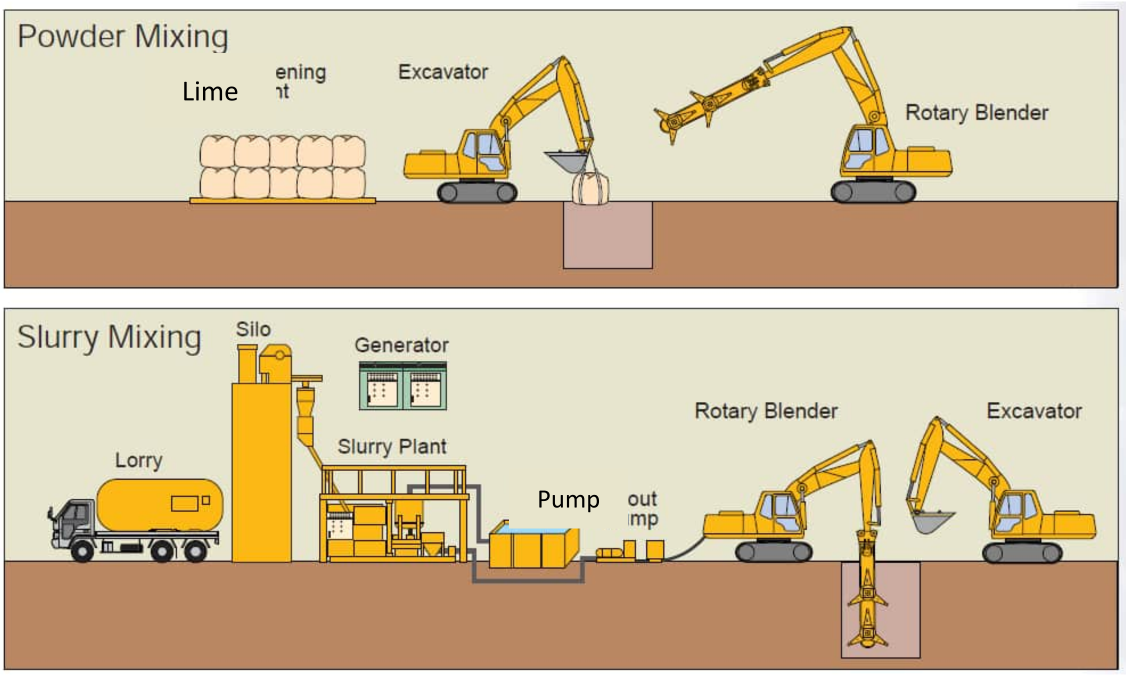


**Figure 7-3 Soil Mixing Concept**

### 7.3.2.3 Expected Performance

Application of the appropriate liming rate and effective mixing of the neutralising agent with the ASS to be treated is likely to be effective in neutralising existing and potential acidity within the 'hot spot' areas targeted for remediation.

However, it is considered that this option is unlikely to achieve a significant reduction of the existing and potential acidity stored within Big Swamp and/or a net improvement of the quality of Boundary Creek water. This is because of the overall limited extent of the soil volumes that can practicably treated by this technology versus the significant amounts of existing and potential acidity that will still remain in Big Swamp following remediation.

#### 7.3.2.4 Geochemical Considerations

GHD has estimated that the total volume of sediments in Big Swamp that have the potential generate acidity in the future (depending of the volumes of supplementary flow delivered to Big Swamp and installation of an hydraulic barrier at the eastern end of Big Swamp, as described in Section 7.3.6) to be between 435,000 $m^3$ and 610,000 $m^3$ (±50%) (GHD, 2019).

The GHD estimate supports the conclusion the treatment of limited 'hot spot' volumes (i.e. in the range of 20,000 $m^3$ per day as assumed for costing purposes) in unlikely to significantly reduce the volume of ASS sediments in Big Swam [ and the mass of acidity exported from Big Swamp to Boundary Creek].

#### 7.3.2.5 Cost Estimate

Cost estimates for this option have been developed considering a total treatment area of 1 ha and an average treatment depth of 2.0 m. Design inputs, cost assumption and estimated costs (per ha) are summarised in Table 7-4 and Table 7-5.

**Table 7-4 Soil Mixing - Design Inputs and Cost Assumptions**

| Design inputs | Cost assumptions | Validation sampling assumptions |
|---|---|---|
| Area: 1 ha<br>Treatment depth: 2 m<br>Treatment volume: 20,000 $m^3$<br>Soil net acidity: 5% S<br>Liming rate: 390 kg/t<br>Soil density: 1.7 t/$m^3$<br>Soil treatment rate: 300 $m^3$/d (treatment period of 70 days) | Excavation rate: $ 20/$m^3$ (two machines) consistent with AMDTreat<br>Clearing and replanting rate: $ 18,000/ha consistent with AMD treat<br>Environmental scientist rate: $ 1500/d<br>Fine Aglime rate: $ 90/t | 15 cores/ha<br>Sample depth 3.5 m<br>One sample every 0.5 m<br>3 days/ha |

**Table 7-5 Soil Mixing – Treatment Cost per ha**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Mixing | $ 400,000 | |
| Clearing and replanting | $ 18,000 | |
| Lime | $ 1,200,000 | |
| Engineering | $ 84,000 | 20% of capital cost. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| Supervision | $ 105,000 | Assumed 70 days required to treat 1 ha to an average depth of 2 m |
| Validation | $ 25,000 | Assumes portable push tube sampler used |
| Total per ha | $ 1,833,000 | |

#### 7.3.2.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Because of the limited extent of ASS volumes that can be practicably treated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.

- **Manage secondary precipitates: No effect.**

  No effect on secondary precipitates is expected from implementation of this technology

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology

- **Improve vegetation: Potentially Worse.**

  Vegetation across 'hot spots' targeted for treatment will require to be cleared prior to the works. Replanting will be required after remediation with reestablishment of vegetation expected within a few years from completion of the site works.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

### 7.3.3 Soil Excavation, Disposal and Rehabilitation

#### 7.3.3.1 Principle

This remediation option is essentially a variation of soil mixing, however the soil is removed and disposed off-site as a waste. Compared to soil mixing, this option has the advantage of removing the source of acidity from the site without the risk of incomplete treatment, which may be a result of inefficient mixing.

#### 7.3.3.2 Implementation

Because of practical constrains and ecological considerations, it is considered that excavation and disposal would be typically implemented at the site for treatment of selected 'hot spots' rather than the entire extent of Big Swamp.

One conventional 30 t excavator will be employed to excavate the soil across the targeted 'hot spot' areas, and several trucks will be required to ensure that the soil can be removed from the site without interruptions (Figure 7-4). The excavated areas will then require reinstatement with clean imported fill before being revegetated.


**Figure 7-4 Soil Excavation and Disposal**

#### 7.3.3.3 Expected Performance and Geochemical Consideration

Similar considerations for soil mixing apply (refer to Sections 7.3.2.3 and 7.3.2.4).

#### 7.3.3.4 Cost Estimate

For consistency, the same assumption on treatment extent and depth have been adopted for estimating the relative costs of this option. While excavation and disposal does not incur costs for lime (except for a small layer of lime to be spread at the base of the excavation), additional costs are associated with transport/disposal of ASS at a suitable facility (an ASS Environmental Management Plan must be developed and approved) and import of clean fill material.

Design inputs, cost assumption and estimated costs (per ha) are summarised in Table 7-6 and Table 7-7.

**Table 7-6 Soil Excavation, Disposal and Rehabilitation - Design Inputs and Cost Assumptions**

| Design inputs | Cost assumptions | Validation sampling assumptions |
|---|---|---|
| Area: 1 ha<br>Excavation depth: 2 m<br>Excavation volume: 20,000 $m^3$<br>Soil density: 1.7 t/$m^3$<br>Soil excavation rate: 350 $m^3$/d (period of 57 days)<br>Soil backfilling and compaction rate: 700 $m^3$/d (period of 29 days) | Excavation rate: \$ 10/$m^3$ (one machine)<br>Backfill and compaction rate: \$ 5/$m^3$ (one machine)<br>Truck and trailer rate: \$ 2,880/day (three machines)<br>Clearing and replanting rate: \$ 18,000/ha consistent with AMD treat<br>Environmental scientist rate: \$ 1500/d<br>ASS loading, transport and disposal rate: \$ 65/t<br>Fill material rate: \$ 35/t | 15 cores/ha<br>Sample depth 3.5 m<br>One sample every 0.5 m<br>3 days/ha |

**Table 7-7 Soil Excavation, Disposal and Rehabilitation – Treatment Cost per ha**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Excavation | $ 210,000 | |
| Backfilling | $ 105,000 | Excludes compaction testing |
| Soil disposal | $ 2,210,000 | |
| Fill Material | $ 1,190,000 | |
| Clearing and replanting | $ 18,000 | |
| Engineering | $ 65,000 | 20% of excavation, backfilling and replanting costs. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| Supervision | $ 130,000 | Assumed 86 days required to excavate/backfill 1 ha to an average depth of 2 m |
| Validation | $ 25,000 | Assumes portable push tube sampler used |
| Total (per ha) | $ 3,953,000 | |

#### 7.3.3.5 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Because of the limited extent of ASS volumes that can be excavated and the residual volumes of existing and potential ASS that would remain in Big Swamp following treatment.

- **Manage secondary precipitates: No effect.**

  No effect on secondary precipitates is expected from implementation of this technology.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: Potentially Worse.**

  Vegetation across 'hot spots' targeted for excavation will require clearing prior to the works. Replanting will be required after remediation with reestablishment of vegetation expected within a few years from completion of the site works.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

### 7.3.4 Aerobic Wetland

#### 7.3.4.1 Principle

This remediation option, implemented alone, would not be suitable for treatment of the water released from Big Swamp (low pH, net acidity and high metal concentrations). However, an aerobic wetland could be employed as a polishing step after other remediation options have removed the bulk of the impacts from the water. Treated water flowing from the aerobic wetland would then be directed to Boundary Creek.

#### 7.3.4.2 Implementation

Development of the concept design and cost estimate of the aerobic wetland has been undertaken using AMDTreat software, a design removal rate for iron of 10 $g/m^2 d^{-1}$ and a water inflow rate of 4 ML/d (refer to Table 7-1 for details on other relevant parameters). Flow in excess of the design treatment capacity would have to by-pass the wetland and be discharged directly in Boundary Creek.

The resulting wetland has an area of 1.2 ha, dimension (assuming a 2:1 length to width ratio) of 160 m x 80 m and a water retention time of 10 hours. Depth of water in the wetland is 0.15 m and depth of organic layers is 0.6 m, in accordance with general design guidance.

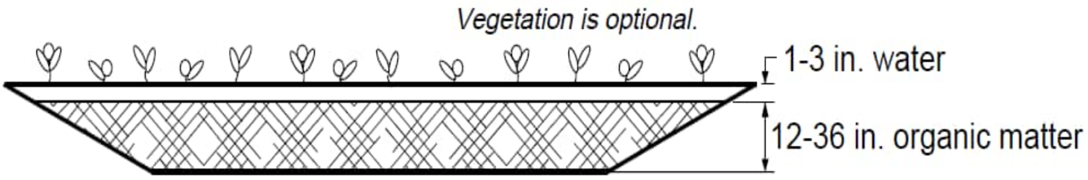


Figure 1—Basic aerobic wetland design (from Skousen and others 1996a).

**Figure 7-5 Typical Aerobic Wetland Cross Section**

#### 7.3.4.3 Expected Performance

As mentioned in the previous sections, an aerobic wetland is not considered to be suitable for effectively treating Boundary Creek water (based on the water quality assumptions supporting the ROA).

However, if the water prior to the aerobic wetland is treated as part of previous steps, then a properly designed and operated aerobic wetland is considered likely to assist in aeration/precipitation of residual metals prior to discharge in Boundary Creek.

Compared to other aeration/precipitation options (such as settling ponds), an aerobic wetland would offer the advantage of supporting ecological values and be more visually pleasing.

#### 7.3.4.4 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-8 and Table 7-9 .

**Table 7-8 Aerobic Wetland - Design Inputs and Cost Assumptions**

| Design inputs | Cost Assumptions | O&M and sampling assumptions |
|---|---|---|
| Fe treatment: 10 $g/m^2 d^{-1}$<br>Mn treatment: 0.5-1.0 $g/m^2 d^{-1}$ | No management cost (i.e. pre-classification and disposal) for soil volumes (8,730 $m^3$) excavated for wetland construction<br>No land acquisition costs (included as part of pre-wetland system)<br>No sludge removal cost (included as part of pre-wetland system) | Monthly water sampling, four samples per event<br>O&M cost 3.5% of capital cost for consistency with AMDTreat |

**Table 7-9 Aerobic Wetland – Treatment Cost per 10 years operational time**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Capital | $ 460,000 | |
| Engineering | $ 95,000 | 20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| O&M per year | $ 16,000 | |
| Sampling per year | $ 20,000 | |
| Total 10 years | $ 905,000 | |

#### 7.3.4.5 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Low.**

  Unlikely to be able to treat the acid load in Boundary Creek water unless coupled with other treatment technologies.

- **Manage secondary precipitates: Medium.**

  As a polishing step, an aerobic wetland will provide additional retention time to assist with oxidation and precipitation of residual metals prior to final release of water into Boundary Creek.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology

- **Improve vegetation: No Effect.**

  Construction of a vegetated wetland is expected to sustain a range of vegetation and ecosystems. However, this will have no impact on the vegetation across Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

### 7.3.5 Reducing and Alkalinity Producing Systems (RAPS)

#### 7.3.5.1 Principle

The principle of operation of a RAPS is passive treatment of acidic water discharges from Big Swamp in a system that establishes reducing conditions and increased pH/alkalinity. The RAPS must be followed by a settling pond (and/or aerobic wetland) to oxidise the reduced water and facilitate precipitation of metals. Treated water flowing from the settling pond would then be directed to Boundary Creek.

#### 7.3.5.2 Implementation

Development of the concept design and cost estimate of the RAPS has been undertaken using AMDTreat software, a design removal rate for acidity of 35 $g/m^2\ d^{-1}$ and a water inflow rate of 4 ML/d (refer to Table 7-1 for details on other relevant water quality parameters). Flow in excess of the design treatment capacity would have to by-pass the RAPS and be discharged directly in Boundary Creek.

The resulting RAPS has an area of 6.3 ha, dimensions (assuming a 2:1 length to width ratio) of 180 m x 360 m and a water retention time of 130 hours. Depth of water in the wetland is 0.9 m, depth of organic layers is 0.3 m and depth of limestone bed is 0.8 m, in general accordance to general design guidance Figure 7-6.

Dimension of the settling pond are 57 m wide, 110 m long and 3 m deep, ensuring a residence time of 48 hours and removal of sludge every year.

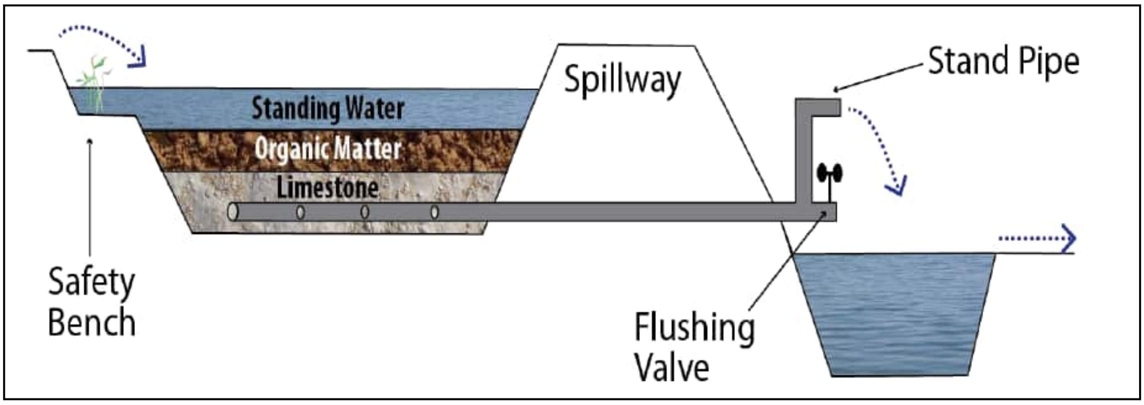


**Figure 7-6 Typical RAPS Cross Section**

### 7.3.5.3 Expected Performance

Amongst the passive systems for treating of acidified waters, RAPS are usually presented as the ones having the highest treatment efficiencies and expected lifetime.

Acidity removal rates are generally higher during the first year of operation (40-60 g/m$^2$/day) when the compost layer has high reactivity and high permeability. Long term removal rates are reported in the range of 20-40 g/m$^2$/day which would be adequate to treat a water flow of up to 4 ML/d under the design assumptions in Table 7-1.

The effect of the system on Boundary Creek water quality is likely to be variable and depending on seasonal variations of streamflow values, acidity loads and RAPS acidity removal rates, as summarised below:

- When Boundary Creek flow rates fall within the RAPS design treatment capacity (i.e. 4 ML/d as assumed in the ROA), it is expected that water into the creek would be of good quality, with a pH greater than 5 units and low concentration of dissolved iron and aluminium.
- Flow rates in excess of the design treatment capacity would have to by-pass the RAPS and water quality in Boundary Creek would be a result of the mixing of the treated and untreated streams.
- Periods of higher acidity loads (which could happen at any flow rate) have the potential to upset the microbiological conditions within the RPAS and cause progressive decrease of treatment efficiency.

It should be also noted that, compared to other passive systems, RAPS require more intensive maintenance, including flushing of aluminium precipitates in the piping system and removal of sludges from the settling pond. Lack of proper maintenance is likely to results in progressive decrease of system performance and degradation of water quality in Boundary Creek.

### 7.3.5.4 Geochemical Considerations

The results of the geochemical assessment (GHD, 2019) are summarised below.

- Precipitate clogging of the organic layer of the RAPS is not anticipated to be significant.
- Formation of aluminium precipitates in response to the increase in pH is predicted in the limestone layer, with the potential for clogging and armouring of the limestone reducing the effectiveness of this treatment layer and decreasing the efficiency and effectiveness of the treatment system.

### 7.3.5.5 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-10 and Table 7-11.

**Table 7-10 RAPS - Design Inputs and Cost Assumptions**

| Design inputs | Cost Assumptions | O&M and sampling assumptions |
|---|---|---|
| Acidity treatment: 35.0 g/$m^2$ $d^{-1}$<br>Settling pond retention time >48 hrs<br>Sludge removal events: one per year<br>Sludge generation rate: 0.0046 $m^3$ sludge / $m^3$ water<br>Sludge solid content: 5% | No management cost (i.e. pre-classification and disposal) for soil volumes excavated for RAPS construction (114,000 $m^3$) and settling pond construction (14,530 $m^3$)<br>Land acquisition cost: $ 20k / ha<br>Sludge removal rate: $ 50/$m^3$ | Monthly water sampling, four samples per event<br>O&M cost 3.5% of capital cost for consistency with AMDTreat |

**Table 7-11 RAPS – Treatment Cost per 10 years operational time**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Capital | $ 4,600,000 | |
| Engineering | $ 920,000 | 20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| Land Acquisition | $ 200,000 | Assumed 10 ha and $20,000 per ha |
| O&M per year | $ 160,000 | O&M (3.5% of capital). Routine O&M, no major reconstruction work. |
| Sludge removal per year | $ 335,000 | |
| Sampling per year | $ 20,000 | |
| Total 10 years | $ 10,870,000 | |

### 7.3.5.6 Overall Assessment

The assessment of the ability of this remediation option (implemented as described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: Medium to High.**

  Subject to proper design and maintenance, a RAPS would have the ability to treat the acid load in Boundary Creek water. However, Boundary Creek flow rates above the design capacity of the system will not be treated by the RAPS.

- **Manage secondary precipitates: High.**

  Secondary precipitates will be captured in the settling pond.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: No effect.**

  Construction of a vegetated RAPS is expected to sustain a range of vegetation and ecosystems, as well as improving downstream ecological values. However, it will have no effect on the vegetation across Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

### 7.3.6 Managed groundwater levels and wetland flooding

#### 7.3.6.1 Principles

The principles supporting flooding of portions of Big Swamp are to provide supplementary flow and install surface water retention structures ('hydraulic barriers') to achieve the following:

- Minimise further oxidation of ASS sediments by maintaining saturated conditions within the alluvium aquifer beneath Big Swamp.
- Promote acid neutralising reactions (iron and sulfate reduction) in permanently flooded areas of Big Swamp that will results from the combined effect of delivering supplementary flows and installing hydraulic barriers.

#### 7.3.6.2 Implementation

Implementation of this option will require Barwon Water to deliver supplementary flow upstream of McDonalds Dam, monitoring of effective release of the supplementary flow from McDonalds Dam and construction of one (or multiple) hydraulic barriers within Big Swamp.

Implementation could be progressed in stages, so that the effect of installing one barrier can be monitored to calibrate modelling results, support design of additional barriers and assess potential side-effects associated with the technology (i.e. increased production of soluble ferrous iron than could be mobilised downstream Big Swamp, impact on vegetation, etc.).

Water release control structures (such as weirs) could be integrated in the barriers to control the level of inundation, adapt to higher rainfall periods and allow future integration with in-stream water treatment systems.

The design presented by Jacobs (2018b) consisting of installation of one hydraulic barrier at the eastern end of Big Swamp has been adopted in this ROA, for the following reasons:

- The design is considered adequate to represent, at a conceptual level, the effect of barrier installation of surface water flow and groundwater levels.
- Considerable surface water and groundwater modelling work has been developed to support assessment of the design presented by Jacobs. Results of this modelling work can be extrapolated to draw a range of conclusions on the general ability of this option to meet the project objectives.

#### 7.3.6.3 Expected Performance

Expected performance of this option has been assessed based on a review of draft reports summarising the results of surface water/groundwater models (Jacobs, 2019b), incubation testing (Monash University, 2019), geochemical model (GHD, 2019) and vegetation study (Eco Logical, 2019).

##### 7.3.6.3.1 Surface Water and Groundwater

Jacobs' modelling was aimed at assessing surface water and groundwater responses to increased supplementary flow volumes (from a minimum of 2 ML/d to a maximum of 20 ML/d) with or without the influence of the hydraulic barrier installed at the eastern end of Big Swamp (barrier elevation set at 142.5 m AHD, Figure 7-7).

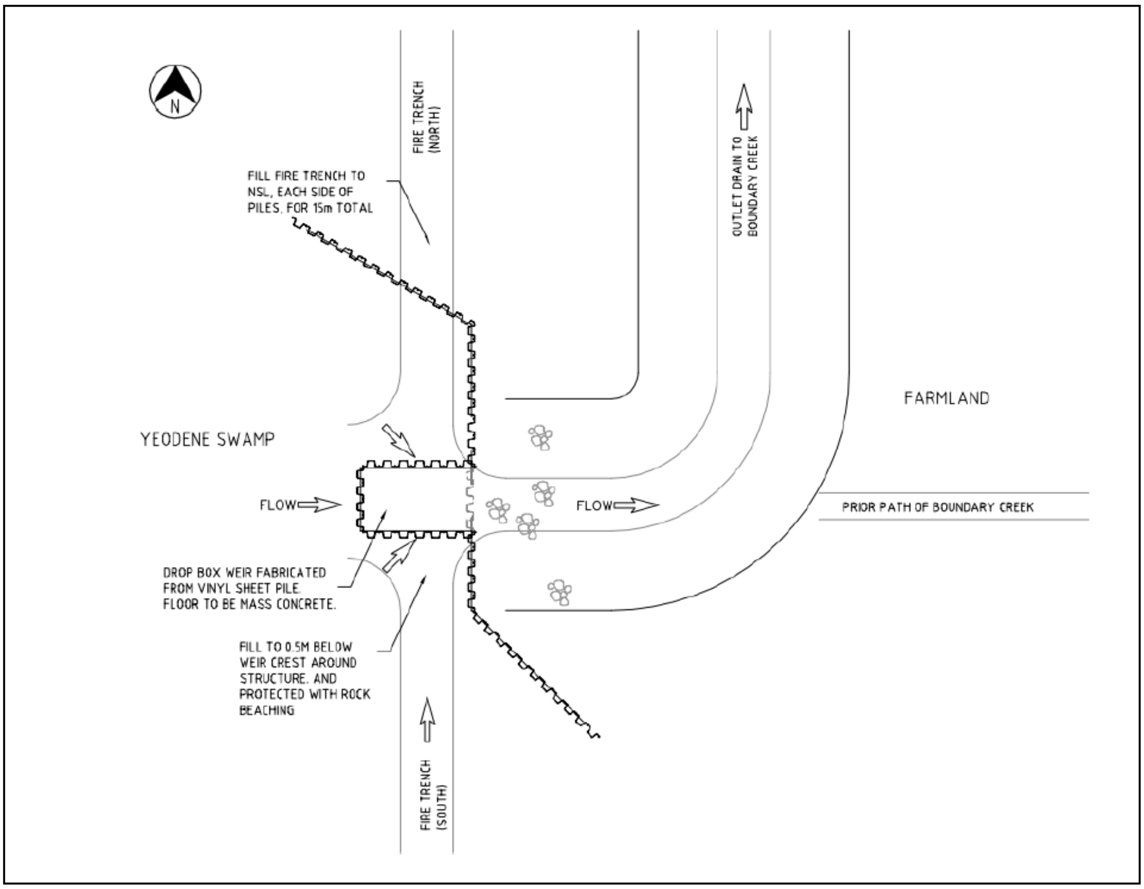


**Figure 7-7 Location of Hydraulic Barrier (Jacobs, 2018b)**

Interpretation of preliminary results from Jacobs' modelling work is provided below.

**Surface Water**

- The barrier is set at an elevation of 142.5 m AHD. Surface water levels are below the top of the barrier for each of the scenarios modelled (i.e. supplementary flows of 2 – 5 – 10 – 20 ML/d, refer to Figure 7-8).

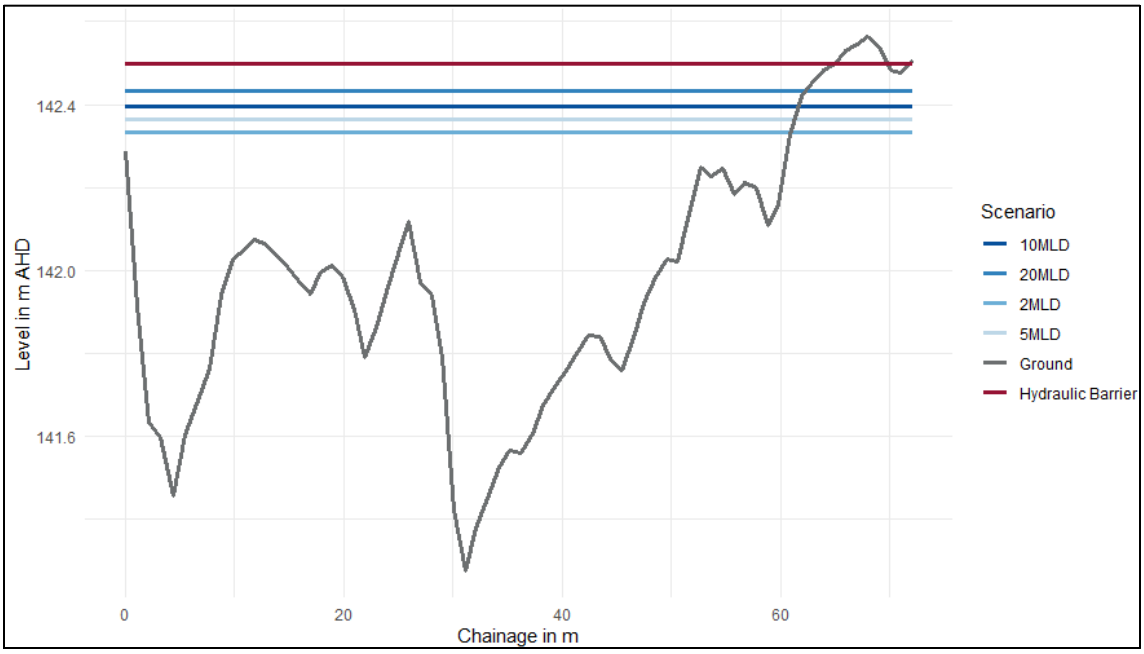


**Figure 7-8 Peak water levels immediately adjacent to the hydraulic barrier for various release flows (Jacobs, 2019b)**

- Modelled surface water flow across Big Swamp appears to primarily develop through a defined channel along the northern boundary. As supplementary flow rate increases, a range of secondary flow channels appear to develop in the upper-central portion of the swamp (Figure 7-9).

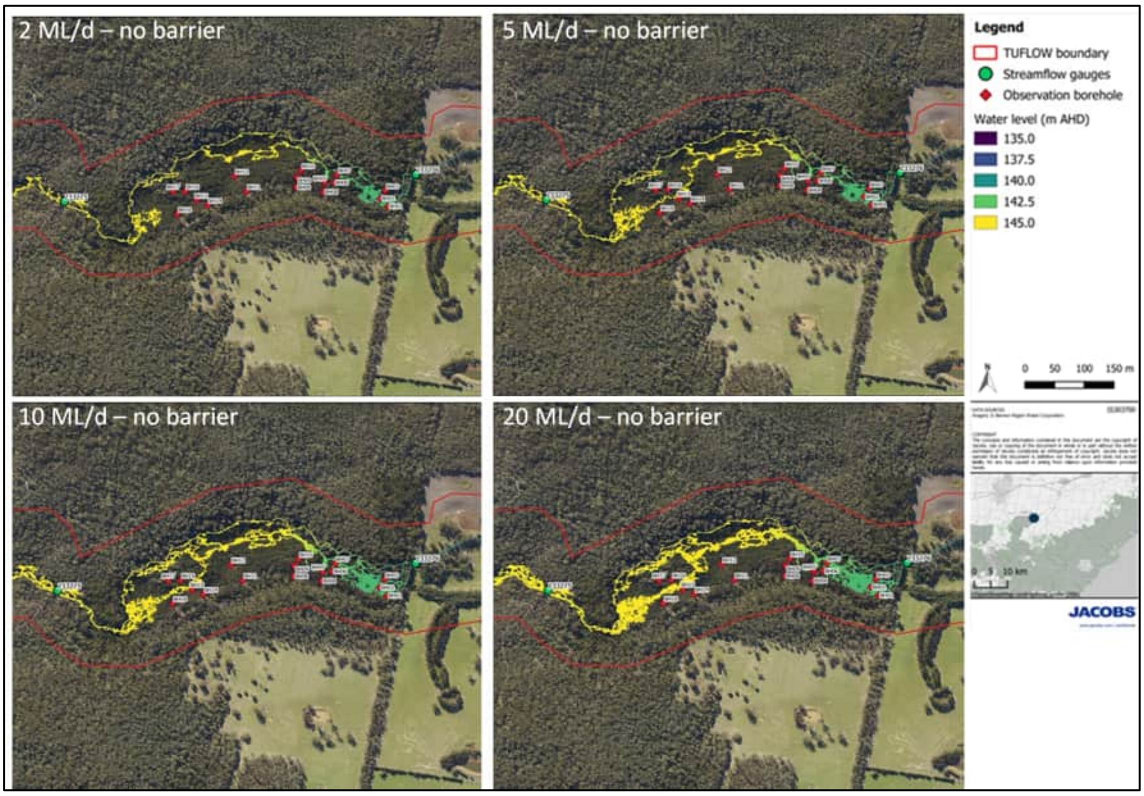


**Figure 7-9 Modelled Surface Water Levels (2 – 5 -10 – 20 ML/d release flow, no barrier (Jacobs, 2019b))**

- The effect of installing a hydraulic barrier at the eastern end of the Big Swamp is to increase the area of inundation immediately upstream of the barrier. As indicated in Figure 7-16, the additional area of inundation due to the hydraulic barrier is diminished with higher supplementary flows. The effect of these supplementary flow appears to be mostly associated with generation of flow paths upstream of the barrier.

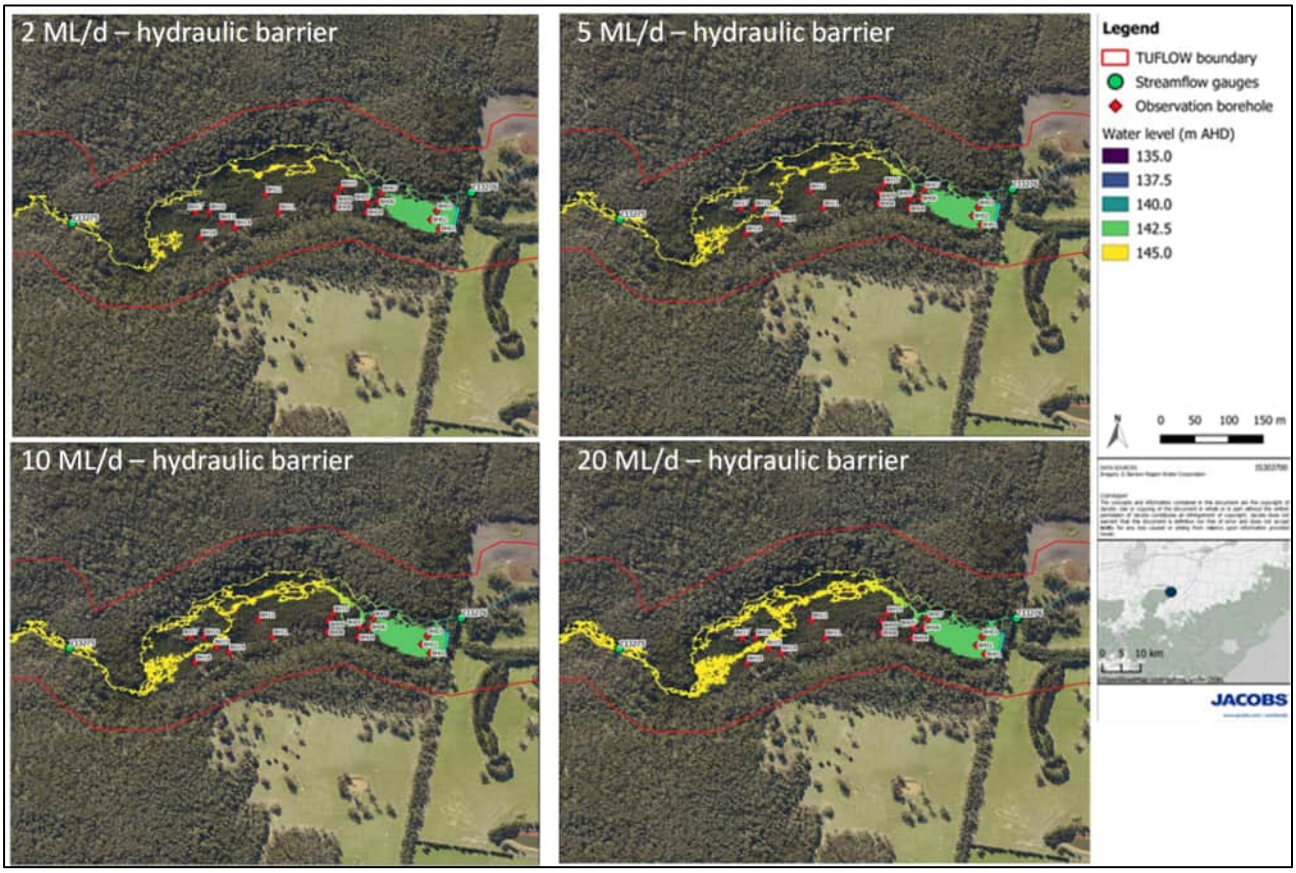


**Figure 7-10 Modelled Surface Water Levels (2 – 5 -10 – 20 ML/d release flow, hydraulic barrier (Jacobs, 2019b)**

- Calculated areas of inundation for each scenario are summarised in Table 7-12 (Jacobs, 2019b). The results indicate that a supplementary flow of 5 ML/d results in an increase in inundation extent of 40% over the 2 ML/d supplementary flow. A supplementary flow of 10 ML/d results in an increase in inundation extent of 85% and a supplementary flow of 20 ML/d results in an increase in inundation extent of 130% compared to the 2 ML/d supplementary flow.

**Table 7-12 Area of inundation over each scenario (Jacobs, 2019b)**

| Supplementary Flow(ML/d) | Area of inundation under existing model structure ($m^2$) | Area of inundation with the inclusion of the hydraulic barrier ($m^2$) |
|---|---|---|
| 2 ML/d | 17,800 | 27,500 |
| 5 ML/d | 25,100 | 34,100 |
| 10 ML/d | 33,300 | 41,100 |
| 20 ML/d | 41,700 | 48,500 |

- Predicted streamflow rates at the Yeodene gauge for each of the modelled scenarios (Figure 7-11) indicate that a minimum flow of at least 0.9 ML/d is maintained in Reach 3 of Boundary Creek.

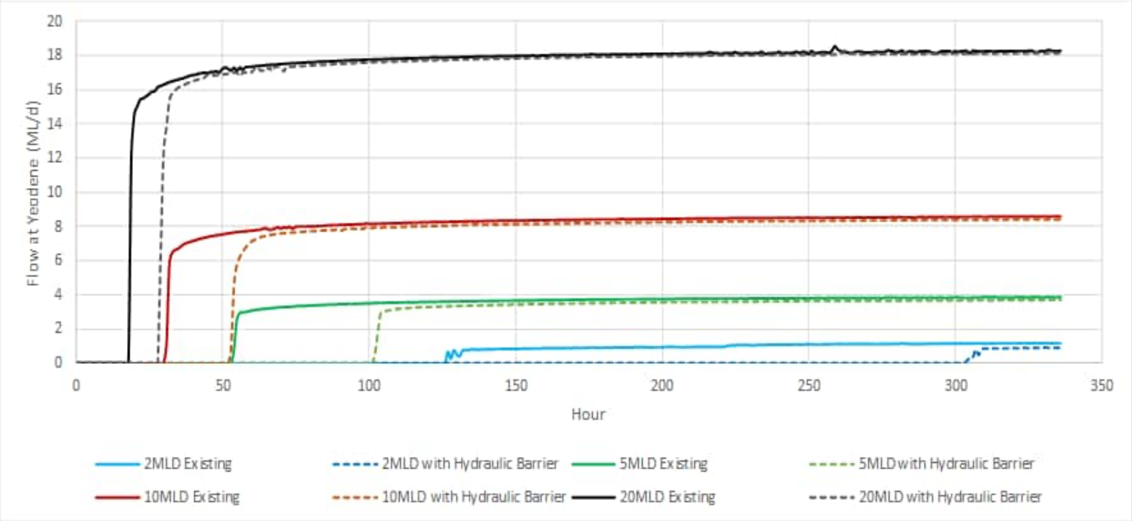


**Figure 7-11 Modelled stream flow under each scenario at the Yeodene gauge 233228**

- **In summary**, surface water modelling results indicate the following:
  - The introduction of supplementary flow increases the inundation extent of the swamp. Installation of a hydraulic barrier at the eastern end of the swamp is effective in increasing extent of inundation, particularly in the areas immediately upstream of the barrier.
  - When the barrier is in place, the area of inundation immediately upstream of the barrier appears to be relatively independent from increasing supplementary flows, which have the main effect of activating additional flow paths in the upper-central portion of Big Swamp, upstream of the barrier.
  - A supplementary flow of 2 ML/s is effective in maintain a streamflow of 1.1 ML/d (no hydraulic barrier) and 0.9 ML/d (hydraulic barrier) in Reach 3 of Boundary Creek.
  - Construction of additional barriers should be considered to achieve more effective inundation of the swamp and target areas where reflooding is considered beneficial (i.e. areas of higher existing and/or potential acidity).

**Groundwater**

- Six predictive scenarios have been formulated and run by Jacobs to assess future surface water and groundwater flow regimes:
  - Scenarios 1 to 4 are short term (150 days) simulations that assume a dry period in which the creek flow is entirely supported by supplementary flow (2 ML/d and 20ML/d, with or without hydraulic barriers).
  - Scenarios 5 and 6 are longer term (10 years) simulations that assume an arbitrary flow regime in Boundary Creek (Figure 7-12) to evaluate groundwater level response in Big Swamp, with or without barrier.

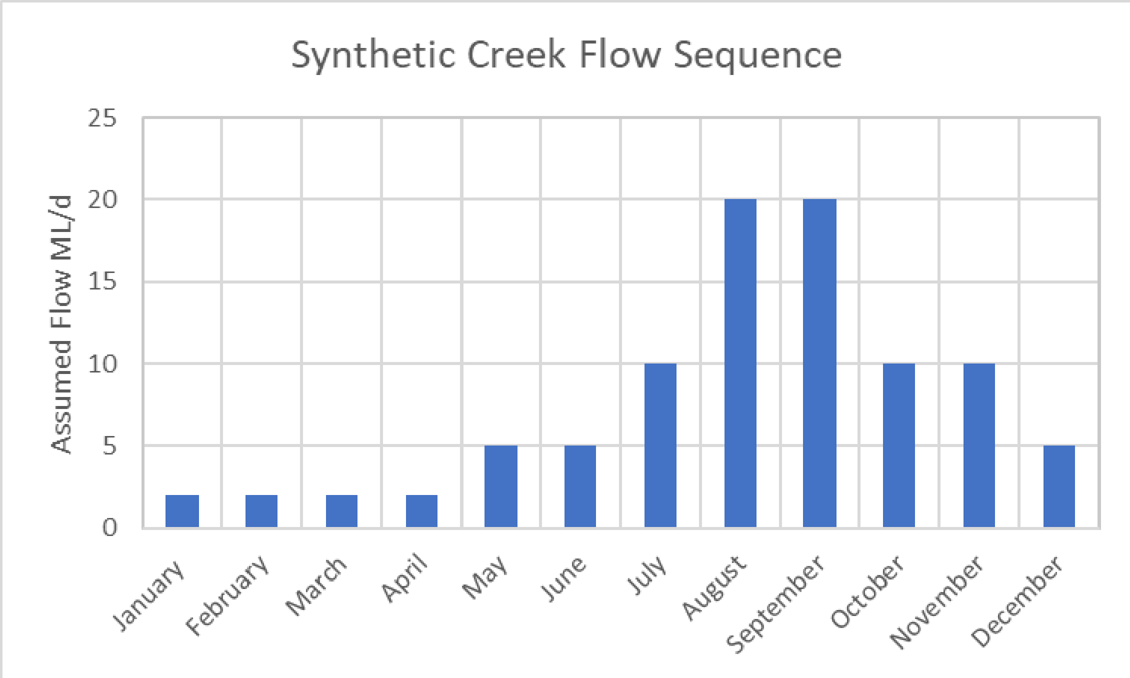


**Figure 7-12 Assumed Boundary Creek flow (Jacobs, 2019b)**

- Contour maps of the predicted change in head across the swamp for scenario 1 (2 ML/d supplementary flow, no hydraulic barrier) and scenario 3 (20 ML/d supplementary flow, no hydraulic barrier) are presented in Figure 7-14. The head change is calculated after 150 days of constant flow release from the modelled September 2019 groundwater levels, which are considered to represent typical winter (i.e. high) levels.

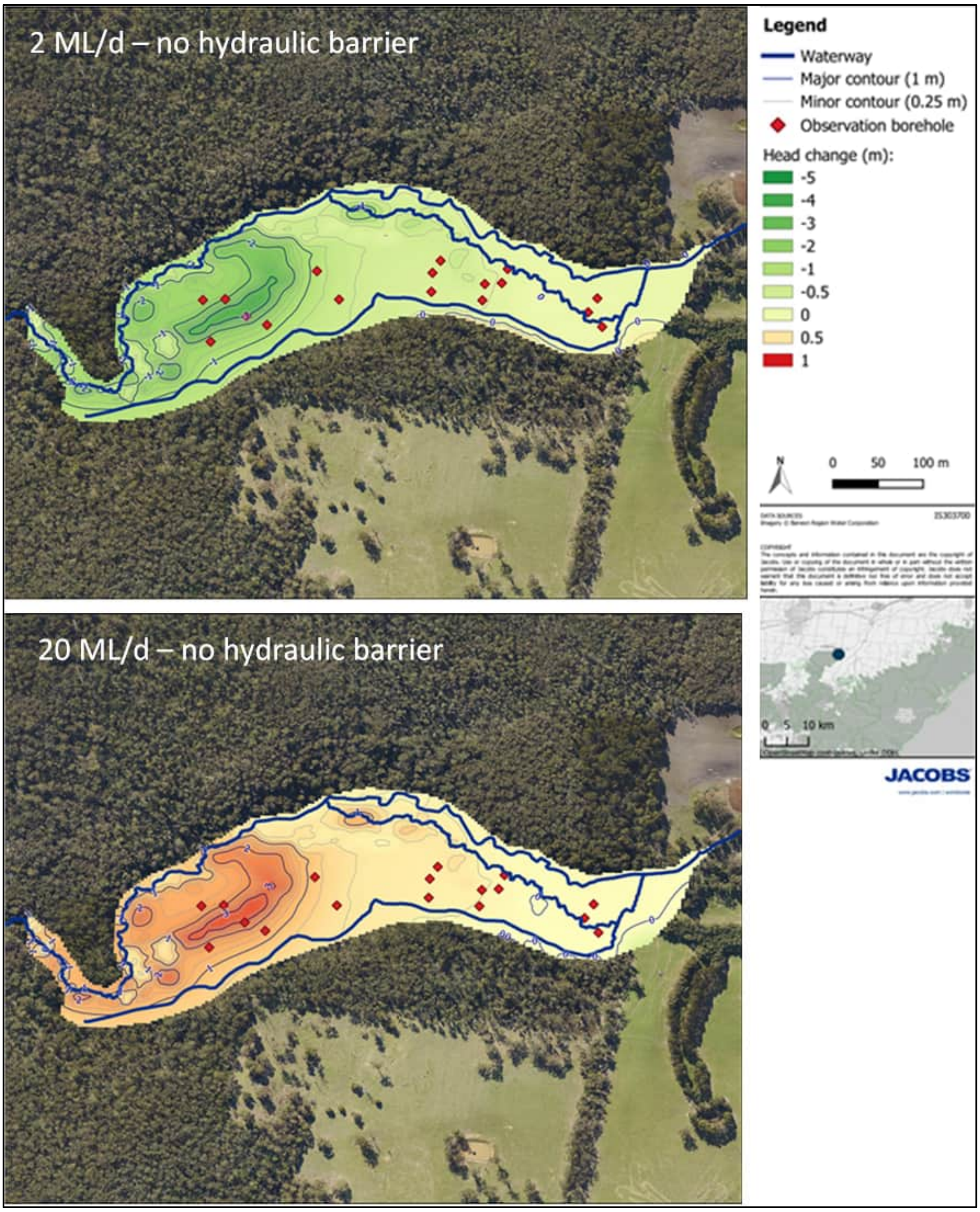


**Figure 7-13 Predicted head changes across Big Swamp after 150 days of supplementary flow release, scenario 1 and scenario 3 (Jacobs, 2019b)**

- Analysis of Figure 7-14 indicates that a supplementary flow of 2 ML/d does not maintain groundwater levels at typical winter levels, particularly at the western part of the swamp. Instead, a supplementary flow 20 ML/d is effective in raising groundwater levels throughout the swamp.
- Contour maps of the predicted change in head across the swamp for scenario 2 (2 ML/d supplementary flow, with hydraulic barrier) and scenario 4 (20 ML/d supplementary flow, with hydraulic barrier) are presented in Figure 7-14. The head change is calculated after 150 days of constant flow release from the modelled September 2019 groundwater levels, which are considered to represent typical winter (i.e. high) levels.

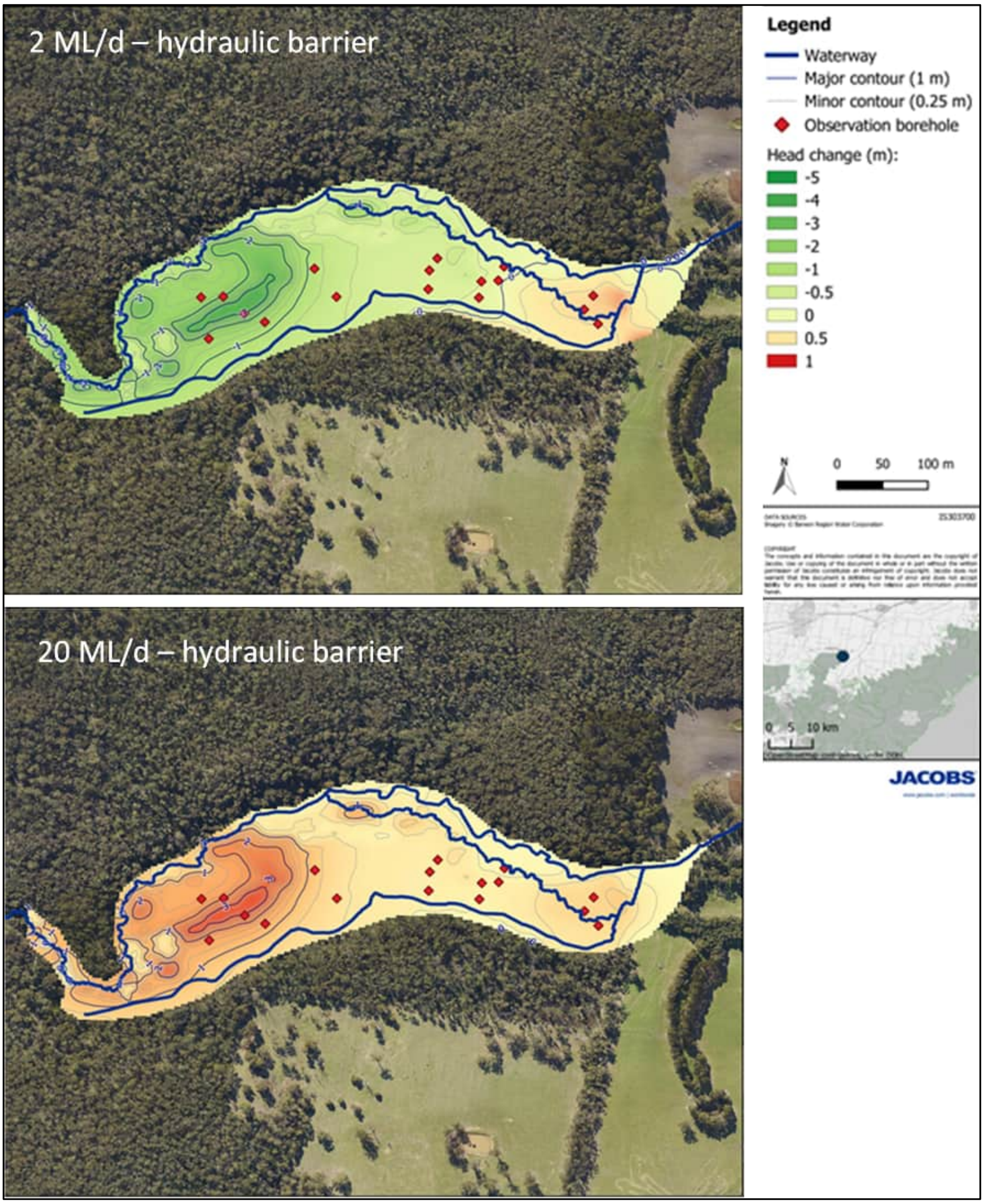


**Figure 7-14 Predicted head changes across Big Swamp after 150 days of supplementary flow release, scenario 2 and scenario 4 (Jacobs, 2019b)**

- Analysis of Figure 7-14 indicates that incorporation of a hydraulic barrier is effective in raising groundwater levels in the areas in close proximity of the barrier, with limited effect on groundwater levels further upstream.
- Results of scenarios 5 and 6 (Figure 7-15) indicate the absence of long-term trends in groundwater heads, which appear to fluctuate seasonally around a long-term average condition. The magnitude of the seasonal head fluctuations is expected to be much greater in the upper reaches of the swamp than the lower reaches. The predicted impacts of the hydraulic barrier are constrained to the downstream part of the swamp and the increases in groundwater head caused by the barrier are not predicted to be propagated upstream of monitoring bores BH7, BH8 and BH9.

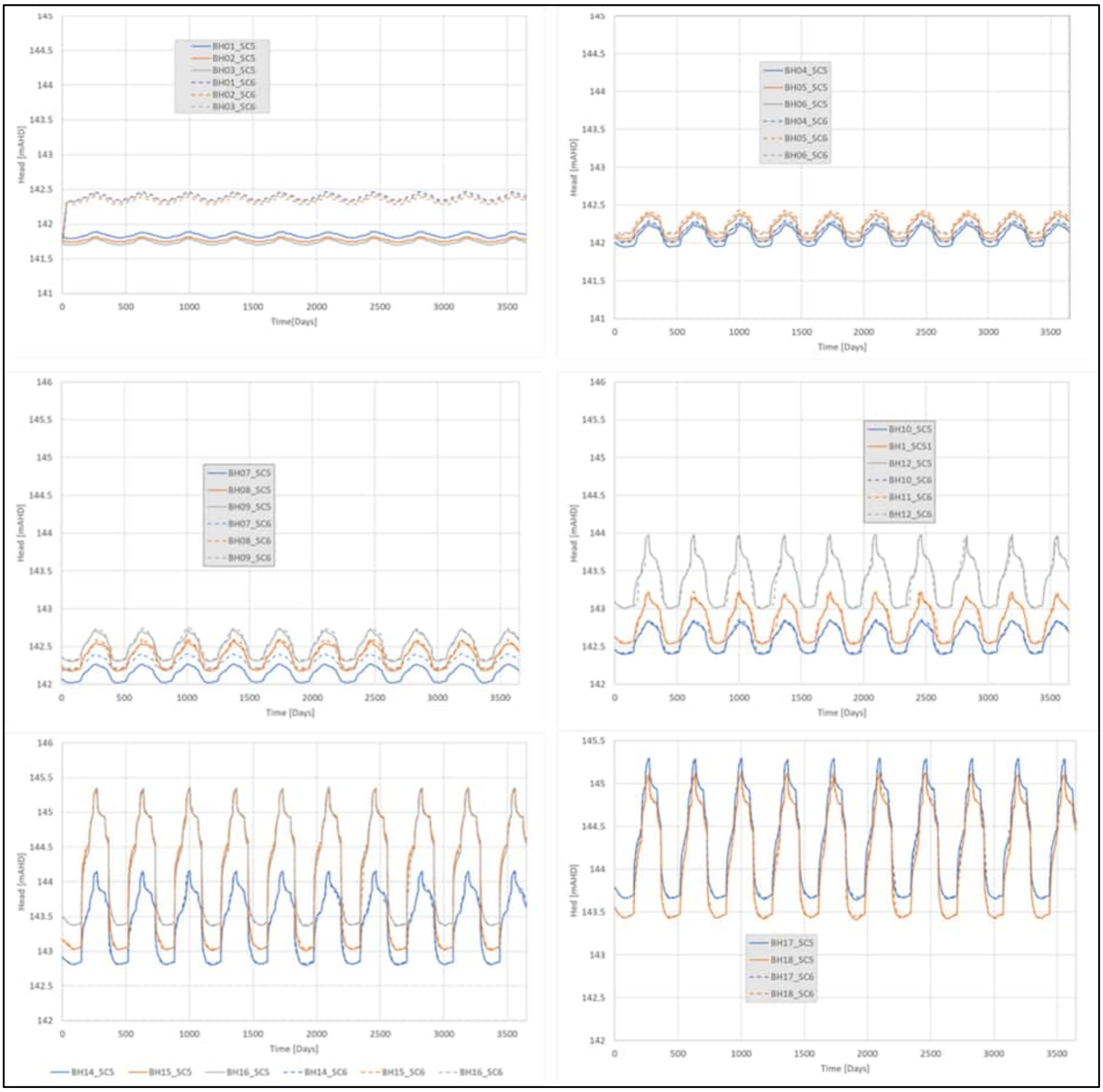


**Figure 7-15 Predicted long-term head changes across Big Swamp under a synthetic flow sequence (Jacobs, 2019b)**

- **In summary**, groundwater modelling results indicate the following:
  - A combination of providing supplementary flow and installation of a hydraulic barrier at the eastern end of the swamp can be effective in maintaining or increasing groundwater levels across Big Swamp and in ensuring a minimum flow in Boundary Creek during the year.
  - The effect of the hydraulic barrier on groundwater levels appears to be localised and is not predicted to propagate to the central and upstream parts of Big Swamp. Similarly, to surface water levels, installation of multiple hydraulic barriers is likely to require less supplementary flow and be more effective in managing groundwater levels across Big Swamp when compared to a single barrier.
  - A supplementary flow of 2 ML/d does not appear maintain groundwater levels at typical winter levels (i.e. at the end of September) throughout the swamp, whereas a supplementary flow 20 ML/d raise groundwater levels throughout the swamp. No information is provided by Jacobs on the effect of intermediate supplementary flows (i.e. 5 and 10 ML/d) on groundwater levels.

  - Long-term (10 years) simulations indicate that groundwater heads are not expected as the groundwater system equilibrates quite rapidly with changing flows in the creek (Figure 7-15). Higher groundwater level fluctuations are predicted across the western end of Big Swamp (as indicated by predicted long-term groundwater changes in groundwater monitoring wells BH14 to BH18) compared to the eastern end of Big Swamp (as indicated by predicted long-term groundwater changes in groundwater monitoring wells BH01 to BH06).

#### 7.3.6.3.2 Incubation Testing

Incubation testing results (Monash University, 2019) relevant to the implementation of this option are summarised as follows:

- The main reaction observed in the incubation testing is iron reduction, which neutralises 8 equivalents of $H^{+}$ for each mole of carbon oxidised.
- No sulfide accumulation has been observed in the incubation testing, indicating sulfate reduction is not taking place to any significant extent.
- Based on the neutralisation rates associated with iron reduction reaction, it was estimated that the net acidities in the soil samples where this reaction was occurring could be neutralised within 1-2 years, assuming steady state reaction rates and continued availability of bioavailable iron and organic carbon.
- The soluble ferrous iron ($Fe^{2+}$) produced by reducing conditions is mobile and has the potential to be exported downstream of Big Swamp to Boundary Creek and Barwon River. This ferrous iron will generate acidity when exposed to oxygen rich water in Reach 3 of Boundary Creek and/or Barwon River.
- It is unlikely that sulfate reduction reaction will contribute to immobilisation (i.e. precipitation as FeS) of the soluble ferrous iron ($Fe^{2+}$) produced by reducing conditions. However, recent results do indicate a significant reduction of iron concentration after 128 of testing, indicating that other reactions may be contributing to precipitation of ferrous iron. This matter is subject of further investigations at the time of this ROA.
- The risks associated with mobilisation of existing acidification products within the oxidised sediments in Big Swamp and the potential mobilisation of mobile aqueous ferrous ions are heightened by the current lack of buffering capacity (i.e. alkalinity) both in the Boundary Creek water as well as in the Big Swamp sediments.

#### 7.3.6.3.3 Geochemical Considerations

The results of the draft geochemical assessment (GHD, 2019) are summarised below.

- The time required to flush out the net acid mass that would remain in Big Swamp has been estimated as follows:
  - 2ML Day and no barrier: 100 years ± 50% depending on density assumption and mass flux variance.
  - 2ML Day with barrier: 80 years ± 50% depending on density assumption and mass flux variance.
  - 20ML Day with barrier: 50 years ± 50% depending on density assumption and mass flux variance.
- The swamp sediments contain high amounts of organic carbon, so there should be sufficient carbon source to form and maintain reducing conditions for the foreseeable future.
- The thermodynamic model results support the results of the Monash University study. As reducing conditions dominate, the ferric iron present is reduced to ferrous iron and enters solution, while sulphate reduction does not appear to occur to any level of significance. The only removal of sulphate from solution, as suggested in the model, is precipitation of Aluminium Sulphate. Figure 7-16 shows the changes predicted by the model.
- The thermodynamic modelling also demonstrated that iron is removed from solution through the precipitation of iron oxides and hydroxides irrespective of the Eh conditions (anoxia is not required). The precipitation is pH controlled; it occurs when the pH is above 3.5 units. These finding as corroborated by the Monash University column studies where it was demonstrated that iron is removed from solution when the pH is above 3.5 units.

The Monash University study also demonstrated that the precipitation of the iron does not affect the concentration of dissolved inorganic carbon (DIC). Although the thermodynamic modelling has not used the water quality form the columns as input, it is likely that there will be sufficient readily available neutralising capacity to manage the areas with acidic conditions or the potential to generate acidic conditions.

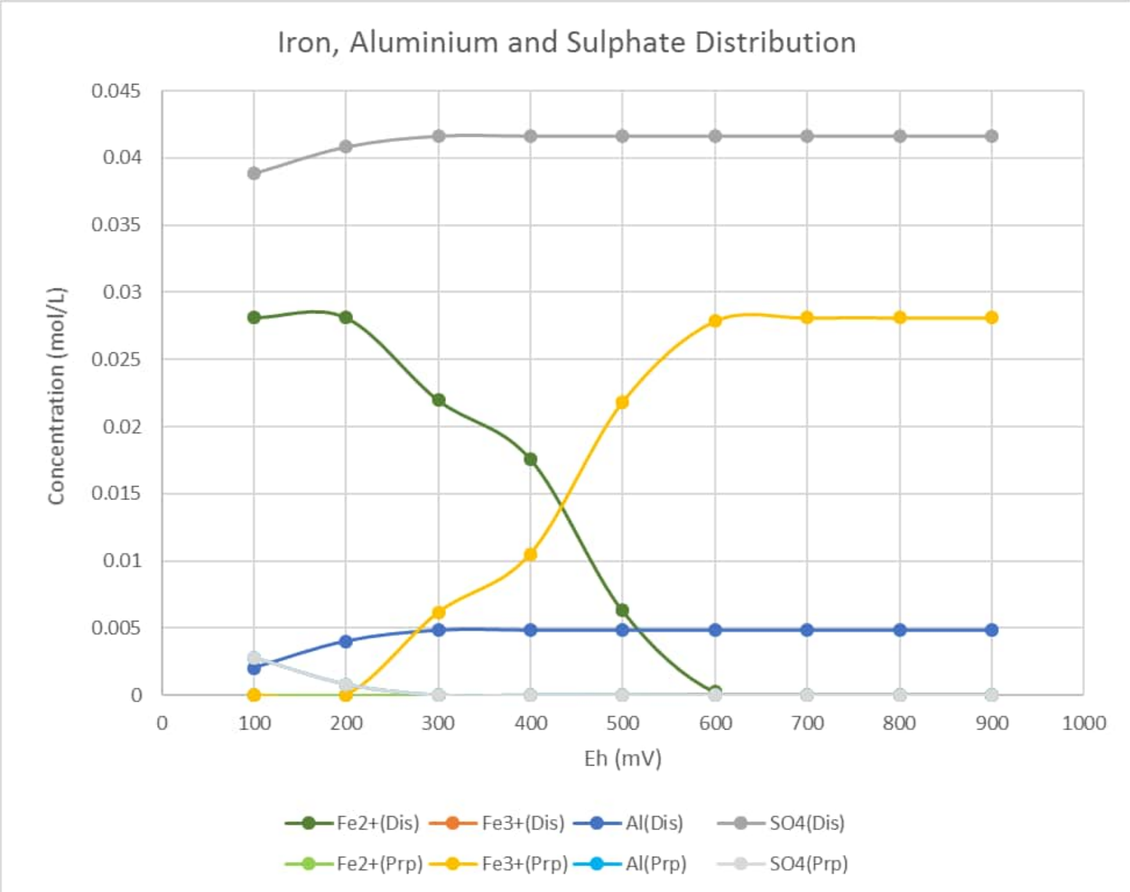


**Figure 7-16 Changes in concentration of various compounds due to a return to reducing conditions predicted by the thermodynamic modelling (GHD, 2019)**

- The system deficiencies identified through the geochemical modelling can be described as follows:
  - The most significant limitation is a lack of sulphate, which will limit the attenuation of acid through sulphide mineral precipitation. The Monash University incubation studies and geochemical assessment suggest that the reduction will proceed to the iron reduction stage, leading to ferrous iron in solution and transport out of the swamp, resulting in the export of acidity.
  - No kinetic data is available for the complete oxidation / reduction cycle, and therefore the reliability of predictions of geochemical processes is limited.
- The most significant benefit of re-flooding would be the increase of groundwater levels in the swamp, limiting the potential for further oxidation of the re-saturated PASS that may be present within Big Swamp.
- The following should be noted with regards to acid flushes:
  - The re-flooding is likely cause an initial increase of acidity being flushed downstream of Big Swamp, which will then abate once the retained and actual acidity is removed from the system.
  - Interpretation of historic stream flow and pH at Yeodene gauge in Reach 3 of Boundary Creek supports this conclusion. At this location, pH was found to be below the long-term average 84% of the time prior to the

release of the 2 ML/d supplementary flow, and 97% of the time after release of the 2 ML/d supplementary flow.

  - This indicates that the supplementary flow is likely to lead to additional acid flushing in the short to medium term but would reduce the overall acid flux in the long term in consideration of decreased potential for oxidation of the saturated ASS sediments.

- In the context of acid flushes in response to storm events, this would be situation dependent. The historic record suggests that in the majority of storm events, pH was higher during high flow, but there are occasional events where this is not the case. By increasing the saturated volume and inundated area of the swamp, there is likely to be an increase in the risk of acid flush events, as the retained and actual acidity enters solution leading to acidic conditions in standing water bodies in the swamp. This acid water could then exist the swamp in a first flush event in response to a localised storm event.

##### 7.3.6.3.4 Vegetation

Eco Logical (2019) provides an assessment of the potential outcomes associated with increasing groundwater levels and creating permanently inundated areas across Big Swamp, as summarised below:

- Establishment of permanently inundated areas will cause in the total loss of all vegetation cover, resulting in similar conditions to those observed in eastern end of Big Swamp, where a small area of ponded water is present (Figure 7-17).

**Figure 7-17 Ponded area at the eastern end of Big Swamp**

- Restoring saturated conditions within the top first meter of Big Swamp alluvium sediments is a requisite to preserve the Riparian Fern Scrub community and reduce encroachment of the surrounding Lowland Forest into areas historically dominated by damp woodlands.
- Blocking the preferential channels that have developed since the 2010 fires is likely to achieve a broader distribution of surface flows across Big Swamp and promote establishment of a diverse range of vegetation.

#### 7.3.6.4 Cost Estimate

A cost estimate for delivering the contingency flow and installation of up to three hydraulic barriers across Big Swamp is provided in Table 7-13. The capital cost for installation of each hydraulic barrier is based on the figures provided in the Yeodene Swamp Study (Jacobs, 2018b) which is considered adequate for the purpose of this ROA.

The estimate assumes that no amendments will be used to promote sulfate reducing conditions in the reflooded areas.

**Table 7-13 Wetland Flooding and Managed Groundwater Levels – Treatment Cost per 10 years operational time**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Capital | $ 1,200,000 | From Jacobs report (Jacobs, 2018b). Cost is for three barriers. |
| Engineering | $ 240,000 | 20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc. |
| Land acquisition | $ 220,000 | Assumed 11 ha and $20,000 per ha. |
| O&M per year | $ 42,000 | 3.5 % of capital costs (excludes cost of water). |
| Sampling per year | $ 20,000 | Monthly water sampling, 4 samples per event. |
| Total 10 years | $ 2,280,000 | |

#### 7.3.6.5 Overall Assessment

Based on the above, our assessment on the ability of this remediation option (as described in the modelling work by Jacobs) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: Medium to High.**

  Based on modelling results, when a 2 ML/d supplementary flow is delivered, it does not appear that groundwater levels can be significantly increased (eastern end of the swamp) or maintained (central and western parts of the swamp) with or without the presence of a hydraulic barrier at the eastern end of the swamp.

  Conversely, when a 20 ML/d supplementary flow is delivered, groundwater levels appear to remain steady or increase across most of the swamp. Under this higher supplementary flow scenario, the influence of a hydraulic barrier at the eastern end of the swamp appears localised.

  By extrapolating these results, it is considered that a combination of practically achievable supplementary flows (i.e. in the range of 5ML/d) and strategically placed hydraulic barriers is likely to be effective in maintaining minimum groundwater levels across targeted areas of Big Swamp.

  Additional surface water and groundwater modelling work will be required to progress design of this option and to support cost-benefit analysis.

- **Control acid release: Initially Low then Medium.**

  This will depend on the volume of supplementary flow delivered, the proportion of Big Swamp that will be permanently inundated and the ability of the natural system to establish iron reducing and sulfate reducing conditions.

  GHD (2019) indicates that, initially, the delivery of supplementary flow has the potential to increase downstream release of actual and retained acidity. However, this process will progressively abate as the acidity is flushed from the system and further aerobic oxidation of ASS sediments is prevented by the establishment of higher groundwater levels.

  The Monash University incubation testing also indicate that, even if the system is unlikely to progress to sulfate reducing conditions, iron reducing conditions also have the ability to neutralise acidity in the permanently flooded areas, within a timeframe estimated in the range of 1-2 years.

  As discussed in Section 8, the risk of increased acid releases will require management in the form of ongoing monitoring and potential implementation of risk mitigation (i.e. contingency) measures. For example, application of neutralising agents could be considered as an effective approach to manage the risk associated with increased export of acidity in Boundary Creek.

- **Manage secondary precipitates: Potentially Worse (if unmanaged).**

The soluble ferrous iron generated under reducing conditions in the permanently flooded portions of Big Swamp has the potential to be exported to downstream receiving environments (i.e. Boundary Creek and Barwon River) generating acidity and iron precipitates.

The magnitude of this secondary effect depends on several factors and ongoing monitoring will be required to evaluate the severity of potential impacts. Recent results from the Monash University testing indicate a reduction of soluble iron after 128 days of incubation, indicating the potential for the iron to be retained in Big Swamp rather than exported downstream.

As discussed in Section 8, the risk of increased acid releases will require management in the form of ongoing monitoring and potential implementation of risk mitigation (i.e. contingency) measures. For example, construction of an intermediate settling pond between Big Swamp and Boundary Creek could be considered as an effective approach to manage the risk of formation of acidity and secondary precipitates in Boundary Creek.

- **Maintain Boundary Creek minimum flow: High.**

  Based on surface water modelling results, release of supplementary flow upstream of McDonalds Dam in the range of 2 ML/d appears to be adequate to sustain a flow in the range of 1 ML/d in Boundary Creek at the Yeodene gauge.

- **Improve vegetation: Medium to High.**

  It is considered that an improved hydrological regime across Big Swamp will have a positive effect in restoring some of the ecological values and diversity over time.

  The Big Swamp ecological assessment (Eco Logical, 2019) indicates that creation of permanently inundated areas across Big Swamp will cause a complete loss of non-aquatic vegetation. However, these losses will be offset by the improvements in areas of increased surface flow and higher groundwater levels.

  To mitigate loss of vegetation, Eco Logical suggests that hydraulic barriers are realised so that a dynamic regime of inundation and drying is established over the year. This could be realised, for example, by incorporating weirs and gates as part of the hydraulic barrier design to allow a degree of control on the level and duration of inundation.

  It is noted that, while a seasonal regime would be beneficial for vegetation, it may not be practical to implement and also have the adverse consequences of increasing acid release downstream of Big Swamp and limit the ability to promote reducing conditions required for neutralisation of acidity.

- **Reduce fire risk: Medium to High.**

  Increasing groundwater levels and maintaining a more permanent surface water coverage across Big Swamp is likely to reduce fire risks, depending on the portion of the Big Swamp that will be permanently inundated.

### 7.3.7 Active Treatment System

#### 7.3.7.1 Principle

This option relies on installing an active treatment system immediately downstream of Big Swamp to increase alkalinity/pH and remove metals (as precipitates) prior to releasing the treated water into Boundary Creek.

Based on a design treatment flow rate of 4 ML/d and water quality parameters summarised in Table 7-1, the proposed solution involves the installation of an in-stream system (water or electric powered) dispensing pebble quicklime ($CaO$) directly into Boundary Creek (such as the Aquafix system in Figure 7-18).

The in-stream system will be followed by a settling pond (and/or aerobic wetland) to oxidise water and facilitate precipitation of metals. Treated water flowing from the settling pond would then be directed to Boundary Creek.

The advantages of an in-stream system over a fixed plant are reduced capital costs, low O&M intensity and small footprint. However, in-stream systems are suitable within a certain acid load range (i.e. treatment flow rate multiplied by water acidity) and input parameters will require to be properly considered when developing system design to assess which option would be more suitable.

**Figure 7-18 Aquafix Quicklime Dispensing System**

### 7.3.7.2 Implementation

Possible implementation and cost estimate of the system has been progressed using AMDTreat software for a reference design flow rate of 4 ML/d and water quality parameters in Table 7-1. Flow in excess of the design treatment capacity would have to by-pass the in-stream system and be discharged directly in Boundary Creek.

Based on AMDTreat estimates, the consumption of quicklime to neutralise acidity is in the range of 1.45 t/day (for a treatment pH of 6) and sludge production in the range of 15-30 $m^3$/day (depending on various parameters including water quality, quicklime mixing efficiency, target pH and sludge density). The Aquafix system would have a storage capacity of 50 t, allowing for one refilling of quicklime per month.

Dimensions of the settling pond are 57 m wide, 110 m long and 3 m deep, ensuring a residence time of 48 hours and allowing for removal of sludge every year.

It is noted that the above figures on chemical consumption and sludge production are based on limited data and need to be verified by laboratory and field trials that would be required to progress design of this option.

### 7.3.7.3 Expected Performance

Use of pebble quick lime is a consolidated approach for treatment of water impacted by acidity and metals, and systems like the Aquafix have been successfully employed in the United States for treatment of high acidity/high flow situations.

The effect of the system on Boundary Creek water quality is likely to be variable and depending on seasonal variations of streamflow values and acidity loads, as summarised below:

- When Boundary Creek flow rates fall within the in-stream design treatment capacity (i.e. 4 ML/d as assumed in the ROA), it is expected that water into the creek would be of good quality, with a pH greater than 6 units and low concentration of dissolved iron and aluminium.
- Flow rates in excess of the design treatment capacity would have to by-pass the in-stream system and water quality in Boundary Creek would be a result of the mixing of the treated and untreated streams.
- Depending on finals system design, periods of higher acidity loads (which could happen at any flow rate) could be managed by increasing the pebble quicklime dosing rates, until the maximum system neutralising capacity is reached. Any acidity load above the system capacity will not be treated by the in-stream system.

#### 7.3.7.4 Geochemical Considerations

The main geochemical consideration associated with this option (GHD, 2019) are summarised below:

- Stream flows at Yeodene gauge in excess of the 4ML/d treatment capacity (as assumed in the ROA) occurred around 27% of the time over the monitoring period post January 2000.
- Acidity concentrations at Yeodene gauge in excess of 500 mg/L (based on automated pH data collected by the Yeodene monitoring station) occurred around 50% of the time over the monitoring period post January 2000.
- Modelled reagent dosing rate (assuming the use of lime and a target pH of 6 units) are estimated in the range of 300 kg/d, which is considerably less than the pebble quicklime dosing rate provided by the AMDTreat software.
- Modelled sludge generation rates are in the range of 2,500-25,000 $m^3$ per year (depending of acidity loads) which is considered to be consistent with the sludge generation rate provided by the AMDTreat software.

This analysis indicates that there is potential for the system capacity assumed in the ROA to be undersized during periods of high flow and/or high acidity, which would result in decreased water quality in Boundary Creek.

Additional data and studies will be required to select system performance requirements as well as to inform and refine the current estimates on chemical dosing rates and sludge production.

#### 7.3.7.5 Cost Estimate

Design inputs, cost assumption and estimated costs (per 10 years operational time) are summarised in Table 7-14 and Table 7-15.

**Table 7-14 In-stream treatment - Design Inputs and Cost Assumptions**

| Design inputs | Cost Assumptions | O&M and sampling assumptions |
|---|---|---|
| Flow rate: 4 ML/day<br>Acidity: 500 mg/L<br>Sludge volume: 6,700 $m^3$/year (at 5% solids)<br>Sludge removal events: one per year<br>Sludge generation rate: 0.0046 $m^3$ sludge / $m^3$ water<br>CaO dosing rate: 1.45 t/day $^{-1}$ | • No management cost (i.e. pre-classification and disposal) for soil volumes excavated for settling pond construction (14,530 $m^3$)<br>• Land acquisition cost: $ 20k/ha<br>• Sludge removal rate: $ 50/$m^3$<br>• Chemical cost with delivery: $ 200/t | Monthly water sampling, 4 samples per event<br>O&M cost 3.5% of capital cost for consistency with AMDTreat |

**Table 7-15 In-stream treatment – Treatment cost per 10 years operational time**

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Capital | $ 550,000 | |
| Engineering | $ 110,000 | 20% of capital. Excludes cost of modelling, treatability studies, pilot trials, etc. |

| Cost item | Estimate (AUD) | Notes |
|---|---|---|
| Land Acquisition | $ 100,000 | Assumed 5 ha |
| Chemical cost per year | $ 110,000 | |
| Sludge removal per year | $ 335,000 | |
| Sampling per year | $ 20,000 | |
| O&M per year | $ 20,000 | O&M (3.5% of capital). Routine O&M, no major reconstruction work. |
| Total 10 years | $ 5,610,000 | |

#### 7.3.7.6 Overall Assessment

Based on the above, our assessment of the ability of this remediation option (in the implementation described above) to achieve the project objectives is as follows:

- **Maintain minimum groundwater levels in Big Swamp: No effect.**

  No effect on groundwater levels is expected from implementation of this technology.

- **Control acid release: High.**

  This technology has a high potential to control the acid discharge from the swamp, assuming that adequate design parameters are selected using additional data from Boundary Creek monitoring (flow rates and water quality), geochemical modelling, treatability studies and pilot trials.

- **Manage secondary precipitates: High.**

  Secondary precipitates will be captured in the settling pond.

- **Maintain Boundary Creek minimum flow: No effect.**

  No effect on surface water flows is expected from implementation of this technology.

- **Improve vegetation: No effect.**

  Implementation of this technology will have no effect on vegetation in Big Swamp.

- **Reduce fire risk: No effect.**

  No effect on fire risk is expected from implementation of this technology.

## 7.4 Ability to Meet Project Objectives

Our assessment of the ability of each technology to meet the project objectives is described in Section 7.3 and summarised in Table 7-16.

**Table 7-16 Ability to Meet Objectives**

| Option / Objective | Maintain minimum GW levels in Big Swamp | Control acid release | Manage secondary precipitates | Maintain Boundary Creek Minimum Flow | Increase Melaleuca/Swamp Ovata ratio | Reduce Peat Fire Risk |
|---|---|---|---|---|---|---|
| Aerial liming | No effect | Low to Medium | Pot. Worse | No effect | Not known | No effect |
| Soil Mixing | No effect | Low(1) | No effect | No effect | Pot. Worse | No effect |
| Excavation and disposal | No effect | Low(1) | No effect | No effect | Pot. Worse | No effect |
| Aerobic Wetland | No effect | Low | Medium(2) | No effect | No effect | No effect |
| RAPS | No effect | Medium to High | High | No effect | No effect | No effect |
| Managed Groundwater Levels and Wetland Flooding | Medium to High(3) | Low to Medium(4) | Pot. Worse (if unmanaged)(5) | High(6) | Medium to high(7) | Medium to high |
| In-Stream dosing | No effect | High | High | No effect | No effect | No effect |

*Notes:*

*(1): Assuming only targeted treatment of 'hot spots' is practicably achievable.*

*(2): Assuming the aerobic wetland is integrated as part of other remediation options.*

*(3): Depending on detailed design, including actual volumes of supplementary flow and number/location/levels of hydraulic barriers.*

*(4): The 'low' ability assessment is related to the potential risk of increased export of acidity by increased volumes of supplementary flow and the formation of soluble/mobile ferrous iron under reducing conditions in the permanently inundated areas of Big Swamp.*

*Both processes will be ongoing until existing and retained acidity is present in Big Swamp and available organic carbon and ferric iron are present, so these side effects are expected to last for several years.*

*The 'medium' ability assessment acknowledges that above processes may be mitigated by several factors, including:*

- *progressive reduction of exported acidity as the actual and retained acidity is flushed away from the system and higher groundwater levels minimising further aerobic oxidation of ASS sediments*
- *neutralisation of acidity as part of iron reduction reactions*
- *precipitation of ferrous iron, as indicated in the Monash University incubation testing*

*Management of the above risks will require collection of additional data to improve the current understanding of the significance and temporal/spatial variability of the above processes as well as ongoing monitoring. Depending on the results of these additional studies and data collection, risk mitigation (i.e. contingency) measures will require to be implemented so that the risks are reduced to acceptable levels.*

*(5): It is recognised that export of ferrous iron in Boundary Creek has the potential to generate acidity as well as precipitation of insoluble iron compounds.*

*Management of the above risks will require collection of additional data to improve the current understanding of the significance and temporal/spatial variability of the above processes as well as ongoing monitoring. Depending on the results of these additional studies and data collection, risk mitigation (i.e. contingency) measures will require to be implemented so that the risks are reduced to acceptable levels.*

*(6): Assuming supplementary flow is effectively released downstream of McDonalds Dam.*

*(7): Depending on the ability to achieve a workable solution that balances the need to increase surface water flow and extent of permanently inundated areas with the goals of promoting higher ecological values and minimising loss of vegetation across Big Swamp.*

## 7.5 Technology Scoring

Ranking of each indicator for the shortlisted remediation options, based on information provided in the previous sections, is presented in Table 7-17.

**Table 7-17 Technology Scoring**

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

| Indicators | Aerial liming | Soil Mixing | Excavation and disposal | Aerobic Wetland | RAPS | In-stream dosing | Flooding and GW levels |
|---|---|---|---|---|---|---|---|
| F2 – Chemical resource use | 4 | 2 | 5 | 4 | 3 | 2 | 5 |
| F3 - Waste generation and recycling potential | 5 | 4 | 1 | 3 | 2 | 2 | 5 |
| F4 – Emissions | 4 | 3 | 3 | 4 | 2 | 3 | 4 |

## 7.6 Technology Ranking and Weighting

The score for each category has been totalled and normalised before a total score is calculated. The total score for each category has been set at 50, with a potential total score of 300 (six categories). This provides an unweighted score, where each category has equal weighting. The total category scores, total unweighted score and ranking of technologies is presented in Table 7-18.

During the first Technical Workshop it was identified that the scores could be weighted, depending on which category the stakeholders and Barwon Water deem to be most important. The weightings used in the weighted assessment were suggested by Darren Baldwin (Technical Expert for the RWG) on behalf of the technical panel and comprise:

- A - Technical = 40%
- B - Logistical = 10%
- C - Financial = 10%
- D - Stakeholders = 30%
- E - Timing = 5%
- F - Sustainability = 5%

The weighted score and ranking are shown in Figure 7-19 Table 7-19. 'Aerial liming' ranks highest in the unweighted scoring with 'managed groundwater levels and wetland flooding' ranking highest in the weighted assessment. The 'aerobic wetland' option and 'in-stream dosing' rank equal third in the unweighted assessment, but when technical aspects are prioritised in the weighting, the 'aerobic wetland' option drops to fourth, with 'in-stream dosing' scoring much higher and ranking third.

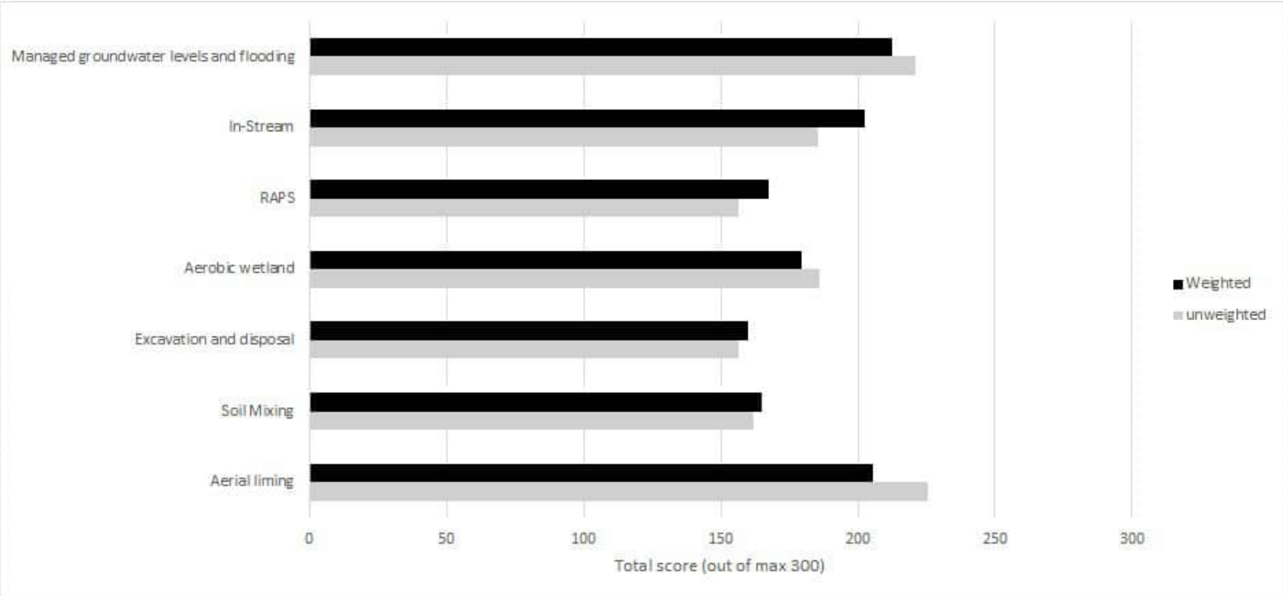


**Figure 7-19 Results of scoring and ranking (weighted and unweighted) for the technologies for detailed assessment**

**Table 7-18 Category scores, total scores and ranking, weighted and unweighted**

| Option | A - Technical | B - Logistical | C- Financial | D - Stakeholders | E - Timing | F - Sustainability | Total unweighted score | Unweighted Rank | Total weighted score | Weighted Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| Aerial liming | 30 | 40 | 40 | 34 | 37 | 45 | 226 | **1** | 206 | **2** |
| Soil Mixing | 28 | 30 | 30 | 26 | 20 | 28 | 162 | **5** | 165 | **6** |
| Excavation and disposal | 28 | 33 | 27 | 24 | 20 | 25 | 157 | **7** | 160 | **7** |
| Aerobic Wetland | 23 | 33 | 37 | 36 | 20 | 38 | 186 | **3** | 180 | **4** |
| RAPS | 30 | 25 | 17 | 30 | 30 | 25 | 157 | **6** | 168 | **5** |
| In-Stream dosing | 35 | 28 | 27 | 38 | 33 | 25 | 186 | **3** | 202 | **3** |
| Managed Groundwater Levels and Wetland Flooding | 30 | 45 | 33 | 40 | 30 | 43 | 221 | **2** | 213 | **1** |

### 7.6.1 The Effects of Weightings

In order to test the effect of different weightings on the overall scores and rankings, a sensitivity analysis was undertaken. This consisted of varying the weightings one by one so that one category had a weighting of 75% whist the remaining had a weighing of 5%. The results are shown in Figure 7-20 and Table 7-19.

As can be seen, managed groundwater levels and wetland flooding score highest where logistical or stakeholders are prioritised, whereas aerial liming ranks highest for financial, timing and sustainability weighted assessments. Where technical considerations are prioritised, in-stream dosing ranks highest. In stream dosing scores highly across most categories, with the exception of logistical (intense ongoing operating requirements), financial and sustainability (large amounts of chemical use).

Soil mixing and excavation score consistently low across all categories as these technologies are very expensive and are unlikely to meet the project objectives. A standalone aerobic wetland scores low technically (unlikely to meet remediation objectives) and when timing is prioritised but relatively well for logistical, financial and sustainability due to the inactive style of treatment requiring little ongoing operation and cost. RAPS score consistently low as this technology is difficult to implement, expensive and produces hydrogen sulphide, which is both an environmental issue and unlikely to be acceptable to stakeholders due to the odour issues.

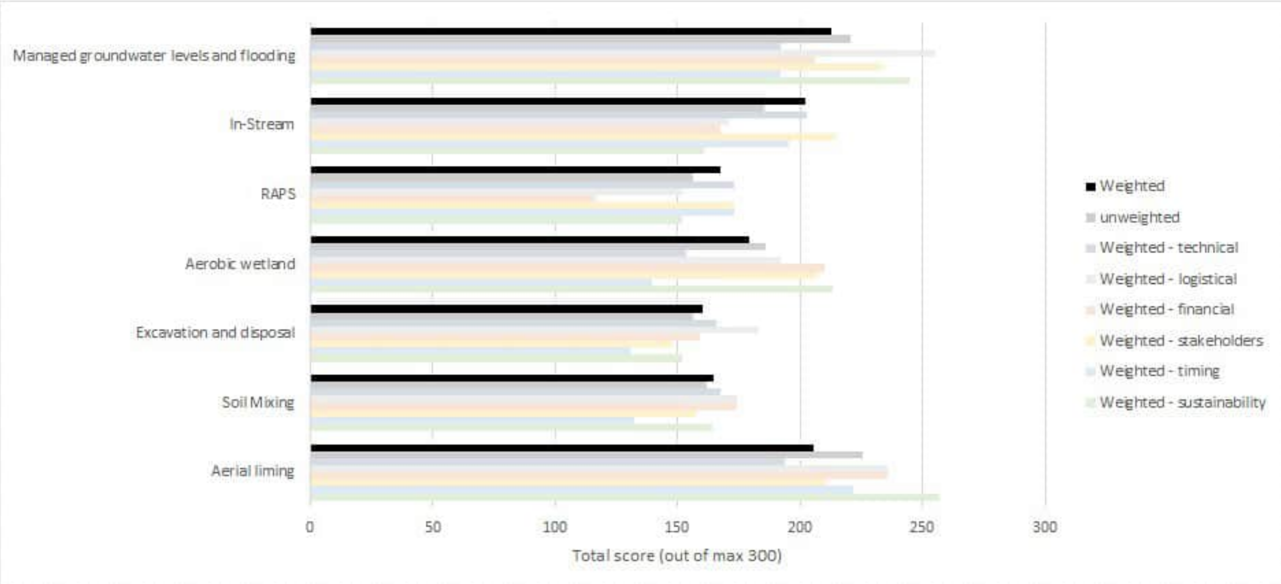


**Figure 7-20 Sensitivity analysis for category weightings**

**Table 7-19 Results of sensitivity analysis of weightings on ranking and overall score**

| Option | Weighted Category | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A - Technical | | B - Logistical | | C – Financial | | D - Stakeholders | | E - Timing | | F - Sustainability | |
| | Total weighted score | Weighted Rank | Total weighted score | Weighted Rank | Total weighted score | Weighted Rank | Total weighted score | Weighted Rank | Total weighted score | Weighted Rank | Total weighted score | Weighted Rank |
| Aerial liming | 195 | 3 | 237 | 2 | 279 | 1 | 212 | 3 | 195 | 5 | 258 | 1 |
| Soil Mixing | 181 | 4 | 181 | 5 | 195 | 4 | 164 | 6 | 209 | 3 | 171 | 4 |
| Excavation and disposal | 178 | 5 | 189 | 4 | 164 | 6 | 153 | 7 | 206 | 4 | 157 | 6 |
| Aerobic Wetland | 157 | 7 | 195 | 3 | 227 | 3 | 210 | 4 | 171 | 7 | 216 | 3 |
| RAPS | 175 | 6 | 154 | 7 | 133 | 7 | 175 | 5 | 189 | 6 | 154 | 7 |
| In-Stream dosing | 204 | 2 | 172 | 6 | 169 | 5 | 216 | 2 | 211 | 2 | 162 | 5 |
| Managed Groundwater Levels and Wetland Flooding | 211 | 1 | 260 | 1 | 253 | 2 | 239 | 1 | 211 | 1 | 250 | 2 |

# Section 8 **Risk Assessment**

The following sections present methodology and results of a risk assessment undertaken on the proposed controls and actions that can be practically implemented for remediation of Big Swamp and Boundary Creek, in accordance to a requirement of the Section 78 Notice.

## 8.1 Identification of Practical Remediation Options

Through the technology identification process (Section 6.1), a total of 17 remediation option have been considered as potentially applicable for remediation of Big Swamp and Boundary Creek. Following preliminary screening (Section 6.2), seven remediation options were then retained for detailed assessment and relative ranking of technologies.

The result of the detailed assessment (Section 7) has indicated that three of the retained remediation options can be practically implemented at the site and include 'managed groundwater levels and flooding', 'in-stream dosing' and 'aerial liming'. Also 'aerobic wetland' has been included in the risk assessment because, while not suitable to be implemented in isolation, it could be considered as a final treatment step of other remediation options for the management of precipitates.

The other three retained options ('RAPS', 'soil mixing' and 'soil excavation/disposal) are considered unlikely to be practicably implemented at the site because of technical, logistical and financial considerations or the overall assessment on their ability to meet the project objectives. Therefore, they have not been included in the risk assessment.

As part of the risk assessment process, the 'managed groundwater levels and flooding' and 'in-stream dosing' remediation options have been broken down in their basic components to assist with identification and assessment of potential risks, as follows:

- 'Managed groundwater levels and flooding' assessed as a combination of the following components:
  - Infilling of fire trench and drains
  - Provision of supplementary flow
  - Installation of hydraulic barriers
- 'In-stream dosing' assessed as a combination of the following components:
  - Dosing system and handling of neutralising agent
  - Settling pond and sludge management

In addition, the 'aerial liming' option has been assessed as a more generic 'surface application of neutralising agents' so that the risks associated with potential implementation of this technology using terrestrial application methodologies.

Lastly, the 'in-stream limestone sand' option, that was not retained following preliminary screening, has also been included in the risk assessment. As discussed further in (Section 9), this technology is basically a simpler version of the 'In-stream dosing' remediation option, and has been included in the risk assessment because it that could be considered as part of a set of contingency measures to manage some of the potential side effects of remediation.

## 8.2 Scope of Risk Assessment

The risk assessment process carried out in the ROA comprised the following tasks:

- Identification of a set of risk groups considered applicable categories for project risk considerations.

- Based on the current understanding of the project context (summarised in the RCM, (Section 3) and the characteristic of the proposed practical remediation options, identification of the potential risks events associated with each option.
- Qualitative evaluation of the potential significance of project risks (risk analysis), based on assessment of likelihood of occurrence and adverse impacts of occurrence.
- Identification of mitigation measures that could be implemented to address project risks and evaluation of residual risks.

Additional details on the risk assessment steps are provided in the following sections.

## 8.3 Risk Group Identification

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

- **Health and safety**: the potential for the remediation option to impact on human health of worker, operators, visitors and members of the public during construction and operation.
- **Environment**: the potential for the remediation option to cause detrimental effects on the environment, including generation dust, vibration, noise, air emission and impacts on soil, groundwater or surface water quality.
- **Financial**: the potential for the remediation option to incur additional capital or ongoing costs, as well as additional potential costs associated with remediation of detrimental side effects or financial impacts to third parties
- **Community**: the potential for the remediation option to cause negative feedback or concerns from the community.
- **Regulatory**: the potential for the remediation technology to cause concern, delays or litigation by the relevant Regulatory Authorities or fail to meet Section 78 Notice requirements.
- **Technical Performance**: the potential for the remediation technology to not perform as expected because of insufficient site characterisation, site complexity, inadequate technology selection, design or construction, lack of maintenance or inappropriate remediation objectives.
- **Logistical, infrastructure and planning**: the potential for the remediation technology to be constrained by difficult access, lack or resources, damage to infrastructure, local zoning or long-term land use plans.

## 8.4 Risk Identification

This task was undertaken as an internal workshop exercise that involved undertaking of a systematic review of each selected remediation options against the risk groups defined in the previous section to identify project-specific risk events to be analysed.

## 8.5 Risk Analysis

Risk analysis involves assessment of the likelihood of a certain risk event occurring and the potential consequences of the event. Project-specific likelihood criteria, consequence framework and risk matrix, developed in consultation with Barwon Water and in general accordance with AS/NZS ISO 31000:2009 Risk management – Principles and guidelines, are provided in Table 8-1 to Table 8-3.

### Table 8-1 Likelihood Rating Criteria

| Scale | Likelihood Descriptor |
|---|---|
| Almost Certain – E | Event is expected to occur in most circumstances |
| Likely - D | Event would probably occur in most instances |
| Possible - C | Event could occur at some time |
| Unlikely - B | Event is not expected to occur |
| Rare - A | Event will only occur in exceptional circumstances |

### Table 8-2 Consequence Framework

| Risk Group / Level | Health and safety | Environment | Financial | Community | Regulatory | Technical (performance) | Logistical / infrastructure |
|---|---|---|---|---|---|---|---|
| **Extreme** 5 | Death or permanent disability | Environment suffers harm for 20+ years | Very serious financial loss | Very serious public outcry | Regulatory approval withheld | Technology causes a worsening of conditions in Big Swamp and Boundary Creek | Constraint causes project to stop |
| **Severe** 4 | Extensive or permanent injury | Environment suffers harm for 10 to 20 years | Major financial loss | Serious adverse public attention | Regulatory approval dependant on significant additional work over long period | Technology fails to provide any improvement of conditions in Big Swamp and Boundary Creek | Constraint causes significant delay and cost |
| **Major** 3 | Injury requiring hospitalisation | Environment suffers harm for 5 to 10 years | Significant financial loss | Adverse localised negative public attention | Regulatory approval dependant on major additional work over medium time period | Technology fails to provide significant improvement of conditions in Big Swamp and Boundary Creek | Constraint causes major delay or cost |
| **Moderate** 2 | Minor injuries requiring hospital treatment | Reversible short term environmental harm | Minor financial loss | Adverse localised public attention | Regulatory approval dependant on some additional work which is already ongoing | Technology provides limited improvement to Big Swamp and Boundary Creek conditions | Limited delay or cost associated with constraint |
| **Minor** 1 | Injury requiring first aid | Minor effect on the environment | Minor and localised financial loss | Very limited public interest | Regulatory approval dependant on minor additional work | Technology provides minor improvement to Big Swamp and Boundary Creek conditions | No delay or cost associated with constraint |

### Table 8-3 Risk Matrix

| Likelihood | Consequence | | | | |
|---|---|---|---|---|---|
| | **Minor (1)** | **Moderate (2)** | **Major (3)** | **Severe (4)** | **Extreme (5)** |
| **Almost Certain (E)** | Low (1E) | Medium (2E) | High (3E) | Critical (4E) | Critical (5E) |
| **Likely (D)** | Low (1D) | Medium (2D) | High (3D) | Critical (4D) | Critical (5D) |
| **Possible(C)** | Insignificant (1C) | Low (2C) | Medium (3C) | High (4C) | Critical (5C) |
| **Unlikely (B)** | Insignificant (1B) | Insignificant (2B) | Low (3B) | Medium (4B) | High (5B) |
| **Rare (A)** | Insignificant (1A) | Insignificant (2A) | Insignificant (3A) | Low (4A) | Medium (5A) |

## 8.6 Mitigation Measures and Residual Risks

Project risk mitigation involves planning and executing a response or mitigation strategy to address project risks. Mitigation efforts reduce the impact of a project risk or decrease its likelihood of occurrence (residual risk). Some project risks may be unavoidable; others may not warrant mitigation if they are low-level risks.

Common risk mitigation measures, generally applicable for remediation projects, include the following:

- Employing redundant systems or processes.
- Considering alternative technologies.
- Conducting treatability studies to better assess technology and remedy performance.
- Setting interim performance goals to identify conditions.
- Communicate to stakeholders that the final objectives may not be met as planned.
- Adopting a simpler process.
- Adding or reallocating resources.
- Negotiating project scope or compliance requirements with regulatory agencies.
- Adjusting schedules; implementing early starts to activities.
- Performing aggressive cost control.

## 8.7 Risk Register

The results of the risk assessment are presented in a risk register as Appendix A. The risk events that resulted in a high or medium residual risk are presented in Table 8-4. No critical residual risks were identified.

**Table 8-4 Risk Register (Medium Residual Risks Only)**

| Risk ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measure | Residual Risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk Ranking | | | Consequence | Likelihood | Risk Ranking | |
| R031 | Environment | Provide supplementary flow | Change in vegetation communities in eastern part of the swamp due to increased extent of permanently inundated areas | 3 - Major | Environment suffers harm for 5 to 10 years | E - Almost Certain | Event is expected to occur in most circumstances | 3E | High | Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with increased surface flow.<br>Establish supplementary flow so that the extent of the permanently inundated areas is kept to a minimum.<br>Allow seasonal variability of supplementary flow to minimise potential loss of vegetation.<br>Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation. | 2 - Moderate | E - Almost Certain | 2E | Medium |
| R037 | Environment | Install hydraulic barriers | Change in vegetation communities across the swamp due to the creation of additional permanently inundated areas | 3 - Major | Environment suffers harm for 5 to 10 years | E - Almost Certain | Event is expected to occur in most circumstances | 3E | High | Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with installation and operation of hydraulic barriers.<br>Design hydraulic barriers so that the extent of the permanently inundated areas is kept to a minimum.<br>Design hydraulic barriers so that inundation levels cab be seasonally adjusted.<br>Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation. | 2 - Moderate | E - Almost Certain | 2E | Medium |
| R056 | Environment | Settling pond and sludge management | Loss of vegetation for construction of settling pond | 3 - Major | Environment suffers harm for 5 to 10 years | E – Almost certain | Event could all the time | 3C | High | Locate settling pond in an area of low ecological value.<br>Consider construction of an aerobic wetland as part of the settling pond to offset loss of vegetation. | 2 - Moderate | E – Almost certain | 2E | Medium |
| R060 | Environment | Aerobic wetland | Change in vegetation type associated with permanently inundated conditions | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Locate aerobic wetland in an area of low ecological value.<br>Design aerobic wetland to incorporate areas of different water depth so that diverse vegetation and ecosystem will establish. | 3 - Major | C - Possible | 3C | Medium |
| R102 | Community | Install hydraulic barriers | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - Major | C - Possible | 3C | Medium |
| R128 | Community | In stream treatment – Boundary Creek | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - Major | C - Possible | 3C | Medium |
| R137 | Community | Settling pond and sludge management | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - Major | C - Possible | 3C | Medium |
| R142 | Community | Aerobic wetland | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - Major | C - Possible | 3C | Medium |
| R155 | Regulatory | Settling pond and sludge management | Approval for waste disposal or onsite storage of generated sludge required | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Include planning for waste disposal early in the design process and engage with potential receivers. Test any sludge developed during pilot trials to inform planning of waste disposal and waste categorisation. | 3 - Major | C - Possible | 3C | Medium |

| Risk ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measure | Residual Risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk Ranking | | | Consequence | Likelihood | Risk Ranking | |
| R170 | Technical | Install hydraulic barriers | Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions) | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 5C | Critical | Continue to monitor during installation of barriers and inundation to improve understanding of geochemical reactions in the swamp. Consider implementation as a staged approach (one barrier at a time) so that the effects can be assessed on a small scale before wider implementation. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment. | 4 - Severe | B - Unlikely | 4B | Medium |

# Section 9 **Preferred Option**

## 9.1 Process Overview

This report details the results of a ROA for identification of preferred remediation options to address ASS impacts to Big Swamp and Boundary Creek, in response of a Section 78 Notice issued to Barwon Water.

The framework developed to identify the preferred remediation option for management of ASS impacts at the site comprised:

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

A risk assessment was also performed on the selected practically achievable remediation options to identify potential risks and required management measures associated with implementation of each option, in accordance with one of the requirements of the Section 78 Notice.

Inputs and feedback from the RWG technical experts and the community were sought at various stages of the process to assist with development of key aspects of the ROA.

## 9.2 Summary of Results

Results of the weighted scoring from the detailed assessment of the options retained after preliminary screening provides the following ranking:

1. Managed Groundwater Levels and Wetland Flooding
2. Aerial liming
3. In-stream treatment
4. Aerobic wetland
5. Soil Mixing
6. RAPS
7. Excavation and disposal

These results, being the outcome of a multi-parameter assessment, provide an indication of the remediation options that, overall, are likely to achieve the best outcomes for the project. The following considerations can be made:

- The three highest ranking options aim to neutralise acidity in Boundary Creek by chemical addition/dosing (‘aerial liming’ and ‘in-stream treatment’) or by reducing further oxidation and establishing favourable natural processes (‘managed groundwater levels and flooding’). As the source of acidity (i.e. oxidised ASS sediments) is unlikely to be significantly affected by any of these technologies (with the possible exclusion of ‘managed groundwater levels and flooding’), it is expected that these options would be required to be implemented, monitored and optimised over long periods (i.e. decades).

- The options aimed at addressing the source of acidity ('soil mixing' and 'excavation and disposal') both achieved low scores, mostly because of the financial and logistical difficulties of treating or removing a substantial volume of soil characterised by high levels of net acidity requiring neutralisation.
- Comparison of weighted and unweighted scoring, as well as sensitivity analysis, seems to indicate that the ROA results are relatively robust, with minor reordering of the preferred options occurring when the weighting is intentionally skewed towards a single category, with the effect of exaggerating the advantages of certain options against the others. For example, when timing is highly prioritised in the weighting system, an option that is quick to implement such as aerial liming is found to score substantially better than other options.

## 9.3 Ability to Meet Project Objectives

Assessment of the ability of each option to achieve the project objectives (Table 7-16) provides additional insights on which options should be preferred, including:

- It is apparent that none of the retained options is capable, in isolation, of meeting the project objectives in the short term. For this reason, a combination of options is likely to be required.
- A range of potential detrimental side effects with respect to the project objectives are associated with each of the options. While some of these are intrinsic to the technology underlying the option (i.e. loss of ecological values caused by soil excavation and disposal) and are difficult to minimise, others can be managed as part of the design/planning stage and/or by implementing a monitoring regime and a range of contingency measures to minimise the impacts of these side effects.
- Of the seven retained options, 'managed groundwater levels and wetland flooding' is the only option that has potential to achieve three of the project objectives ('maintain minimum groundwater levels in Big Swamp', 'maintain Boundary Creek minimum flow' and 'reduce fire risk/threat'). Therefore, it is unlikely that any remediation strategy that does not include this option will be able to achieve the project objectives and vision.
- The 'managed groundwater levels and wetland flooding' is an option that carries some potentially negative side effects, as discussed below:
  - By increasing surface water flow across Big Swamp, it is likely that actual acidity (and to a minor extent retained acidity) will be mobilised and transported to downstream receiving environments (GHD, 2019). This export of acidity is expected to gradually abate over time as actual and retained acidity are flushed from the system, ongoing aerobic oxidation of ASS sediments is minimised and potential acid neutralisation reactions (i.e. iron reduction) occur in the reflooded portions of Big Swamp.
  - The soluble and mobile ferrous iron produced in permanently inundated areas of Big Swamp, if not retained as a stable precipitate, has the potential to migrate in downstream surface water environments (i.e. Boundary Creek and Barwon River) and generate acidity and secondary precipitates. While recent incubation testing data (Monash University, 2019) indicate a reduction of soluble ferrous iron which could mitigate this issue, additional data are required to understand if the same process would occur in Big Swamp, as well as the temporal stability of the precipitated form. Ongoing monitoring and planning for potential implementation of contingency measures (i.e. construction of a settling pond) should be included in remediation planning to mitigate these risks.
  - Eco Logical (2019) indicates that changes (i.e. loss) to vegetation would occur in response to the creation of permanently inundated areas across Big Swamp. This issue will required to be addressed as part of detailed design where the loss of vegetation in some areas of Big Swamp is balanced against improved conditions in other areas of Big Swamp and Boundary Creek. In addition, the loss of vegetation could be mitigated as part of detailed design, where the hydraulic barriers are designed to allow for flooded waters (if of suitable quality) to be released downstream of the barriers during certain periods of the year (for example by providing the barriers with mobile weirs or other means to adjust inundation levels).

  - When compared to other retained options (such as 'aerial liming' and 'in-stream' treatment') this option is likely to require longer timeframes to achieve improvements on Boundary Creek water quality. While estimates of these timeframes is extremely uncertain at the state of current knowledge, no significant improvement to Boundary Creek water quality should be expected in the first 5-10 years of operation, depending on the following factors:
    - The rate of flushing of actual and retained acidity by increased surface water flows across Big Swamp.
    - The effectiveness of higher groundwater levels to prevent further oxidation of ASS sediments.
    - The occurrence of acid neutralising reaction in permanently flooded areas of Big Swamp.
    - The potential for downstream export of the newly generated acidity in the form of soluble ferrous iron.
- Aerial liming is a relatively simple and cost-effective option that offers several advantages compared to more complex options and, as a result, scores particularly well when assessed using a broad range of parameters. However, when assessed against the ability to meet the project objectives (which is only reflected in one of the scoring indicators), aerial liming does not appear as favourable as the total scoring (based on the remaining 24 indicators) would suggest.

## 9.4 Assessment and Management of Potential Risks

The risk assessment process has identified a total of 223 risk associated with potential implementation of the following practical remediation measures:

- 'Managed groundwater levels and flooding' assessed as a combination of the following components:
  - Infilling of fire trench and drains
  - Provision of supplementary flows
  - Installation of hydraulic barriers
- 'In-stream dosing' assessed as a combination of the following components:
  - Dosing system and handling of neutralising agent
  - Settling pond and sludge management
- 'Aerobic wetland'
- 'Surface application of neutralising agents'
- 'In-stream limestone sand'

For each of the identified risks, a range of potentially applicable mitigation and management measures have been identified and the residual risks determined based on the mitigation proposed.

The outcomes of the risk assessment process, summarised in the risk register (Appendix A), indicates that the risks associated with the practical remediation measures can be adequately managed through implementation of mitigation measures, with only 10 residual risks ranked as 'medium'.

The risk mitigation measures generally include collection of additional data to improve understanding and assessment of risks, undertaking monitoring activities to confirm if the identified risks are present and implementation of contingency measures to treat unacceptable risks.

## 9.5 Preferred Option and Next Steps

Based on these above considerations, the 'managed groundwater levels and wetland flooding' remediation option is considered to be the preferred remediation option and is to be included as part of the remediation strategy.

The main reason for this outcome is that this option is the only one with the ability to achieve the 'maintain minimum groundwater levels', 'maintain Boundary Creek minimum flow' and 'reduce peat/fire risk' project objectives.

The following steps should be considered as part of remediation planning:

- To assist with successful implementation of the preferred option, address the uncertainties associated with performance and manage its potential side effects, the following provision should be included as part of remediation planning:
  - Collection of additional data on surface water and groundwater (flow, levels and quality).
  - Use the additional data to refine calibration of surface water and groundwater models, as wells running additional modelling scenarios to support design (i.e. groundwater response to a range of intermediate supplementary flows and groundwater/surface water response to installation of multiple barriers).
  - Undertake kinetic testing to support further geochemical reaction to refine assessment of remediation timeframes.
  - Incorporate ecological condition assessment within the preferred remediation option design to inform practical solution to mitigate potential unacceptable changes to vegetation associated with this option.
  - Consider an adaptive approach for implementation of the preferred remediation options, where the critical or more informed elements of each option are prioritised.
- The 'aerial liming' and 'in-stream treatment' remediation options are considered either as contingency measures or in conjunction with the preferred remediation option, depending on the effectiveness of the preferred remediation option in achieving the project objectives and/or the severity of its potential negative side effects.
- The 'limestone sand' remediation option is also retained as part of remediation planning as a contingency measure, considering low cost and ease of implementation.
- The risk assessment undertaken as part of the ROA is periodically reviewed and updated on the base of the new data and available information.
- An adequate monitoring regime, trigger levels and contingency measures are incorporated as part of the design of the preferred remediation option so that the risks associated with its potential detrimental side effects can be addressed in a timely and effective manner.
- Additional data collection and testing to support feasibility of the other contingency or supplementary options ('aerial liming', 'in-stream treatment' and 'limestone sand') is undertaken to facilitate timeline implementation of these technologies, should this be required. This is particularly important for the 'in-stream treatment' option in consideration of its higher complexity and financial implications.

# Section 10 **Disclaimer and Limitations**

This report has been prepared by CDM Smith Australia Pty Ltd (CDM Smith) for the sole benefit of Barwon Water for the sole purpose of undertaking a Remediation Option Assessment for technologies to treat ASS at Big Swamp.

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If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

# Section 11 **References**

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# Appendix A Risk Register

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R001 | Health and safety | Infilling fire trench and drainage channels | Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R002 | Health and safety | Infilling fire trench and drainage channels | Injury to public and workers associated with increased truck traffic on local roads | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R003 | Health and safety | Install hydraulic barriers | Injury to workers associated with operating or being in the vicinity of machinery (e.g. piling) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R004 | Health and safety | Install hydraulic barriers | Injury associated with increased truck traffic on local roads | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R005 | Health and safety | Install hydraulic barriers | Drowning risk to third parties in standing water | 5 - Extreme | Death or permanent disability | A - Rare | Event will only occur in exceptional circumstances | 5A | Medium | Limit access of third parties to inundated areas | 1 - | A - | 1A | Insignificant |
| R006 | Health and safety | Surface application of neutralising agents | Injury to workers associated with operating of being in vicinity of machinery (e.g. helicopters/suspended loads) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R007 | Health and safety | Surface application of neutralising agents | Injury to public and workers associated with increased truck traffic on local roads | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R008 | Health and safety | Surface application of neutralising agents | Injury to workers associated with inhalation of or contact with neutralising agent | 2 - Moderate | Minor injuries requiring hospital treatment | C - Possible | Event could occur at some time | 2C | Low | Implement appropriate health and safety planning to reduce access and exposure to neutralising agent | 2 - | A - | 2A | Insignificant |
| R009 | Health and safety | Surface application of neutralising agents | Injury to workers and third parties associated with contact with highly alkaline water (if over dosed) | 2 - Moderate | Minor injuries requiring hospital treatment | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these | 2 - | A - | 2A | Insignificant |
| R010 | Health and safety | Channel treatment (Big Swamp) – limestone sand | Injury to workers associated with inhalation of or contact with neutralising agent | 2 - Moderate | Minor injuries requiring hospital treatment | C - Possible | Event could occur at some time | 2C | Low | Implement appropriate health and safety planning to reduce access and exposure to neutralising agent | 2 - | A - | 2A | Insignificant |
| R011 | Health and safety | Channel treatment (Big Swamp) – limestone sand | Injury to workers and third parties associated with contact with highly alkaline water (if over dosed) | 2 - Moderate | Minor injuries requiring hospital treatment | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these | 2 - | A - | 2A | Insignificant |
| R012 | Health and safety | Channel treatment (Big Swamp) – limestone sand | Injury to workers associated with operating or being in the vicinity of machinery (e.g. tipper trucks) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R013 | Health and safety | Channel treatment (Big Swamp) – limestone sand | Injury to public and workers associated with increased truck traffic on local roads | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R014 | Health and safety | In stream treatment – Boundary Creek | Injury to workers associated with inhalation of or contact with neutralising agent | 2 - Moderate | Minor injuries requiring hospital treatment | C - Possible | Event could occur at some time | 2C | Low | Implement appropriate health and safety planning to reduce access and exposure to neutralising agent | 2 - | A - | 2A | Insignificant |
| R015 | Health and safety | In stream treatment – Boundary Creek | Injury to workers and third parties associated with contact with highly alkaline water (if over dosed) | 2 - Moderate | Minor injuries requiring hospital treatment | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, limit access to these | 2 - | A - | 2A | Insignificant |
| R016 | Health and safety | In stream treatment – Boundary Creek | Injury to workers associated with construction of plant (general construction site hazards) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R017 | Health and safety | In stream treatment – Boundary Creek | Injury to public and workers associated with increased and ongoing truck traffic on local roads | 5 - Extreme | Death or permanent disability | C - Possible | Event could occur at some time | 5C | Critical | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R018 | Health and safety | In stream treatment – Boundary Creek | Injury to operators from electrical hazards associated with the constructed plant | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any electrical accidents | 4 - | A - | 4A | Low |
| R019 | Health and safety | In stream treatment – Boundary Creek | Injury to operators associated with machinery in operating plant (e.g. rotating machinery) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any plant operation accidents | 4 - | A - | 4A | Low |
| R020 | Health and safety | Settling pond and sludge management | Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R021 | Health and safety | Settling pond and sludge management | Injury associated with increased and ongoing truck traffic on local roads | 5 - Extreme | Death or permanent disability | C - Possible | Event could occur at some time | 5C | Critical | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R022 | Health and safety | Settling pond and sludge management | Drowning risk to third parties in standing water | 5 - Extreme | Death or permanent disability | A - Rare | Event will only occur in exceptional circumstances | 5A | Medium | Limit access of third parties to settling pond | 1 - | A - | 1A | Insignificant |
| R023 | Health and safety | Settling pond and sludge management | Injury to workers and third parties associated with contact with contaminated soil or water | 3 - Major | Injury requiring hospitalisation | C - Possible | Event could occur at some time | 3C | Medium | Limit access of third parties to settling pond. Implement appropriate health and safety measures for operators of the settling pond | 3 - | B - | 3B | Low |
| R024 | Health and safety | Aerobic wetland | Injury to workers associated with operating or being in the vicinity of machinery (e.g. excavators) | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate health and safety planning to reduce likelihood and consequence of any machinery accidents | 4 - | A - | 4A | Low |
| R025 | Health and safety | Aerobic wetland | Injury associated with increased truck traffic on local roads | 5 - Extreme | Death or permanent disability | B - Unlikely | Event is not expected to occur | 5B | High | Implement appropriate traffic management measures to reduce likelihood and consequence of any traffic accidents | 4 - | A - | 4A | Low |
| R026 | Health and safety | Aerobic wetland | Drowning risk to third parties in standing water | 5 - Extreme | Death or permanent disability | A - Rare | Event will only occur in exceptional circumstances | 5A | Medium | Limit access of third parties to wetland | 1 - | A - | 1A | Insignificant |
| R027 | Environment | Infilling fire trench and drainage channels | Impact to vegetation associated with heavy machinery movement in Big Swamp | 2 - Moderate | Reversible short term environmental harm | D - Likely | Event would probably occur in most instances | 2D | Medium | Plan access routes to areas of infill to minimise vegetation damage. If significant damage occurs, revegetate area | 2 - | A - | 2A | Insignificant |
| R028 | Environment | Infilling fire trench and drainage channels | Importation of weeds and foreign species via infilled soil | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Conduct soil validation and sampling including weed and seed checks | 2 - | B - | 2B | Insignificant |
| R029 | Environment | Infilling fire trench and drainage channels | Activation of additional flow patterns in Big Swamp resulting in mobilisation of actual and retained acidity | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Use the topographical data to model predicted flow patterns | 2 - | B - | 2B | Insignificant |
| R030 | Environment | Provide supplementary flow | Activation of additional flow patterns in Big Swamp resulting in mobilisation of actual and retained acidity | 2 - Moderate | Reversible short term environmental harm | D - Likely | Event would probably occur in most instances | 2D | Medium | Use the topographical data and geochemical model (distribution of acidity) to predict new flow paths and likely acidity risk | 2 - | C - | 2C | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R031 | Environment | Provide supplementary flow | Change in vegetation communities in eastern part of the swamp due to increased extent of permanently inundated areas | 3 - Major | Environment suffers harm for 5 to 10 years | E - Almost Cert | Event is expected to occur in most circumstances | 3E | High | Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with increased surface flow.<br>Establish supplementary flow so that the extent of the permanently inundated areas is kept to a minimum.<br>Allow seasonal variability of supplementary flow to minimise potential loss of vegetation.<br>Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation. | 2 - | E - | 2E | Medium |
| R032 | Environment | Provide supplementary flow | Mobilisation of actual acidity through the soil profile via capillary rise due to increased groundwater levels | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Estimate the additional acidity load via capillary rise and assess whether additional remediation is required or whether the additional load is minor compared to other inputs. If additional remediation is required, consider implantation of additional measures such as soil or water liming within the swamp. | 2 - | C - | 2C | Low |
| R033 | Environment | Provide supplementary flow | Export of acidity and acidity products associated with reducing conditions in permanently inundated areas | 4 - Severe | Environment suffers harm for 10 to 20 years | B - Unlikely | Event is not expected to occur | 4B | Medium | Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of acidity export | 3 - | B - | 3B | Low |
| R034 | Environment | Provide supplementary flow | Generation of groundwater plume of acid and acid products (sulfate and metals) due to inundation of soils | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Use groundwater model to predict potential for a groundwater plume to migrate from the site. Low permeability of sediments is likely to restrict migration of plume | 2 - | C - | 2C | Low |
| R035 | Environment | Provide supplementary flow | Local destabilisation of waterway banks and channel profile, leading to landslips and increased erosive action on creek banks and bed | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Use surface water model to predict changes in geomorphology and erosion risk. If risk is confirmed, install erosion management measures such as riffles and gabions | 2 - | B - | 2B | Insignificant |
| R036 | Environment | Provide supplementary flow | Production of hydrogen sulfide and methane due to degradation of organic matter in reducing conditions | 1 - Minor | Minor effect on the environment | D - Likely | Event would probably occur in most instances | 1D | Low | Use geochemical model to estimate the rates and likelihood of gas production and likely impacts on the environment. If impact is expected, develop and implement an air quality monitoring plan including management measures for exceedances of threshold values. | 1 - | B - | 1B | Insignificant |
| R037 | Environment | Install hydraulic barriers | Change in vegetation communities across the swamp due to the creation of additional permanently inundated areas | 3 - Major | Environment suffers harm for 5 to 10 years | E - Almost Cert | Event is expected to occur in most circumstances | 3E | High | Conduct further assessment on the significance of vegetation loss against benefits to vegetation associated with installation and operation of hydraulic barriers.<br>Design hydraulic barriers so that the extent of the permanently inundated areas is kept to a minimum.<br>Design hydraulic barriers so that inundation levels cab be seasonally adjusted.<br>Develop and implement a vegetation management plan to allow ongoing monitoring of changes to vegetation. | 2 - | E - | 2E | Medium |
| R038 | Environment | Install hydraulic barriers | Disturbance of ASS during excavation associated with barrier construction (if required) | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Treat exposed soil with lime during excavations to prevent the generation of acidity during earthworks | 2 - | B - | 2B | Insignificant |
| R039 | Environment | Install hydraulic barriers | Impact to vegetation associated with heavy machinery movement in Big Swamp | 2 - Moderate | Reversible short term environmental harm | D - Likely | Event would probably occur in most instances | 2D | Medium | Plan access routes to construction areas to minimise vegetation damage. If significant damage occurs, revegetate area | 2 - | A - | 2A | Insignificant |
| R040 | Environment | Install hydraulic barriers | Mobilisation of actual acidity through the soil profile via capillary rise due to increased groundwater levels | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Estimate the additional acidity load via capillary rise and assess whether additional remediation is required or whether the additional load is minor compared to other inputs. If additional remediation is required, consider implantation of additional measures such as soil or water liming within the swamp. | 2 - | C - | 2C | Low |
| R041 | Environment | Install hydraulic barriers | Export of acidity and acidity products associated with reducing conditions in permanently inundated areas | 3 - Major | Environment suffers harm for 5 to 10 years | D - Likely | Event would probably occur in most instances | 3D | High | Conduct additional data collection and studies to further characterise magnitude and likelihood of acidity export.<br>Implement contingency measures in the form of surface liming, limestone sand application and/or in-stream treatment. | 2 - | C - | 2C | Low |
| R042 | Environment | Install hydraulic barriers | Generation of groundwater plume of acid and acid products (sulfate and metals) due to inundation of soils | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Use groundwater model to predict potential for a groundwater plume to migrate from the site. Low permeability of sediments is likely to restrict migration of plume | 2 - | C - | 2C | Low |
| R043 | Environment | Install hydraulic barriers | Local destabilisation of waterway banks and channel profile, leading to landslips and increased erosive action on creek banks and bed | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Use surface water model to predict changes in geomorphology and erosion risk. If risk is confirmed, install erosion management measures such as riffles and gabions | 2 - | B - | 2B | Insignificant |
| R044 | Environment | Install hydraulic barriers | Production of hydrogen sulfide and methane due to degradation of organic matter in reducing conditions | 1 - Minor | Minor effect on the environment | D - Likely | Event would probably occur in most instances | 1D | Low | Use geochemical model to estimate the rates and likelihood of gas production and likely impacts on the environment. If impact is expected, develop and implement an air quality monitoring plan including management measures for exceedances of threshold values. | 1 - | B - | 1B | Insignificant |
| R045 | Environment | Surface application of neutralising agents | Loss of wetland vegetation due to increased alkalinity conditions in surface soil | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Develop and implement a vegetation management plan so that impacts on vegetation can be monitored and any impacts managed. Management may include replanting or remediating impacted vegetation. | 2 - | C - | 2C | Low |
| R046 | Environment | Surface application of neutralising agents | Precipitation of metal oxy hydroxides in Big Swamp and downstream environments due to neutralising reactions | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of potential export of precipitates. If significant precipitates are predicted to be exported, design and construct a settling pond. | 2 - | C - | 2C | Low |
| R047 | Environment | Surface application of neutralising agents | Impact on vegetation and aquatic ecology in Big Swamp due to short term generation of local highly alkaline surface waters | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, mix with lower pH water or treat | 2 - | B - | 2B | Insignificant |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R048 | Environment | Surface application of neutralising agents | Generation of dust - airborne neutralising agent | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Plan application for days with low wind to ensure targeted treatment and limited migration of dust | 2 - | B - | 2B | Insignificant |
| R049 | Environment | Channel treatment (Big Swamp) – limestone sand | Loss of wetland vegetation due to increased alkalinity conditions in surface water | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Develop and implement a vegetation management plan so that impacts on vegetation can be monitored and any impacts managed. Management may include replanting or remediating impacted vegetation. | 2 - | C - | 2C | Low |
| R050 | Environment | Channel treatment (Big Swamp) – limestone sand | Precipitation of metal oxy hydroxides in Big Swamp and downstream environments due to neutralising reactions | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Conduct further surface water and groundwater modelling as well as geochemical modelling and pilot trials to understand the magnitude and likelihood of potential export of precipitates. If significant precipitates are predicted to be exported, design and construct a settling pond. | 2 - | C - | 2C | Low |
| R051 | Environment | Channel treatment (Big Swamp) – limestone sand | Impact on vegetation and aquatic ecology in Big Swamp due to short term generation of local highly alkaline surface waters | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, mix with lower pH water or treat | 2 - | B - | 2B | Insignificant |
| R052 | Environment | Channel treatment (Big Swamp) – limestone sand | Generation of dust - airborne neutralising agent | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Plan application for days with low wind to ensure targeted treatment and limited migration of dust | 2 - | B - | 2B | Insignificant |
| R053 | Environment | In stream treatment – Boundary Creek | Formation of metal oxy hydroxides downstream of the treatment infrastructure | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Conduct further monitoring and modelling to ensure settling pond is designed to capture precipitates. Monitor the settling pond (or other designed infrastructure) to ensure it has suitable capacity and is regularly emptied | 3 - | B - | 3B | Low |
| R054 | Environment | In stream treatment – Boundary Creek | Impact on vegetation and aquatic ecology in Boundary Creek due to short term generation of local highly alkaline surface waters | 2 - Moderate | Reversible short term environmental harm | C - Possible | Event could occur at some time | 2C | Low | Monitor effects of treatment to identify highly alkaline water. If highly alkaline waters occur, modify treatment or mix with lower pH water | 2 - | B - | 2B | Insignificant |
| R055 | Environment | Settling pond and sludge management | Disturbance of ASS caused by excavation of settling pond | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Presence of ASS and PASS at the location of the settling pond should be assessed prior to excavation. If ASS/PASS is identified, implement an construction plan to treat ASS if disturbed (e.g. liming in excavations) | 2 - | B - | 2B | Insignificant |
| R056 | Environment | Settling pond and sludge management | Loss of vegetation for construction of settling pond | 3 - Major | Environment suffers harm for 5 to 10 years | E - Almost Cert | Event is expected to occur in most circumstances | 3E | High | Locate settling pond in an area of low ecological value. Consider construction of an aerobic wetland as part of the settling pond to offset loss of vegetation. | 2 - | E - | 2E | Medium |
| R057 | Environment | Settling pond and sludge management | Failure of settling pond (or other on site waste storage/facilities) resulting in uncontrolled release of sludge | 4 - Severe | Environment suffers harm for 10 to 20 years | B - Unlikely | Event is not expected to occur | 4B | Medium | Conduct further surface water and geochemical modelling to inform detailed design of the settling pond so that catastrophic failures are unlikely | 4 - | A - | 4A | Low |
| R058 | Environment | Settling pond and sludge management | Reduced fish migration due to fish barrier associated with treatment system (i.e. settling pond) | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Conduct ecological survey to assess the requirement for a fish ladder past the treatment infrastructure. If required, construct a fish ladder. | 1 - | A - | 1A | Insignificant |
| R059 | Environment | Aerobic wetland | Disturbance of ASS caused by construction of wetland | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Presence of ASS and PASS at the location of the wetland should be assessed prior to excavation. If ASS/PASS is identified, implement an construction plan to treat ASS if disturbed (e.g. liming in excavations) | 2 - | B - | 2B | Insignificant |
| R060 | Environment | Aerobic wetland | Change in vegetation type associated with permanently inundated conditions | 3 - Major | Environment suffers harm for 5 to 10 years | C - Possible | Event could occur at some time | 3C | Medium | Locate aerobic wetland in an area of low ecological value. Design aerobic wetland to incorporate areas of different water depth so that diverse vegetation and ecosystem will establish. | 2 - | C - | 2C | Low |
| R061 | Financial | Infilling fire trench and drainage channels | Additional costs caused by unexpected logistical difficulties and potential requirement for revegetation | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R062 | Financial | Provide supplementary flow | Additional costs associated with providing supplementary flow or upgrading infrastructure | 3 - Major | Significant financial loss | B - Unlikely | Event is not expected to occur | 3B | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 3 - | A - | 3A | Insignificant |
| R063 | Financial | Provide supplementary flow | Cost of requirement to remediate indirect impacts from delivery of supplementary flow (e.g. erosion) | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation | 1 - | A - | 1A | Insignificant |
| R064 | Financial | Provide supplementary flow | Additional cost for implementation of contingency measures should they be required | 3 - Major | Significant financial loss | C - Possible | Event could occur at some time | 3C | Medium | Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation | 3 - | A - | 3A | Insignificant |
| R065 | Financial | Install hydraulic barriers | Additional costs associated with installation of multiple barriers (i.e. more than designed) | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R066 | Financial | Install hydraulic barriers | Additional costs associated with unexpected logistical constraints or bad weather | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R067 | Financial | Install hydraulic barriers | Cost of increased monitoring requirements to assess and manage the technology's side effects | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R068 | Financial | Install hydraulic barriers | Additional cost for implementation of contingency measures should they be required | 3 - Major | Significant financial loss | C - Possible | Event could occur at some time | 3C | Medium | Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation | 3 - | A - | 3A | Insignificant |
| R069 | Financial | Install hydraulic barriers | Cost of replacement of barrier due to loss of barrier/integrity due to natural disaster | 2 - Moderate | Minor financial loss | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R070 | Financial | Surface application of neutralising agents | Additional cost due to a requirement for higher than expected frequency of application and/or higher rates of liming | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R071 | Financial | Surface application of neutralising agents | Additional cost to restore damaged vegetation impacted by liming | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R072 | Financial | Surface application of neutralising agents | Cost of ongoing monitoring requirements due to higher than anticipated negative side effects | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation | 2 - | A - | 2A | Insignificant |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R073 | Financial | Channel treatment (Big Swamp) – limestone sand | Additional costs due to an increase of required liming rates or frequency | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R074 | Financial | Channel treatment (Big Swamp) – limestone sand | Additional costs due to logistical constraints for application | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R075 | Financial | Channel treatment (Big Swamp) – limestone sand | Cost of ongoing monitoring requirements due to higher than anticipated negative side effects | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected events/consequences of implementation | 2 - | A - | 2A | Insignificant |
| R076 | Financial | In stream treatment – Boundary Creek | Cost for additional lime due to an underestimation of liming rates required | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R077 | Financial | In stream treatment – Boundary Creek | Cost of replacement of equipment due to loss of equipment caused by fires | 4 - Severe | Major financial loss | B - Unlikely | Event is not expected to occur | 4B | Medium | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 4 - | A - | 4A | Low |
| R078 | Financial | In stream treatment – Boundary Creek | Cost of replacement of equipment due to loss of equipment caused by floods | 4 - Severe | Major financial loss | B - Unlikely | Event is not expected to occur | 4B | Medium | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 4 - | A - | 4A | Low |
| R079 | Financial | In stream treatment – Boundary Creek | Cost of additional infrastructure/treatment steps into process (e.g. a mixing tank, power upgrades) | 3 - Major | Significant financial loss | B - Unlikely | Event is not expected to occur | 3B | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 3 - | A - | 3A | Insignificant |
| R080 | Financial | In stream treatment – Boundary Creek | Ongoing cost increase due to an increase in the cost of chemicals | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R081 | Financial | In stream treatment – Boundary Creek | Ongoing cost increase due to unfavourable exchange rates (if chemicals sourced from overseas) | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R082 | Financial | In stream treatment – Boundary Creek | Ongoing cost increase due to requirement to use different chemicals | 2 - Moderate | Minor financial loss | C - Possible | Event could occur at some time | 2C | Low | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 2 - | A - | 2A | Insignificant |
| R083 | Financial | Settling pond and sludge management | Additional costs associated with unexpected logistical constraints or bad weather during construction or emptying | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R084 | Financial | Aerobic wetland | Additional costs associated with unexpected logistical constraints or bad weather during construction | 1 - Minor | Minor and localised financial loss | C - Possible | Event could occur at some time | 1C | Insignificant | Expected costs should be based on detailed design including contingency costs for unexpected overruns | 1 - | A - | 1A | Insignificant |
| R085 | Community | Infilling fire trench and drainage channels | Higher than expected impacts on vegetation | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Make ecological studies and risks available to community. | 2 - | B - | 2B | Insignificant |
| R086 | Community | Infilling fire trench and drainage channels | Perception that infilling fire trench would increase fire risk | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts. Communicate with local CFA. | 1 - | B - | 1B | Insignificant |
| R087 | Community | Infilling fire trench and drainage channels | Increased traffic in local area | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |
| R088 | Community | Infilling fire trench and drainage channels | Loss of usable land due to wetter conditions in previously drained areas | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R089 | Community | Infilling fire trench and drainage channels | Requirement to access private land | 1 - Minor | Very limited public interest | D - Likely | Event would probably occur in most instances | 1D | Low | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | C - | 1C | Insignificant |
| R090 | Community | Infilling fire trench and drainage channels | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | C - Possible | Event could occur at some time | 1C | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | C - | 1C | Insignificant |
| R091 | Community | Infilling fire trench and drainage channels | Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Keep community informed of the process, the risks and the management and mitigation measures. | 1 - | C - | 1C | Insignificant |
| R092 | Community | Provide supplementary flow | Perception that water is being prioritised for ecological outcomes over water security | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public. | 1 - | C - | 1C | Insignificant |
| R093 | Community | Provide supplementary flow | Side effects of implementation - potential increase in export of acidity | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | C - | 2C | Low |
| R094 | Community | Provide supplementary flow | Modified character of Big Swamp - loss of vegetation | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Make ecological studies, risks and management measures available to community. | 2 - | B - | 2B | Insignificant |
| R095 | Community | Provide supplementary flow | Hydrogen sulfide and methane produced due to degradation of organic matter and reducing conditions | 3 - Major | Adverse localised negative public attention | B - Unlikely | Event is not expected to occur | 3B | Low | Maintain open communication with the community, including the RWG technical experts. Provide estimates of gas production and likely impacts on locals. | 2 - | B - | 2B | Insignificant |
| R096 | Community | Provide supplementary flow | Community opposition to the final design due to differences from the Concept Design on which the community were consulted. | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community. | 1 - | B - | 1B | Insignificant |
| R097 | Community | Provide supplementary flow | Length of time required for remediation | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community. | 2 - | B - | 2B | Insignificant |
| R098 | Community | Provide supplementary flow | Disagreement about natural resource use | 3 - Major | Adverse localised negative public attention | B - Unlikely | Event is not expected to occur | 3B | Low | Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public. | 2 - | B - | 2B | Insignificant |
| R099 | Community | Install hydraulic barriers | Side effects of implementation - potential increase in export of acidity | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | C - | 2C | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R100 | Community | Install hydraulic barriers | Modified character of Big Swamp - loss of vegetation and increase of infrastructure | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Make ecological studies, risks and management measures available to community. | 2 - | B - | 2B | Insignificant |
| R101 | Community | Install hydraulic barriers | Hydrogen sulfide and methane produced due to degradation of organic matter reducing conditions | 3 - Major | Adverse localised negative public attention | B - Unlikely | Event is not expected to occur | 3B | Low | Maintain open communication with the community, including the RWG technical experts. Provide estimates of gas production and likely impacts on locals. | 1 - | B - | 1B | Insignificant |
| R102 | Community | Install hydraulic barriers | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - | C - | 3C | Medium |
| R103 | Community | Install hydraulic barriers | Requirement to access private land | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R104 | Community | Install hydraulic barriers | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R105 | Community | Install hydraulic barriers | Community opposition to the final design due to differences from the Concept Design on which the community were consulted. | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community. | 3 - | B - | 3B | Low |
| R106 | Community | Install hydraulic barriers | Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site. | 3 - Major | Adverse localised negative public attention | B - Unlikely | Event is not expected to occur | 3B | Low | Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site. | 2 - | B - | 2B | Insignificant |
| R107 | Community | Install hydraulic barriers | Length of time required for remediation | 4 - Severe | Serious adverse public attention | C - Possible | Event could occur at some time | 4C | High | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community. | 3 - | B - | 3B | Low |
| R108 | Community | Install hydraulic barriers | Disagreement about natural resource use | 3 - Major | Adverse localised negative public attention | B - Unlikely | Event is not expected to occur | 3B | Low | Maintain open communication with the community, including the RWG technical experts. Ensure detailed design includes risk/benefit analysis of water use and communicate this to the public. | 2 - | B - | 2B | Insignificant |
| R109 | Community | Surface application of neutralising agents | Side effects of application - dust | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | B - | 2B | Insignificant |
| R110 | Community | Surface application of neutralising agents | Side effect of application - secondary precipitates | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | C - | 2C | Low |
| R111 | Community | Surface application of neutralising agents | Increased traffic in local area | 2 - Moderate | Adverse localised public attention | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |
| R112 | Community | Surface application of neutralising agents | Requirement to access private land | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R113 | Community | Surface application of neutralising agents | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | C - Possible | Event could occur at some time | 1C | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R114 | Community | Surface application of neutralising agents | Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site. | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site. | 3 - | B - | 3B | Low |
| R115 | Community | Surface application of neutralising agents | Length of time required for remediation | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design and the expected timeframes are supported by the technical studies and communicate this to community. | 2 - | B - | 2B | Insignificant |
| R116 | Community | Channel treatment (Big Swamp) – limestone sand | Side effect of application - dust | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | B - | 2B | Insignificant |
| R117 | Community | Channel treatment (Big Swamp) – limestone sand | Side effect of application - secondary precipitates | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | C - | 2C | Low |
| R118 | Community | Channel treatment (Big Swamp) – limestone sand | Increased traffic in local area | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |
| R119 | Community | Channel treatment (Big Swamp) – limestone sand | Requirement to access private land | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R120 | Community | Channel treatment (Big Swamp) – limestone sand | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R121 | Community | Channel treatment (Big Swamp) – limestone sand | Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site. | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site. | 3 - | B - | 3B | Low |
| R122 | Community | In stream treatment – Boundary Creek | Amenity impact of treatment infrastructure (visual and noise) | 4 - Severe | Serious adverse public attention | C - Possible | Event could occur at some time | 4C | High | Maintain open communication with the community, including the RWG technical experts. Make detailed design plan available for public comment. | 3 - | B - | 3B | Low |
| R123 | Community | In stream treatment – Boundary Creek | Increased and ongoing traffic in the local area | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R124 | Community | In stream treatment – Boundary Creek | Side effect of application - secondary precipitates | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Include risk management measures into detailed design planning and communicate this to the community. | 2 - | B - | 2B | Insignificant |
| R125 | Community | In stream treatment – Boundary Creek | Perception of waste (sludge) generated by technology | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by technical studies, including sludge volume predictions and management plans. | 2 - | C - | 2C | Low |
| R126 | Community | In stream treatment – Boundary Creek | Perception of cost of treatment (rate increases or financial viability) | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts. Ensure budget for the implementation of this technology is secured, including contingency costing. | 2 - | C - | 2C | Low |
| R127 | Community | In stream treatment – Boundary Creek | Residential property owners subject to acquisition or in proximity to construction areas postpone or reconsider their plans for their properties. | 2 - Moderate | Adverse localised public attention | C - Possible | Event could occur at some time | 2C | Low | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R128 | Community | In stream treatment – Boundary Creek | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - | C - | 3C | Medium |
| R129 | Community | In stream treatment – Boundary Creek | Land use changes that would result in minor inconsistencies with local planning policies and current planning scheme provisions | 1 - Minor | Very limited public interest | C - Possible | Event could occur at some time | 1C | Insignificant | Maintain open communication with Local Council including development of plans and design requirements. | 1 - | B - | 1B | Insignificant |
| R130 | Community | In stream treatment – Boundary Creek | Community opposition to the final design due to differences from the Concept Design on which the community were consulted. | 4 - Severe | Serious adverse public attention | C - Possible | Event could occur at some time | 4C | High | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community. | 3 - | B - | 3B | Low |
| R131 | Community | In stream treatment – Boundary Creek | Works within Big Swamp and surrounding land have the potential to create distress for members of the community who value the site. | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts and relevant landholders. Ensure detailed design ties back to the vision and objectives for the site. | 3 - | B - | 3B | Low |
| R132 | Community | Settling pond and sludge management | Increased traffic in local area | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |
| R133 | Community | Settling pond and sludge management | Requirement to access private land | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R134 | Community | Settling pond and sludge management | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R135 | Community | Settling pond and sludge management | Loss of usable land due to settling pond construction | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R136 | Community | Settling pond and sludge management | Community opposition to the final design due to differences from the Concept Design on which the community were consulted. | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Ensure that detailed design is supported by the technical studies and communicate this to community. | 3 - | B - | 3B | Low |
| R137 | Community | Settling pond and sludge management | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - | C - | 3C | Medium |
| R138 | Community | Aerobic wetland | Increased traffic in local area | 3 - Major | Adverse localised negative public attention | C - Possible | Event could occur at some time | 3C | Medium | Maintain open communication with the community, including the RWG technical experts. Plan for traffic disruptions and volumes. | 2 - | B - | 2B | Insignificant |
| R139 | Community | Aerobic wetland | Requirement to access private land | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R140 | Community | Aerobic wetland | Temporary limited access (potential short term disruption to existing land use) to properties but properties are still able to be used for existing purposes (potential long term access changes) | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R141 | Community | Aerobic wetland | Loss of usable land due to wetland construction | 1 - Minor | Very limited public interest | B - Unlikely | Event is not expected to occur | 1B | Insignificant | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 1 - | B - | 1B | Insignificant |
| R142 | Community | Aerobic wetland | Acquisition of titles for the project | 3 - Major | Adverse localised negative public attention | D - Likely | Event would probably occur in most instances | 3D | High | Maintain open communication with the community, including the RWG technical experts and relevant landholders. | 3 - | C - | 3C | Medium |
| R143 | Regulatory | Infilling fire trench and drainage channels | Opposition of infilling of fire trench by CFA | 1 - Minor | Regulatory approval dependant on minor additional work | C - Possible | Event could occur at some time | 1C | Insignificant | Engage CFA early to discuss the fire risk benefits of infilling the fire trenches (i.e. a wetter swamp) | 1 - | A - | 1A | Insignificant |
| R144 | Regulatory | Provide supplementary flow | Delivery of supplementary flows above 2 ML/d opposed by regulator under Water Act | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional groundwater and surface water modelling to refine the likely volume of supplementary flow required for rewetting and present as a risk/benefit analysis with respect to water supply requirements | 2 - | B - | 2B | Insignificant |
| R145 | Regulatory | Provide supplementary flow | Regulatory approval required due to potential side effects (exporting of acidity) | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | C - | 2C | Low |
| R146 | Regulatory | Provide supplementary flow | Regulatory approval required due to potential side effects (acid groundwater plume) and impact under SEPP | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R147 | Regulatory | Install hydraulic barriers | Regulatory approval required due to potential side effects (exporting of acidity) | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | C - | 2C | Low |
| R148 | Regulatory | Install hydraulic barriers | Regulatory approval required due to potential side effects (acid groundwater plume) and impact under SEPP | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |
| R149 | Regulatory | Surface application of neutralising agents | Regulatory approval required due to potential side effect (precipitates in Boundary Creek) | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | C - | 2C | Low |
| R150 | Regulatory | Surface application of neutralising agents | Regulatory approval required due to potential side effect (vegetation impacts) | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |
| R151 | Regulatory | Channel treatment (Big Swamp) – limestone sand | Regulatory approval required due to potential side effect (precipitates in Boundary Creek) | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | C - | 2C | Low |
| R152 | Regulatory | Channel treatment (Big Swamp) – limestone sand | Regulatory approval required due to potential side effect (vegetation impacts) | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |
| R153 | Regulatory | In stream treatment – Boundary Creek | Regulatory approval required due to potential side effect (precipitates in Boundary Creek) | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | C - | 2C | Low |
| R154 | Regulatory | In stream treatment – Boundary Creek | Planning approval required for infrastructure | 1 - Minor | Regulatory approval dependant on minor additional work | D - Likely | Event would probably occur in most instances | 1D | Low | Follow planning approval procedures and undertaken detailed design of the treatment infrastructure | 1 - | D - | 1D | Low |
| R155 | Regulatory | Settling pond and sludge management | Approval for waste disposal or onsite storage of generated sludge required | 4 - Severe | Regulatory approval dependant on significant additional work over long period | C - Possible | Event could occur at some time | 4C | High | Include planning for waste disposal early in the design process and engage with potential receivers. Test any sludge developed during pilot trials to inform planning of waste disposal and waste categorisation. | 3 - | C - | 3C | Medium |
| R156 | Regulatory | Settling pond and sludge management | Regulatory approval required due to potential side effect (vegetation impacts) | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |
| R157 | Regulatory | Aerobic wetland | Regulatory approval required due to potential side effect (vegetation impacts) | 3 - Major | Regulatory approval dependant on major additional work over medium time period | B - Unlikely | Event is not expected to occur | 3B | Low | Undertake additional monitoring, modelling and pilot trials to ensure potential negative side effects are well understood. Develop and implement an Environmental Management Plan | 2 - | B - | 2B | Insignificant |
| R158 | Technical (performance) | Provide supplementary flow | Selection of inappropriate remediation technology | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. | 2 - | A - | 2A | Insignificant |
| R159 | Technical (performance) | Provide supplementary flow | Remediation technology improperly designed | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. | 2 - | B - | 2B | Insignificant |
| R160 | Technical (performance) | Provide supplementary flow | Inappropriate remediation objectives | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. | 2 - | A - | 2A | Insignificant |
| R161 | Technical (performance) | Provide supplementary flow | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | D - Likely | Event would probably occur in most instances | 2D | Medium | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update modelling to incorporate additional data. | 2 - | C - | 2C | Low |
| R162 | Technical (performance) | Provide supplementary flow | Supplementary flows do not raise the groundwater levels as expected | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Continue to monitor during delivery of supplementary flows and update modelling to improve understanding of how the groundwater levels react to inundation. If groundwater levels are not rising as expected, consider contingencies such as increasing flow rates or modifying flow through the swamp. | 2 - | C - | 2C | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R163 | Technical (performance) | Provide supplementary flow | Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions) | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | D - Likely | Event would probably occur in most instances | 2D | Medium | Continue to monitor during delivery of supplementary flows to improve understanding of geochemical reactions in the swamp. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment. | 2 - | C - | 2C | Low |
| R164 | Technical (performance) | Provide supplementary flow | Failure to deliver minimum flow at Boundary Creek (Yeodene gauge) due to higher than expected losses to groundwater | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 3B | Low | Continue to monitor during delivery of supplementary flows and update modelling to improve understanding of streamflow losses. If losses are significant and minimum flow requirements are not met, increase the supplementary flow volumes. | 1 - | B - | 1B | Insignificant |
| R165 | Technical (performance) | Install hydraulic barriers | Selection of inappropriate remediation technology | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 5B | High | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test. | 3 - | B - | 3B | Low |
| R166 | Technical (performance) | Install hydraulic barriers | Remediation technology improperly designed | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test. | 3 - | B - | 3B | Low |
| R167 | Technical (performance) | Install hydraulic barriers | Inappropriate remediation objectives | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Complete further monitoring and modelling to ensure design of measure is based on robust scientific reasoning. Further modelling should include surface water, groundwater and geochemical modelling. Consider the potential use of a staged approach (one barrier at a time) to provide a pilot study scale test. | 2 - | B - | 2B | Insignificant |
| R168 | Technical (performance) | Install hydraulic barriers | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update modelling to incorporate additional data. | 2 - | B - | 2B | Insignificant |
| R169 | Technical (performance) | Install hydraulic barriers | Hydraulic barriers do not raise the groundwater levels as expected | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Continue to monitor during implementation and update modelling to improve understanding of how the groundwater levels react to inundation. If groundwater levels are not rising as expected, consider contingencies such as increasing flow rates or modifying flow through the swamp / install additional barriers. | 2 - | B - | 2B | Insignificant |
| R170 | Technical (performance) | Install hydraulic barriers | Limited effectiveness of permanently flooded areas (insufficient surface coverage or lack of establishment of appropriate geochemical reactions) | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 5C | Critical | Continue to monitor during installation of barriers and inundation to improve understanding of geochemical reactions in the swamp. Consider implementation as a staged approach (one barrier at a time) so that the effects can be assessed on a small scale before wider implementation. Monitor quality of water leaving the swamp and if quality improvement is insufficient consider implementing contingency measures such as downstream treatment. | 4 - | B - | 4B | Medium |
| R171 | Technical (performance) | Surface application of neutralising agents | Selection of inappropriate remediation technology | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | B - | 2B | Insignificant |
| R172 | Technical (performance) | Surface application of neutralising agents | Remediation technology improperly designed | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | C - | 2C | Low |
| R173 | Technical (performance) | Surface application of neutralising agents | Inappropriate remediation objectives | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application). | 2 - | B - | 2B | Insignificant |
| R174 | Technical (performance) | Surface application of neutralising agents | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data. | 2 - | B - | 2B | Insignificant |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R175 | Technical (performance) | Surface application of neutralising agents | Liming of soils fails to have measurable impact on Boundary Creek water quality | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Use existing geochemical data and any further data collected to plan appropriate liming rates and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 3 - | B - | 3B | Low |
| R176 | Technical (performance) | Surface application of neutralising agents | Excessive coating of lime by metal precipitates | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Consider pilot scale application or laboratory testing to understand the timing and severity of armouring. Plan for armouring by using an appropriate chemical and application rate/frequency. | 3 - | B - | 3B | Low |
| R177 | Technical (performance) | Surface application of neutralising agents | Uneven surface application due to inappropriate delivery method | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Use existing understanding of topography and streamflow to ensure reagent is applied at the appropriate scale and location. Use 3D geochemical model (updated to include any additional data) to plan extent of application and appropriate delivery method. | 3 - | B - | 3B | Low |
| R178 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Selection of inappropriate remediation technology | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Use existing geochemical data and any further data collected to plan targeted application and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | B - | 2B | Insignificant |
| R179 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Remediation technology improperly designed | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Use existing geochemical data and any further data collected to plan targeted application and frequency. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 3 - | B - | 3B | Low |
| R180 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Inappropriate remediation objectives | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | B - Unlikely | Event is not expected to occur | 2B | Insignificant | Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application). | 2 - | B - | 2B | Insignificant |
| R181 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data. | 2 - | B - | 2B | Insignificant |
| R182 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Liming in channel fails to have measurable impact on Boundary Creek water quality | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Use existing geochemical data and any further data collected to plan targeted application of limestone sand. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | C - | 2C | Low |
| R183 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Excessive coating of limestone sand by metal precipitates | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Consider pilot scale application or laboratory testing to understand the timing and severity of armouring. Plan for armouring by using an appropriate chemical and application rate/frequency. | 3 - | B - | 3B | Low |
| R184 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Uneven surface application due to inappropriate delivery method | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Use existing understanding of topography and streamflow to ensure reagent is applied at the appropriate scale and location. Use 3D geochemical model (updated to include any additional data) to plan target locations | 2 - | B - | 2B | Insignificant |
| R185 | Technical (performance) | Channel treatment (Big Swamp) – limestone sand | Incorrect placement of limestone (i.e. surface flows not understood) | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Complete further surface water modelling to understand surface flows through the swamp at an appropriate timestep for entrainment of sand into surface flow. Use topographical data and stream flow modelling to plan targeted application of sand to areas of known stream flow. | 1 - | B - | 1B | Insignificant |
| R186 | Technical (performance) | In stream treatment – Boundary Creek | Selection of inappropriate remediation technology | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 4B | Medium | Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | C - | 2C | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R187 | Technical (performance) | In stream treatment – Boundary Creek | Remediation technology improperly designed | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | C - | 2C | Low |
| R188 | Technical (performance) | In stream treatment – Boundary Creek | Inappropriate remediation objectives | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application). | 2 - | B - | 2B | Insignificant |
| R189 | Technical (performance) | In stream treatment – Boundary Creek | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data. | 2 - | B - | 2B | Insignificant |
| R190 | Technical (performance) | In stream treatment – Boundary Creek | Plant infrastructure is undersized for the actual acidity load | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the variability of acidity loads can be planned for. Base calculations on modelled acidity and measured acidity when data is available. Undertake pilot trials to guide appropriate selection of chemical and dosing requirements. | 2 - | C - | 2C | Low |
| R191 | Technical (performance) | In stream treatment – Boundary Creek | Incorrect choice of neutralising agent | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the variability of acidity loads can be planned for. Base calculations on modelled acidity and measured acidity when data is available. Undertake pilot trials to guide appropriate selection of chemical and dosing requirements. | 2 - | C - | 2C | Low |
| R192 | Technical (performance) | In stream treatment – Boundary Creek | Inefficient mixing of neutralising agent in stream | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Analyse existing streamflow data to predict mixing of various loads of reagent in the stream immediately downstream of the dosing. Monitor effectiveness of treatment and modify if required (e.g. addition of a mixing tank) | 2 - | B - | 2B | Insignificant |
| R193 | Technical (performance) | Settling pond and sludge management | Selection of inappropriate remediation technology | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 5B | High | Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | B - | 2B | Insignificant |
| R194 | Technical (performance) | Settling pond and sludge management | Remediation technology improperly designed | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 5C | Critical | Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design is oversized to allow for contingency volumes (if pond cannot be emptied at the planned frequency). | 3 - | B - | 3B | Low |
| R195 | Technical (performance) | Settling pond and sludge management | Inappropriate remediation objectives | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application). | 2 - | B - | 2B | Insignificant |
| R196 | Technical (performance) | Settling pond and sludge management | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data. | 2 - | B - | 2B | Insignificant |
| R197 | Technical (performance) | Settling pond and sludge management | Excessive production of sludge | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 5B | High | Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design is oversized to allow for contingency volumes (if pond cannot be emptied at the planned frequency). | 3 - | B - | 3B | Low |
| R198 | Technical (performance) | Settling pond and sludge management | No formation of sludge in pond due to incorrect pond conditions | 5 - Extreme | Technology causes a worsening of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 5B | High | Collect additional water quality data for flows leaving the swamp over a range of flow regimes so that the potential sludge volumes can be estimated. Base calculations on pilot trials that demonstrate actual precipitation rates. Ensure pond design allows for appropriate residence times. | 3 - | B - | 3B | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R199 | Technical (performance) | Aerobic wetland | Selection of inappropriate remediation technology | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Use existing geochemical data and any further data collected to plan implementation of technology. Monitor effects of initial application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | B - | 2B | Insignificant |
| R200 | Technical (performance) | Aerobic wetland | Remediation technology improperly designed | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 4C | High | Collect additional water quality data for flows expected to enter the wetland. Base design on estimations from more detailed modelling. Ensure wetland design is oversized to allow for contingency flow rates. | 2 - | B - | 2B | Insignificant |
| R201 | Technical (performance) | Aerobic wetland | Inappropriate remediation objectives | 3 - Major | Technology fails to provide significant improvement of conditions in Big Swamp and/or Boundary Creek | C - Possible | Event could occur at some time | 3C | Medium | Ensure technology is designed to meet the required objective using existing modelling and future monitoring data (including during application). | 2 - | B - | 2B | Insignificant |
| R202 | Technical (performance) | Aerobic wetland | Remediation is too slow | 2 - Moderate | Technology provides limited improvement to Big Swamp and/or Boundary Creek conditions | C - Possible | Event could occur at some time | 2C | Low | Complete further modelling to understand likely timeframes for remediation and assess whether these expected timeframes are acceptable. Monitor during implementation and update understanding to incorporate additional data. | 2 - | B - | 2B | Insignificant |
| R203 | Technical (performance) | Aerobic wetland | Wetland provides no measurable improvement to water quality in Boundary Creek | 4 - Severe | Technology fails to provide any improvement of conditions in Big Swamp and/or Boundary Creek | B - Unlikely | Event is not expected to occur | 4B | Medium | Use existing geochemical data and any further data collected to design wetland, especially water quality data of water expected to enter wetland, such as after other treatments. Monitor effects of application to ensure technology is performing as expected. If technology does not deliver expected results, either modify the application or consider a different technology or implementation method. | 2 - | B - | 2B | Insignificant |
| R204 | Logistical / infrastructure | Infilling fire trench and drainage channels | Access constraints limit the ability to completely infill the trenches | 2 - Moderate | Limited delay or cost associated with constraint | C - Possible | Event could occur at some time | 2C | Low | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R205 | Logistical / infrastructure | Infilling fire trench and drainage channels | Requirements to upgrade access tracks to the swamp and to the trenches requiring filling | 2 - Moderate | Limited delay or cost associated with constraint | C - Possible | Event could occur at some time | 2C | Low | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R206 | Logistical / infrastructure | Provide supplementary flow | Reliability of supplementary water supply | 4 - Severe | Constraint causes significant delay and cost | C - Possible | Event could occur at some time | 4C | High | Ensure regular maintenance and upgrades of water supply infrastructure so that failures are reduced. Investigate potential back up supplies for the supplementary flow (such as an agreement with the owners of McDonalds Dam) | 3 - | B - | 3B | Low |
| R207 | Logistical / infrastructure | Provide supplementary flow | Failure of downstream delivery mechanism at McDonalds dam | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Maintain current management measures in place to ensure delivery is maintained. Continue monitoring downstream flow. Establish open communication with the owners/operators of McDonalds Dam | 2 - | A - | 2A | Insignificant |
| R208 | Logistical / infrastructure | Install hydraulic barriers | Access constraints limit the ability to install barriers at target locations | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R209 | Logistical / infrastructure | Install hydraulic barriers | Failure of automated gates/weirs which may be part of the barrier design to periodically release flows | 3 - Major | Constraint causes major delay or cost | B - Unlikely | Event is not expected to occur | 3B | Low | Assess requirement for gates/weirs in detailed design. If deemed necessary (for ecological health of the swamp), establish a suitable monitoring and maintenance regime for the infrastructure to maintain condition. | 1 - | C - | 1C | Insignificant |
| R210 | Logistical / infrastructure | Install hydraulic barriers | Loss of barrier integrity | 4 - Severe | Constraint causes significant delay and cost | C - Possible | Event could occur at some time | 4C | High | Establish a regular maintenance program for the barriers so that potential integrity issues are identified before loss of integrity occurs. Conduct regular monitoring of barrier performance so that failures are identified in a timely manner and can be addressed. | 3 - | B - | 3B | Low |
| R211 | Logistical / infrastructure | Surface application of neutralising agents | Access constraints limit the ability to deliver the required neutralising agent | 2 - Moderate | Limited delay or cost associated with constraint | C - Possible | Event could occur at some time | 2C | Low | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R212 | Logistical / infrastructure | Channel treatment (Big Swamp) – limestone sand | Access constraints limit the ability to deliver the required neutralising agent | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R213 | Logistical / infrastructure | In stream treatment – Boundary Creek | Identification of suitable location for system installation | 3 - Major | Constraint causes major delay or cost | D - Likely | Event would probably occur in most instances | 3D | High | Early works should include planning for a fixed treatment system so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design. | 2 - | C - | 2C | Low |
| R214 | Logistical / infrastructure | In stream treatment – Boundary Creek | Requirements to upgrade access tracks to deliver the neutralising agent to the system | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R215 | Logistical / infrastructure | In stream treatment – Boundary Creek | Provision and reliability of power/water supply | 4 - Severe | Constraint causes significant delay and cost | C - Possible | Event could occur at some time | 4C | High | Begin planning for power and water supply to plant as soon as a location is identified (or as part of location identification). | 2 - | C - | 2C | Low |

| ID | Risk Group | Practicable measure implemented | Risk Event | Initial Risk | | | | | | Risk Mitigation Measures | Residual risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Consequence | | Likelihood | | Risk ranking | | | C | L | Risk ranking | |
| R216 | Logistical / infrastructure | In stream treatment – Boundary Creek | Reliability of mechanical and electrical components of the system (dosers, mixers instrumentation etc) | 3 - Major | Constraint causes major delay or cost | C - Possible | Event could occur at some time | 3C | Medium | Ensure regular maintenance is carried out on all system components and develop an infrastructure management plan that includes actions for system failures. | 2 - | C - | 2C | Low |
| R217 | Logistical / infrastructure | In stream treatment – Boundary Creek | Requirement for adequate storage of chemicals (i.e. environmental conditions) | 3 - Major | Constraint causes major delay or cost | B - Unlikely | Event is not expected to occur | 3B | Low | Include chemical storage and consideration of environmental controls required for chemicals in the planning stage so that adequate storage is designed. | 2 - | B - | 2B | Insignificant |
| R218 | Logistical / infrastructure | In stream treatment – Boundary Creek | System loss due to flooding/fire | 5 - Extreme | Constraint causes project to stop | B - Unlikely | Event is not expected to occur | 5B | High | Include measures in the design to minimise the risk of total system loss, such as fire management measures (vegetation clearing) and flood risk assessment and management. | 4 - | A - | 4A | Low |
| R219 | Logistical / infrastructure | Settling pond and sludge management | Constraints associated with disposal of potentially high sludge volumes | 3 - Major | Constraint causes major delay or cost | C - Possible | Event could occur at some time | 3C | Medium | Ensure that design includes development of a sludge management plan, including contingency measures associated with system failure. | 3 - | B - | 3B | Low |
| R220 | Logistical / infrastructure | Settling pond and sludge management | Identification of suitable location for settling pond | 3 - Major | Constraint causes major delay or cost | D - Likely | Event would probably occur in most instances | 3D | High | Early works should include planning for a settling pond so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design. | 2 - | C - | 2C | Low |
| R221 | Logistical / infrastructure | Settling pond and sludge management | Requirements to upgrade access tracks to settling pond location | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |
| R222 | Logistical / infrastructure | Aerobic wetland | Identification of suitable location for wetland | 3 - Major | Constraint causes major delay or cost | D - Likely | Event would probably occur in most instances | 3D | High | Early works should include planning for a wetland so that approvals for land acquisition and community consultation can be completed early and avoid delays to the program. Include costs for land acquisition and negotiations with landholders into design. | 2 - | C - | 2C | Low |
| R223 | Logistical / infrastructure | Aerobic wetland | Requirements to upgrade access tracks to wetland location | 2 - Moderate | Limited delay or cost associated with constraint | D - Likely | Event would probably occur in most instances | 2D | Medium | Ensure that planning stage includes assessment of access and provision for access upgrades if necessary | 1 - | B - | 1B | Insignificant |