



Barwon Water

PRB Assessment

13 September 2022

Table of Contents

Figures

Tables

Appendices

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Section 1 Introduction

1.1 Introduction

CDM Smith was engaged by Barwon Water to conduct a remediation options assessment for permeable reactive barriers (PRB), at Big Swamp, Yeodene, Victoria. The aim of the assessment is to undertake a review of the PRB technology and relevant hydrogeological conditions, then consider likely cost versus environmental benefit of installing PRB in upstream locations (to inundation points) in Boundary Creek, adjacent to Big Swamp.

Based on discussions between CDM Smith and Barwon water (29 June 2022), it is understood that there is evidence of increasing groundwater/surface water interactions and water levels in 2021/2022, beyond that previously modelled and considered as part of the previous PRB assessment (CDM Smith 2019). PRB technology was previously discounted from the ROA (CDM Smith, 2019), where previous modelling approaches (for data up to 2020/2021) inferred groundwater to be only a small proportion of total flow (less than 0.3 ML/day). The evidence relating to the potential increase in groundwater/surface water interaction (noted in 2021/2022), has opened the case for PRB to be further explored as a contingency measure to mitigate acidity (and subsequent metals precipitation), into surface water in Boundary Creek and Barwon River.

Note: this assessment will be completed as a separate document to the remediation options assessment (ROA) (CDM Smith, 2019), however, will refer to the base document for context, as required.

1.2 Objectives

The objectives of this work are:

- Review client supplied information including hydrogeological conditions, that have resulted in the consideration of permeable reactive barriers (PRB) as a risk contingency at the site.
- Provide clear rationale in relation to the above changes in hydrogeological conditions and reasons that PRB technology has been reconsidered, following early omission in the ROA (CDM Smith 2019).
- Provide a clear and objective remediation options assessment for PRB technology including consideration of social, economic, technical and environmental conditions, that will work to validate (or disprove) the use of this PRB technology for risk mitigation at the site.
- Where relevant (if PRB considered viable), recommendations for 'next step' in relation to design and construction risk assessment.

1.3 Scope

The objective and tasks related to this work are summarised below:

- Review and conceptualise new information supplied by Barwon Water in relation to hydrogeology in the Big Swamp/Boundary River systems. Specifically in relation to groundwater levels and recovery, which has led to further review of PRB as a viable option for acid reduction in Boundary Creek.
- Review of currently known (and relevant) hydrogeological factors, such as groundwater levels and surface water interactions in Big Swamp. Consideration of low and high flow inundations that may be relevant to the proposed locations of the PRBs.
- Consideration of PRB as a viable option for mitigation of acidity and metals precipitation into Boundary Creek (and Barwon River). This will consider the general inputs for a remediation options assessment (technology, principal, site implementation, advantages, disadvantages, key issues). The assessment will also highlight 'next steps' moving forward with conceptualisation, prior to the detailed design phase, should the technology be considered viable.

Section 2 Site Background

2.1 Site Locality and Reaches

Big Swamp is a peat swamp along Boundary Creek, a tributary of the Barwon River, in the Otway Ranges of Victoria, Australia. The locality of Big Swamp and Boundary Creek, Yeodene VIC is shown on Figure 1 below. Boundary Creek as a tributary of Barwon River, forms a part of the Barwon River Catchment. Boundary Creek is approximately 19 km long and flows from Barongarook to Yeodene, where it joins the Barwon River approximately 16 km south-east of Colac.

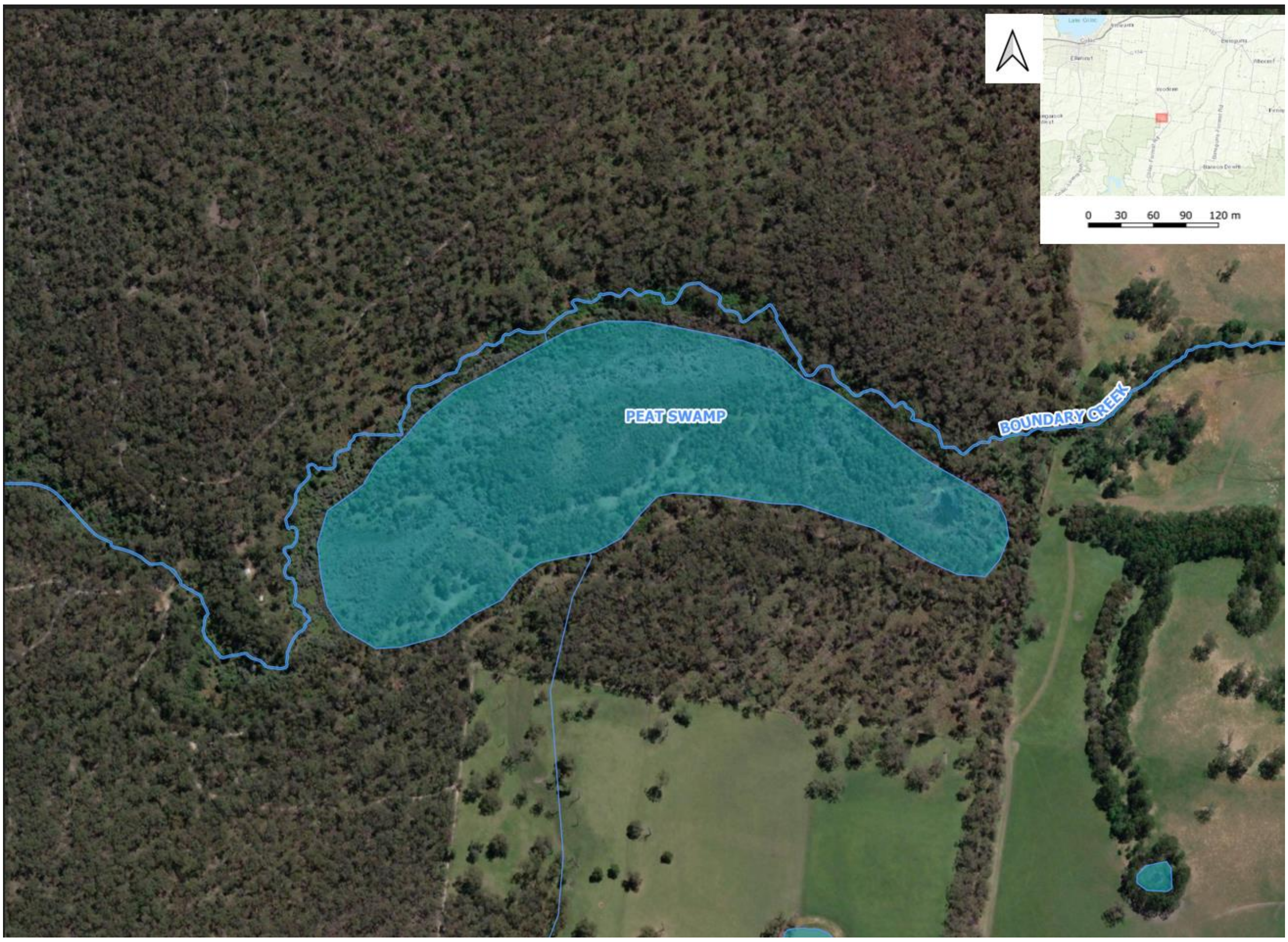

Figure 1 Site Locality (Big Swamp and Boundary Creek)

The following reaches are present in broader study area, that have relevance to Big Swamp/Boundary Creek groundwater/surface water interactions.

- **Reach 1** - This is the upper reach of the creek and includes a large private on-stream dam (160 ML capacity) that was constructed in 1979. This reach can be further broken into 2 sub-reaches based on the underlying geological units, as follows:
  - **Reach 1a** represents the section of the creek from Barongarook to ~500 m upstream of McDonalds Dam. The Quaternary Sediments within this reach are predominantly underlain by outcropping bedrock which comprise impermeable Paleozoic sandstone, siltstone and mudstone and is weakly gaining.
  - **Reach 1b** represents the ~500 m stretch from reach 1a through to McDonalds Dam. The Quaternary Sediments within this reach are underlain by the Lower Tertiary Aquifer (LTA) system. This reach is within the recharge zone and is classified as a losing stream.

- **Reach 2 -** Represents the portion of Boundary Creek between the outlet of the private on-stream dam and the downstream end of Big Swamp. This reach can also be further broken down into 3 sub-reaches based on the nature of the streambed, the vegetation classes and underlying geological units, as follows:
  - **Reach 2a**, represents a likely artificial channelised section immediately downstream of the private on-stream dam. The Quaternary Sediments within this reach are underlain by the by the Lower Tertiary Aquifer (LTA) system. Similar to reach 1b, this reach is within the recharge zone and is classified as a losing stream.
  - **Reach 2b**, represents a densely vegetated and marshy low-land area known as the 'damplands', located upstream of Big Swamp. This reach is characterised by highly braided flow pathways and waterlogged conditions. Similar to reach 2a, the Quaternary Sediments within this reach are underlain by the Lower Tertiary Aquifer (LTA) system. Historically, this portion of the stream was likely a gaining stream that received rejected recharge/baseflow from the Lower Tertiary Aquifer system.
  - **Reach 2c**, represents the area from the end of reach 2b to the downstream end of Big Swamp where the Boundary Creek and Big Swamp flow paths meet. The Quaternary Sediments within this reach are underlain by the Upper Mid-Tertiary Aquifer (UMTA) that is separated from the Lower Tertiary Aquifer system by the Narrawaturk marl – that acts as a confining layer. This reach is considered to have some degree of groundwater connection that will contribute to during dry low flow periods.
- **Reach 3 -** Represents the channelised portion of Boundary Creek from the downstream end of Big Swamp to the confluence of Boundary Creek and the Barwon River. This section has been heavily modified to support agricultural activities, with the Quaternary Sediments being underlain by the Upper Mid-Tertiary Aquifer (UMTA). Regionally the Upper Mid-Tertiary Aquifer is separated from the Lower Tertiary Aquifer system by the Narrawaturk marl - that acts as a confining layer and enables pressurization of the Lower Tertiary Aquifer system.

The location of each reach and the underlying geology is provided in Figure 2 below.

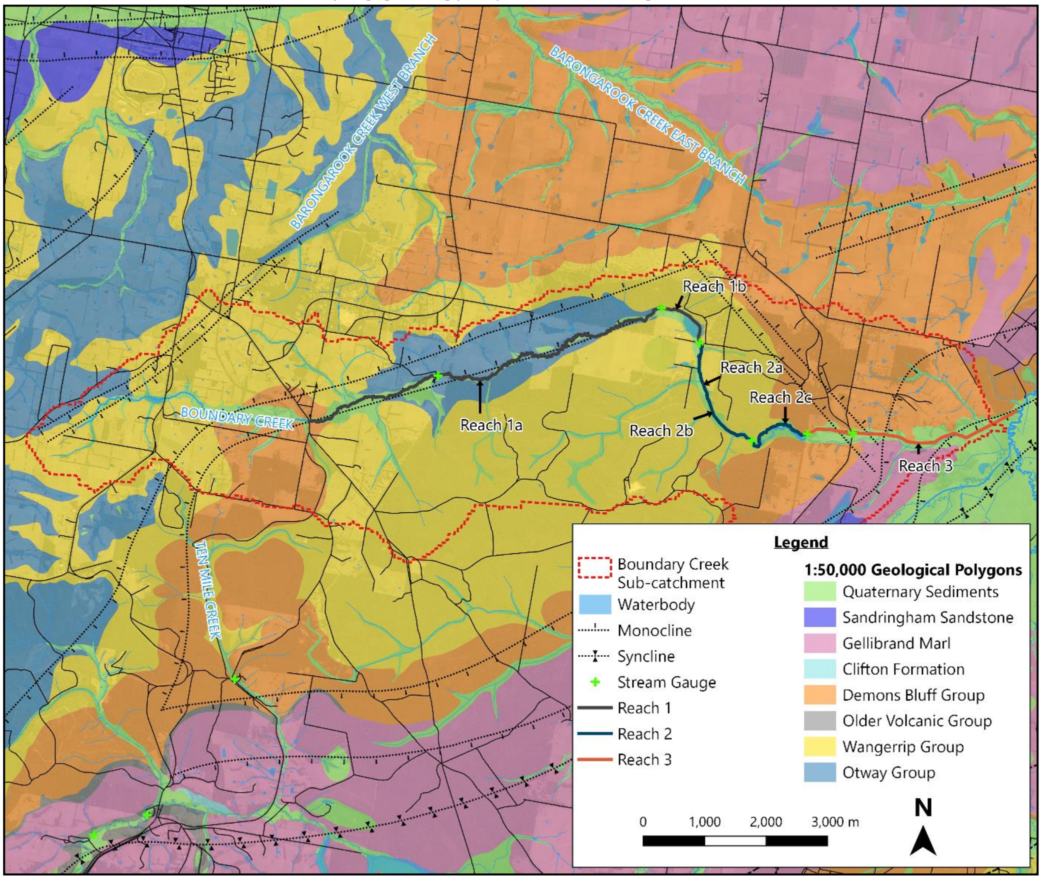

Figure 2 **Simplified geology and hydrology of the Boundary Creek Catchment (Supplied by Barwon Water)**

The alluvial sediments in Big Swamp contain significant amounts of pyrite (FeS_2), one of the iron sulfides commonly associated with acid sulphate soils (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:

- Drying (desaturation) of the alluvial sediments within Big Swamp.
- Oxidation of the acid sulphate soils contained within 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.
- Increased 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).

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.

2.2 Water Quality Review

A review of recent water quality data at Big Swamp and Boundary Creek from June 2022 is provided in Table 2-1 below. Table 2-1 looks at the primary contaminants of concern associated with the acidification of Big Swamp - pH, sulphate, iron and metals. Further review of surface water results from May 2022 and June 2022 for locations upstream of Big Swamp (BCUSBS), Boundary Creek downstream, of Big Swamp (BCDSBS) and Boundary Creek at Yeodene (BCY) is provided in Appendix A. Groundwater bore locations and streams sampling locations are shown on locations are shown on Figure 3 below.

Based on the review of information in Table 2-1 below, it was evident that surface water impacts in Boundary Creek were primarily associated with the lower reaches of Boundary Creek, downstream of Big Swamp. It was also evident that acidification impacts in the western portion of the swamp were more pronounced than the eastern portion of the swamp. This was expected based as groundwater levels are nearer to the surface in the eastern portion of the site (see hydrographs in Section 3.2 below), saturating the majority of swamp sediments.

Table 2-1 Water Quality (mg/L – unless specified)

Sample Location	pH (pH units)	Sulphate	Total Alkalinity (as CaCO3)	Total Iron (MS)	Aluminium	Manganese	Nickel	Zinc
Boundary Creek Surface Water								
USBS (background)	**6.7**	**6**	**18**	**0.14**	**<0.01**	**<0.001**	**<0.001**	**<0.001**
DSBS	5	78	<2	2.5	1.9	0.025	0.014	0.048
BCY	4.3	84	<2	3	2	0.04	0.025	0.1
Big Swamp Groundwater Bores – East								
BSBH01	6.4	1	84	0.01	<0.01	0.77	<0.001	<0.001
BSBH02	7	<1	98	<0.01	<0.01	0.068	0.015	0.011
BSBH03	6.6	1	68	0.02	<0.01	0.069	0.002	0.003
BSBH04	3.7	210	<2	8.3	0.84	0.33	0.073	0.087
BSBH05	5.8	29	<2	<0.01	<0.01	0.11	0.015	0.018

Sample Location	pH (pH units)	Sulphate	Total Alkalinity (as CaCO3)	Total Iron (MS)	Aluminium	Manganese	Nickel	Zinc
BSBH06	6.5	38	44	0.08	0.33	0.12	0.003	0.007
BSBH07	6	21	50	0.03	0.07	0.28	0.006	0.015
BSBH08	3.6	870	<2	130	21	0.67	0.4	1.2
BSBH09	4	1100	<2	190	17	1.2	0.26	0.54
BSBH10	5	8	43	<0.01	0.05	0.16	0.028	0.021
Big Swamp Groundwater Bores - West								
BSBH11	3.3	430	<2	8.1	18	0.48	0.1	0.43
BSBH12	3.3	700	<2	70	44	0.18	0.58	4.4
BSBH14	3.3	2400	<2	400	150	1.5	1.6	9.7
BSBH15	3.3	1200	<2	250	100	0.2	0.59	1.3
BSBH16	3.4	510	<2	23	89	1	0.24	0.36
BSBH17	4	1000	<2	59	13	1.4	0.01	0.17
BSBH18	2.9	660	<2	67	31	0.074	0.078	0.19
LTA Aquifer								
BH13	5.1	24	10	0.08	0.02	0.09	0.027	0.036

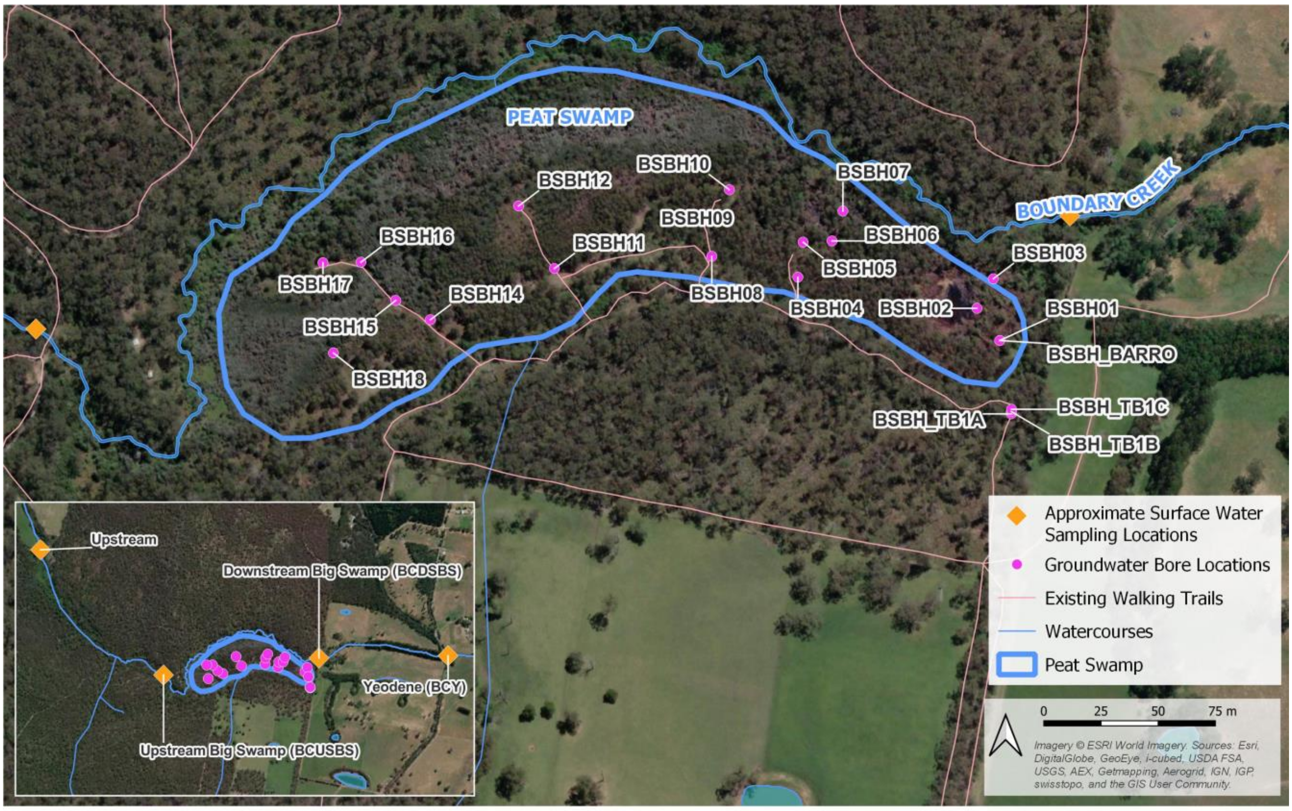

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Figure 3 Surface Water and Groundwater Sample Locations

Section 3 Hydrogeological Site Conditions

3.1 Overview

The hydrogeology of the Swamp has been described in GHD's Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design (2021) and CDM Smith's Big Swamp Success Target Assessment (2021). The hydrogeology of Big Swamp and Boundary Creek is complex and understanding of hydraulic conditions that contribute to acidity and groundwater/surface water interactions is continually evolving, as more information is obtained. It is noted that further information has become available that updates the conceptual site model, leading to the re-consideration of PRB as a potential remediation contingency.

The current understanding of hydrogeological conditions at the swamp is summarised below:

- Big Swamp occupies a narrow valley containing a shallow alluvial system comprised of sediments associated with Boundary Creek. The thickness of the alluvial sediments is not known, however bores drilled into the swamp show at least 6 m of sediments. GHD (2021) analysis of regional bores suggests the alluvial sediments will increase in thickness along the course of Boundary Creek, from less than 8 m at McDonalds Dam to around 14 m at the lower end (eastern end) of Big Swamp. This analysis also suggested the thickness of the alluvial sediments will taper off towards the edge of the swamp where the recent alluvium pinches out against the underlying units (GHD, 2021).
- The swamp sediments are underlain by older strata comprising the Gellibrand Marl (an Upper Middle Tertiary Aquitard), the Narrawaturk Marl (Lower Middle Tertiary Aquitard) and Mepunga/Dilwyn Formation (Lower Tertiary Aquifer) (GHD, 2021). The alluvial sediments and Gellibrand Marl comprise the "upper groundwater flow system" and the Narrawaturk Marl separates these from the underlying LTA in the area.
- Previous conceptualisations suggested that the LTA directly underlies the upper groundwater flow system of the swamp in the western portion of the swamp, although the exact location of the contact was unknown. The recent installation of bore BSBH13 to a depth below the swamp sediments and into the LTA has indicated the presence of the Narrawaturk Marl (the regional confining layer) extends beyond the western portion of Big Swamp, as shown in Figure 5 below. The presence of the Narrawaturk Marl over the western portion of big swamp has significant relevance to the connectivity of the upper groundwater flow system and LTA, including that increasing groundwater levels in the LTA may not influence the groundwater levels within the swamp upper flow system, beyond preventing losses from the swamp to the underlying units. Therefore, although the pressures in the LTA will be supporting groundwater levels in the swamp sediments, there is unlikely to be direct flow of LTA groundwater into the swamp. This is discussed further below.
- Changes in groundwater levels in the Big Swamp upper groundwater flow system are closely linked to the stream flow in Boundary Creek, with rapid rises in swamp groundwater levels corresponding with increases in stream flow (GHD, 2021 and CDM Smith, 2021). The minimal lag time in swamp groundwater response indicates a small unsaturated zone proceeding the flow events (GHD, 2021). The infiltration rate is estimated to be 2 to 18 mm/d (GHD, 2021) and the creek is conceptualised to be net losing to the swamp upper groundwater flow system.
- In finer detail it is likely there is both groundwater recharge and groundwater discharge occurring within the Big Swamp upper groundwater flow system, varying seasonally. In the western portion of Big Swamp, the water table (present in the swamp sediments), is deeper and the creek is likely to be losing most of the time. In the eastern portion of Big Swamp, sediments are fully saturated for a lot of the time and this area is a discharge zone for the throughflow in the swamp (in the swamps upper groundwater flow system). So although the creek is net losing, there is a component of groundwater flow from the swamp sediments contributing to creek flows.
- Groundwater discharge from the swamp sediments occurs via throughflow out of the swamp (and discharge to the creek), diffuse discharge to ponded areas where groundwater levels in the swamp sediments are above ground level (i.e. sediments are fully saturated), as well as evapotranspiration via swamp flora and direct

evaporation from the water table, where this is close to the surface. Evapotranspiration is expected to be significant in the drier months (GHD, 2021).

- There is an upward hydraulic gradient between the Lower Tertiary Aquifer (LTA) and the swamp sediments (upper groundwater flow system), however, the hydrograph responses in the swamp upper groundwater flow system indicate that upward vertical leakage from the LTA is likely to be limited by the low hydraulic conductivity of the confining layers. The historical link between the LTA and the swamp is likely to be restricted to the LTA contributing baseflow to Boundary Creek upstream of the swamp where it outcrops, assuming groundwater levels in the LTA are above the creek bed elevation.
- Recent groundwater level monitoring (described in more detail in Section 3.2 below) indicates that:
  - Groundwater levels in the LTA have shown an increase since cessation of pumping in 2016 and more recently from late 2021 (see section 3.2 and Appendix B). Although (as described above) this increase in groundwater levels is unlikely to be transferred directly to the swamp sediments via any existing direct connection, the upward pressure from the LTA will prevent groundwater being lost from the swamp sediments to underlying units. In addition, when LTA groundwater levels have recovered sufficiently to provide baseflow to Boundary Creek upstream of the swamp, this will increase overall water inflow to the swamp.
  - Management of releases from the private on-stream dam and post millennium drought climate will also increase overall water inflow to the swamp, however, some of these supplementary flows are still being lost to the LTA as water levels in this aquifer are still below the levels of Boundary Creek upstream of the swamp. There is currently insufficient time series data to confirm whether further groundwater level recovery in the LTA, climate and managed water releases will result in increases of groundwater levels in Big Swamp to the assumed historical levels (based on soil acidity). This can be further assessed as more information becomes available.
  - Groundwater levels in the upper groundwater flow system suggest that the swamp may have reached a steady state, or maximum groundwater controlled saturation. Where, during wet periods the water table is expressing at the swamp surface. From the long section provided below (Figure 6), it can be seen that groundwater discharge is occurring where the elevation of the water table is equal to or greater than the swamps elevation. What remains unclear at this stage is whether continued recovery of the LTA aquifer (to the point where Boundary Creek is no longer losing water upstream of the swamp) and water release from MacDonalds dam will create sufficient recovery and pressure to fully saturated the localised elevated topographic highs within the swamp, between BSBH12 and BSBH09. This concept considers that the creek surface/elevation has been significantly altered from its natural state, following a series of earthworks events including the fire in 2010, which saw the clearing of land and installation of a fire trench in the area. Also, slumpage from the peat fires and loss of soil structure.
- It is possible that the groundwater levels presented in Figure 6 (swamp sediment groundwater levels) may not rise further as the system has entered a discharge controlled state. Where any increase in swamp groundwater levels results in an increase in groundwater discharge, that prevents any further increase in groundwater levels. As above, there is insufficient time series data to confirm whether groundwater levels in the LTA, climate and management will result in continual recovery of groundwater levels in Big Swamp and fully saturate localised elevated sections of the swamp, that may still generate acidity.

The conceptualisation of the swamp hydrogeology is shown in Figure 4 (from CDM Smith, 2021) and the most recent conceptualisation of the area produced by Barwon Water is shown in Figure 5. Further information in relation to recent groundwater levels and groundwater contributions to stream flow are provided in Section 3.2 and 3.3. An overview of conditions relative to the PRB is detailed in Section 3.4 below.

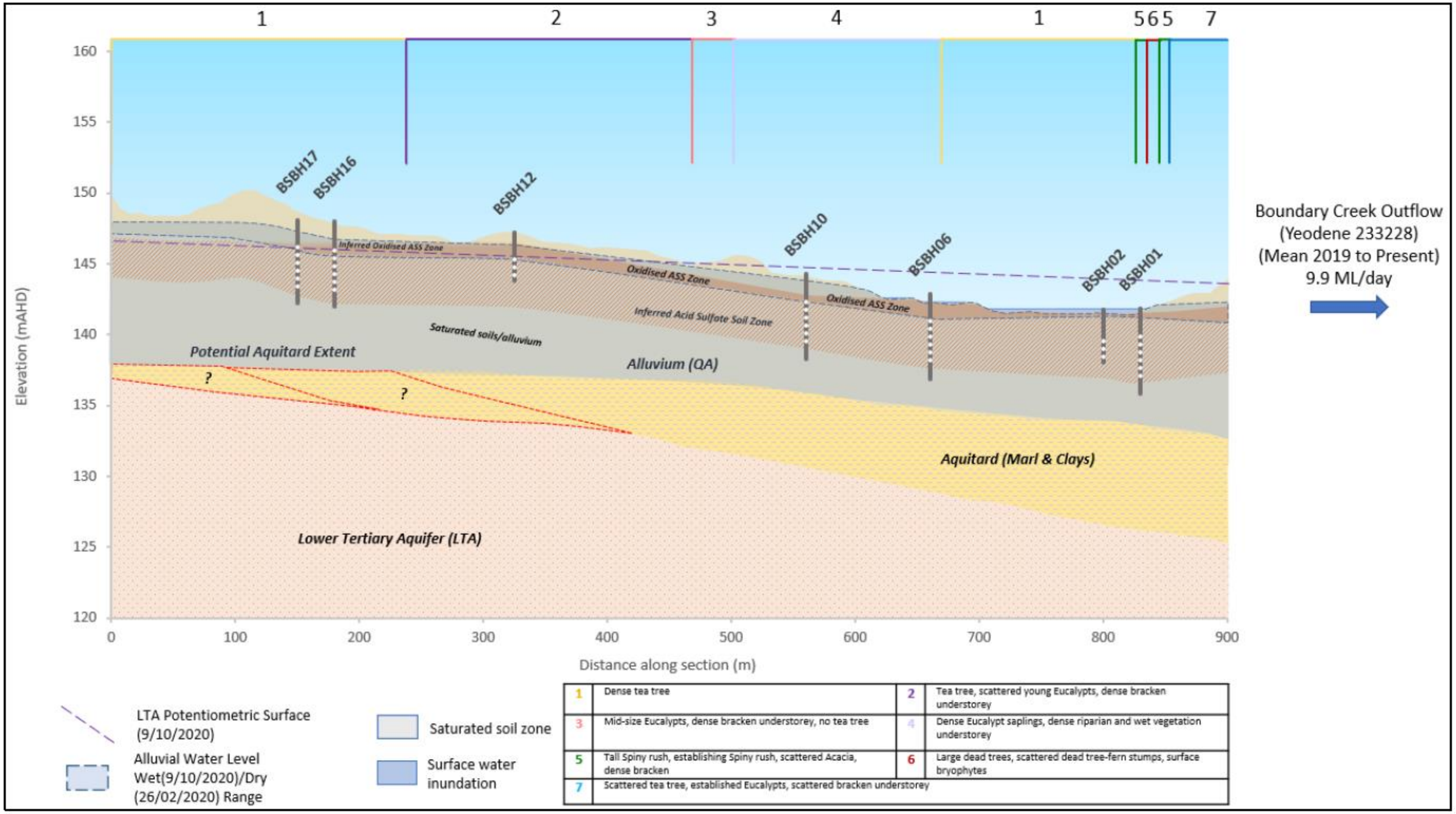

Figure 4 Conceptual cross section of Big Swamp (adapted from CDM Smith, 2021) showing conditions of Big Swamp (2019-2021)

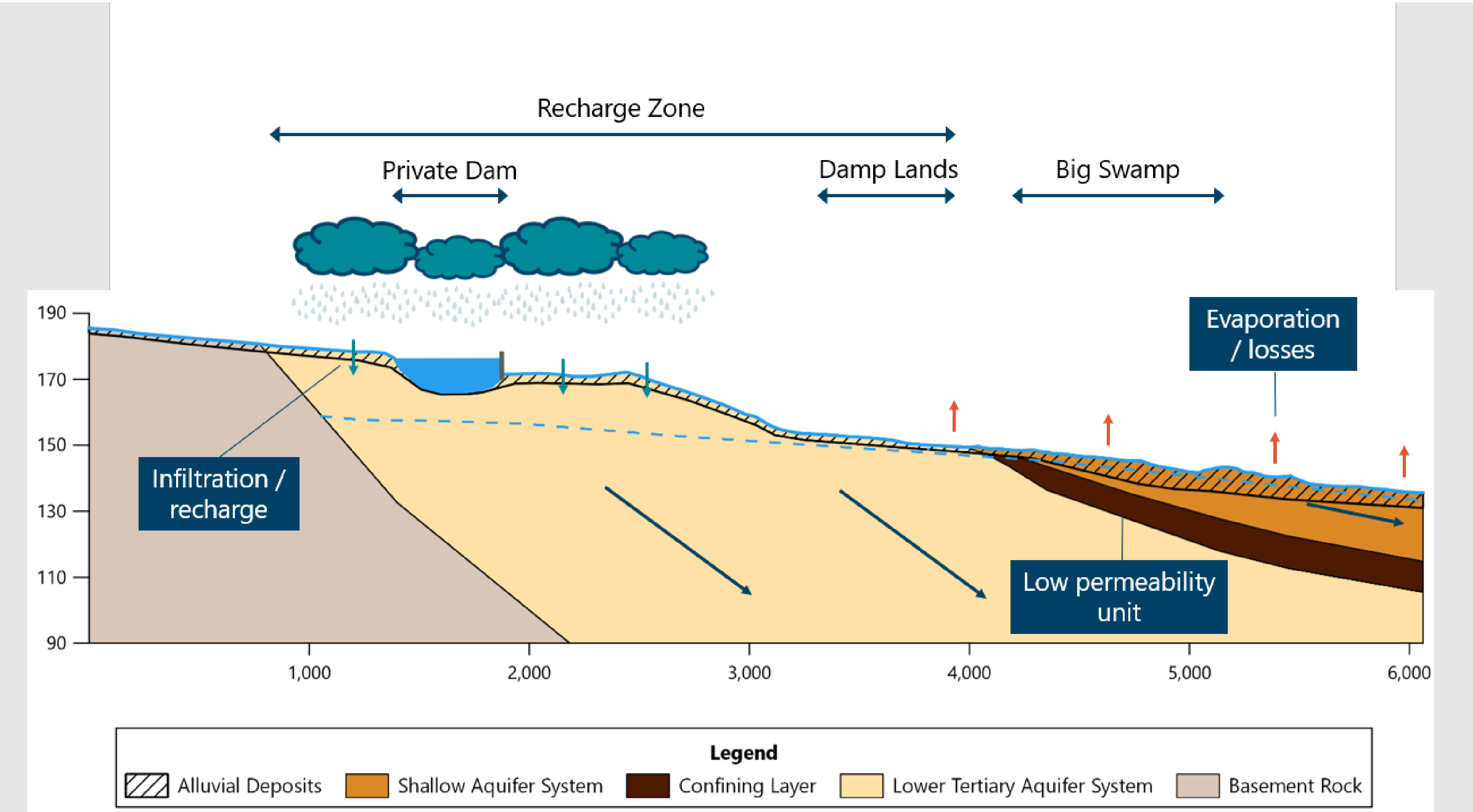

Figure 5 Conceptual cross section of Big Swamp (2022) – supplied by Barwon Water

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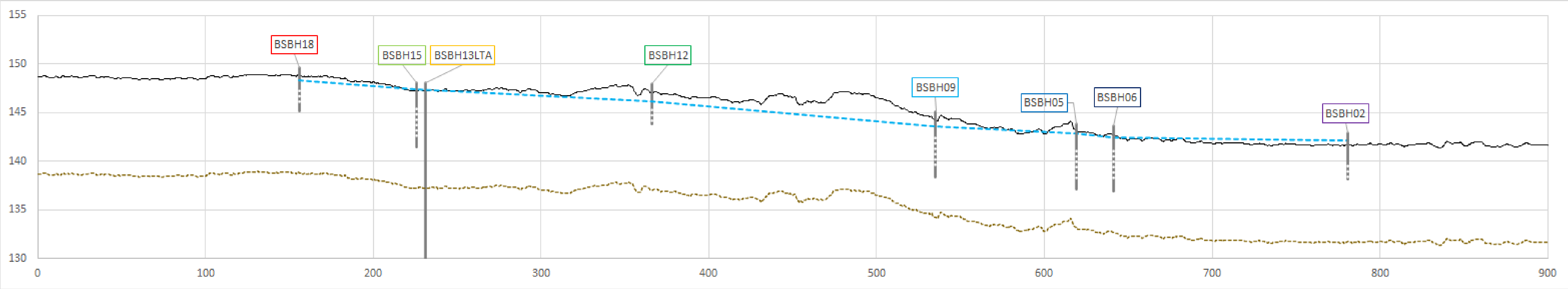

Figure 6 **Big Swamp Long Section**

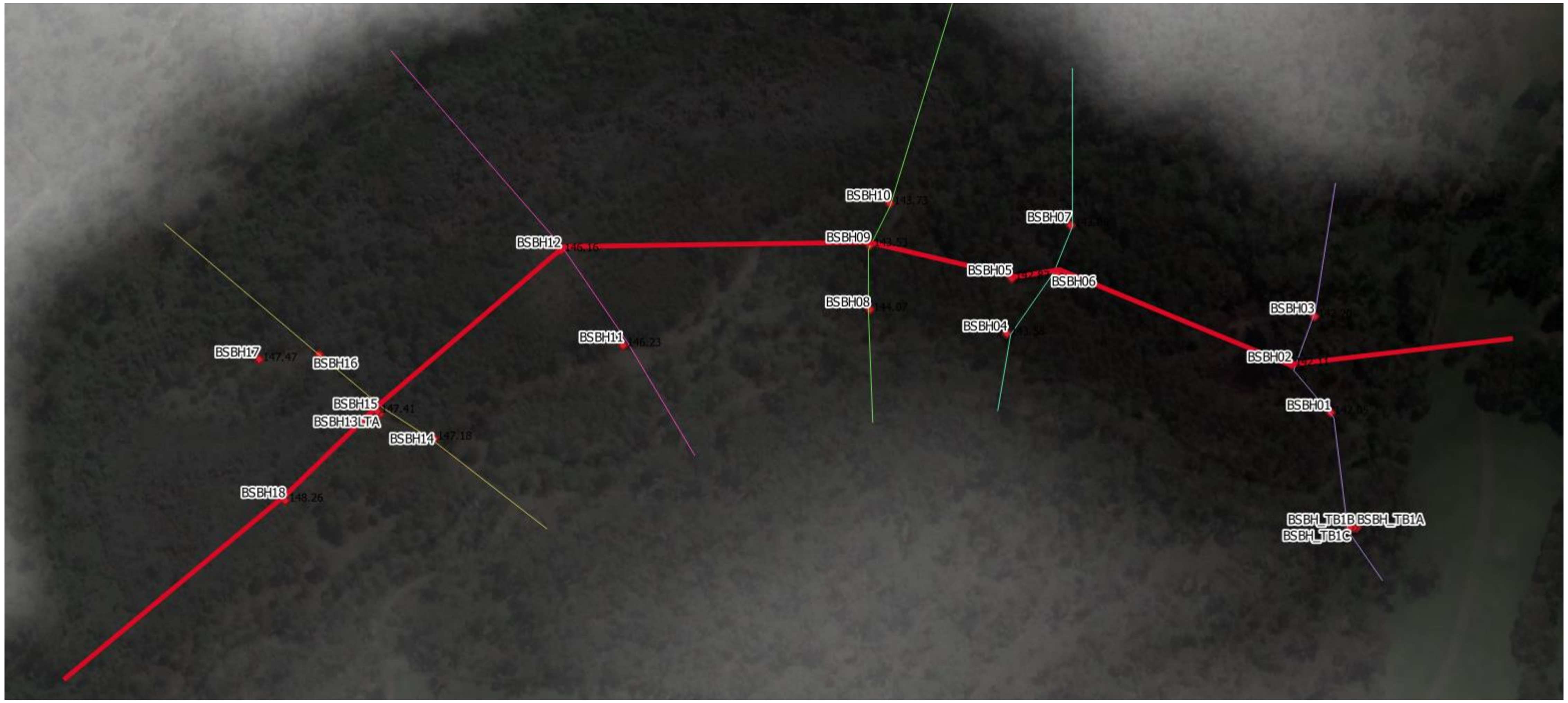

Figure 7 **Long Section Location Overview**

3.2 Review of recent groundwater level data

The Barwon Water owned bores in and near the swamp are monitored using groundwater levels loggers. The monitoring period for these wells is from June 2019 to June 2022. Other nearby SOBN bores are monitored quarterly. DELWPs telemetered bores are currently unavailable for download.

3.2.1 Lower Tertiary Aquifer

Groundwater levels for bores screened in the LTA within 3 km of Big Swamp are shown in Figure 8 since the cessation of pumping in 2016 and Figure 9 for the monitoring period for the Big Swamp bores. Groundwater levels in the LTA have risen since the cessation of pumping by 3 to 10 m and over the Big Swamp monitoring period (i.e. from June 2019) by 2 to 4 m. The cumulative departure from mean rainfall shows above average precipitation (and consequently increased recharge) since June 2020.

The high frequency level logger data for LTA bores close to and in the swamp (BSBH13 and BSTB1C) show little to no short term variation and follow the general rising trend similar to other LTA bores. BSTB1C (near the downstream end of the swamp) is artesian, with groundwater pressure above the ground surface. BSBH13 is artesian in the last three months of the monitoring period, with groundwater pressure sub artesian before this time. Bore 109112 (700 m downstream of Big Swamp along Boundary Creek) is also artesian. Bores 109133 (3km north of the swamp) and 64240 (2.5 km southwest of the swamp) are located on the edge of the Narrawaturk Marl and are both sub artesian

Bores 109128 and 109130 are located upstream of Big Swamp along Boundary Creek (1 km and 2 km upstream respectively) in the outcropping LTA (unconfined) and the maximum groundwater levels in these wells since 2016 are 8 m and 7 m below ground level, respectively.

The overall rising trends will be due to a combination of recent higher rainfall periods and the ongoing recovery of the aquifer due to the cessation of groundwater extraction (in 2016). As well as this, there has been localised increased recharge associated with gains to the LTA from supplementary surface water flows from McDonalds Dam.

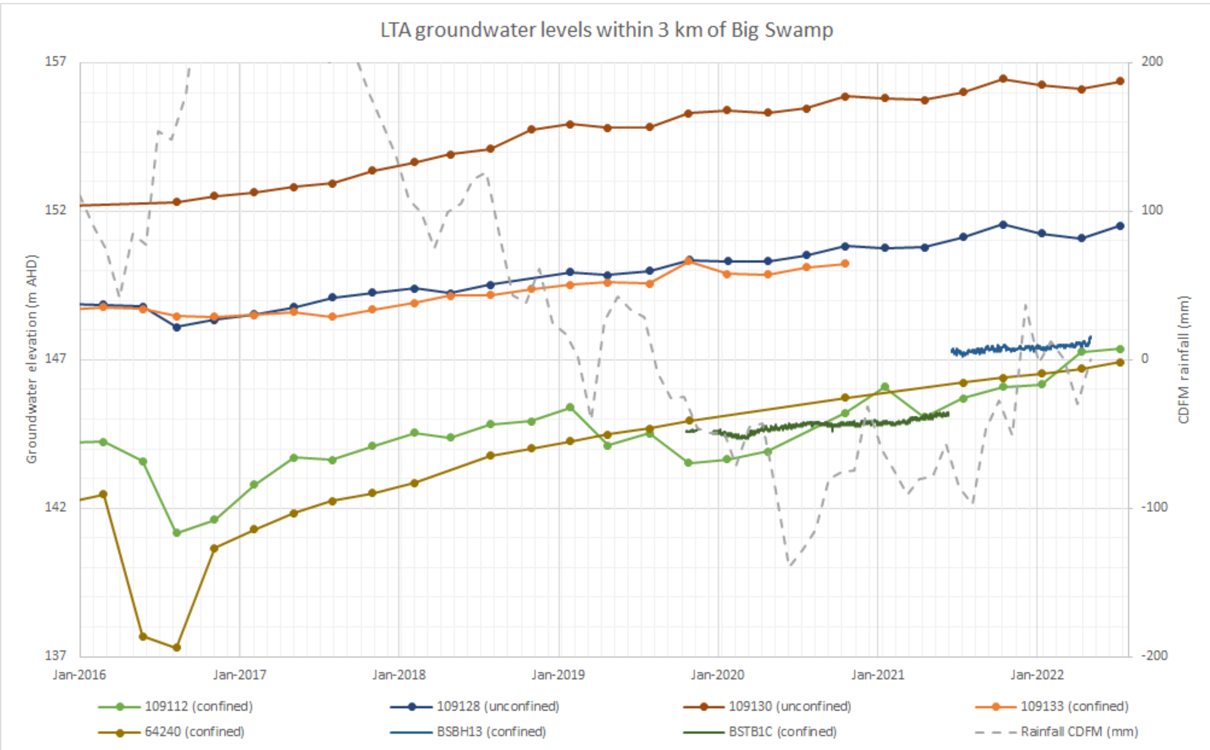

Figure 8 **Groundwater levels in LTA bores since cessation of pumping in 2016 within 3 km of Big Swamp alongside cumulative departure from Mean (CDFM) rainfall**

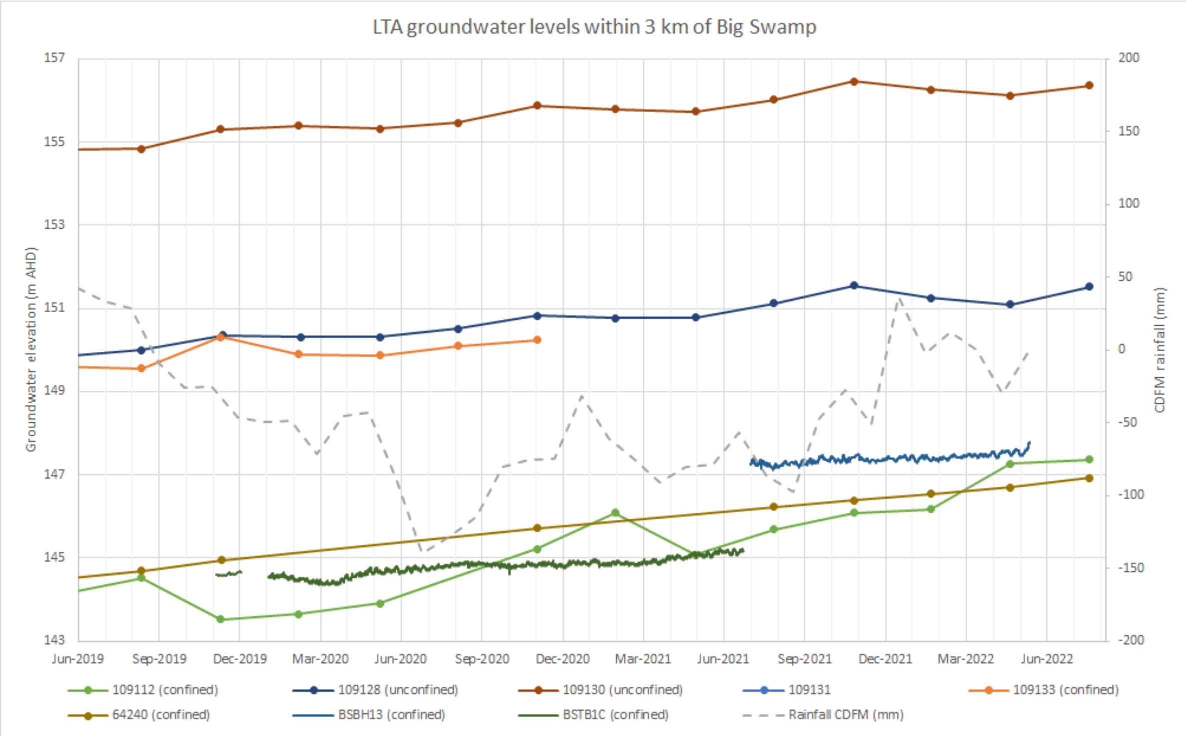

Figure 9 Groundwater levels in LTA bores within 3 km of Big Swamp alongside cumulative departure from Mean (CDFM) rainfall (scale set to monitoring period of Big Swamp bores for comparison)

3.2.2 Big Swamp upper groundwater flow system

Geographically, the monitoring bores in the Big Swamp upper groundwater flow system can be classified into two groups: eastern monitoring bores (BSBH01 to BSBH10) of lower elevation ranging between 142 m and 144.5 m AHD, and western monitoring bores (BSBH11 to BSBH18) of higher elevation ranging between 147 m and 148.5 m AHD. Hydrographs of the western and eastern monitoring bores in comparison to streamflow measured at the Big Swamp upstream gauge are shown in Figure 10 and Figure 11, respectively.

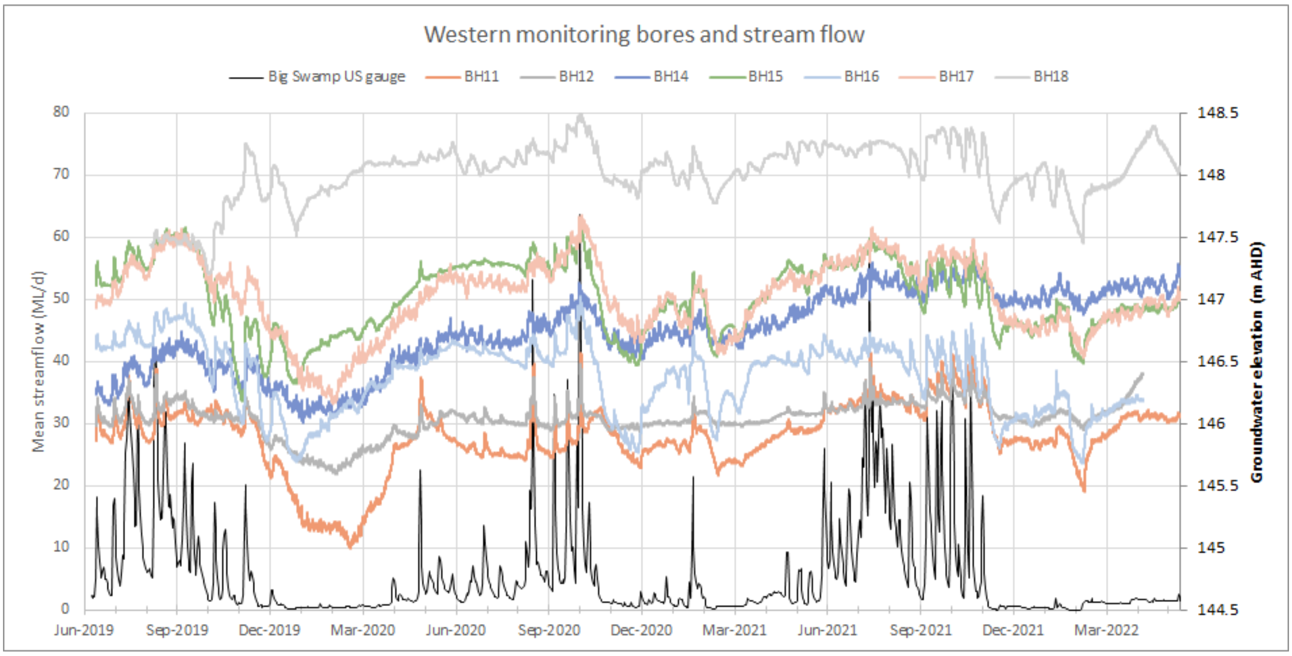

Figure 10 **Hydrographs for western (upstream) monitoring bores with streamflow**

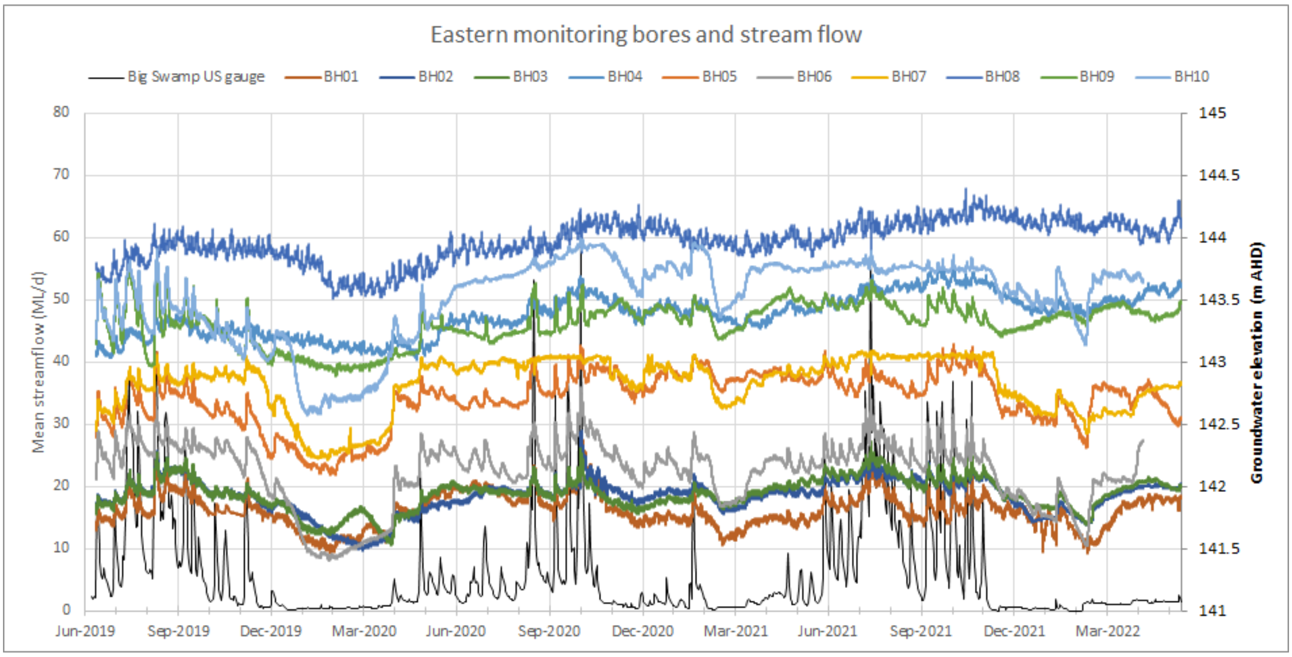

Figure 11 **Hydrographs for eastern (downstream) monitoring bores with streamflow**

The hydrographs support the conceptualisation of the streamflow through Big Swamp being the predominant driver of groundwater levels within the upper groundwater flow system, where periods of high streamflow correspond with sustained and elevated swamp groundwater levels and periods of low streamflow correspond with lower and decreasing groundwater levels. From the beginning of 2022 there has been a rise in groundwater levels in most wells that does not correspond to high stream flows (although there is approximately 1 ML/d of streamflow at the upper gauge over this period). This may be due to the effects of direct rainfall, but further information is required to assess this trend.

Seasonal variations average around 1.0 m in the eastern monitoring bores with greater fluctuation observed in the western monitoring bores, averaging around 1.5 m over the period of record. This suggests the western monitoring bores are more sensitive to streamflow showing greater decreases in water levels during periods of reduced streamflow and greater increases during periods of increased streamflow. There is a larger unsaturated zone in the western end of the swamp, giving more available head rise.

Over the two year monitoring period there has been variable trends in groundwater levels in the swamp, and given the seasonal variability, a longer monitoring period is required to confirm these trends. Most bores showed no trend or a very slight rise over the monitoring period (BH01, BH02, BH03, BH05, BH06, BH07, BH09, BH11, BH12 BH17 and BH18). Bores BH15 and BH16 at the western end of the swamp in the middle of the swamp showed a slight decrease over the monitoring period. Slight increasing trends were seen at BH04, BH08, BH10 and BH14, all of which except for BH10 are located on the southern edge of the swamp.

Hydrographs for individual wells showing ground level at each well are presented in Appendix B. These hydrographs indicate that some of the monitoring bores are artesian (positively pressured), meaning that the sediments are fully saturated and water is ponding at the surface for part of the period of record. The term “artesian” generally refers to confined aquifers but is used in this instance to describe when the groundwater level in the aquifer is breaching the ground surface such that groundwater discharge occurs. This differentiates from “ponding” which could mean ponding without a fully saturated aquifer. BH02, BH03, BH04 and BH07 are artesian the majority of the time (88%, 93%, 56% and 91% of the monitoring period, respectively). BH04 was sub artesian until June 2020 and has been predominately artesian since then due to a rising hydrograph trend. BH01 is artesian 35% of the time, BH15 6% of the time and BH05 only 0.5% of the time during the highest flow periods.

The majority of these artesian pressures are seen at the eastern (downstream) end of the swamp whereas the western monitoring bores (apart from BH15 very occasionally) are behaving as an unconfined system with water levels remaining below the ground surface over the entire period of record. This suggests that groundwater is being recharged at the western end of the swamp by streamflow and this groundwater throughflow through the swamp is increasing positive head pressures downstream in the east of the swamp and creating artesian flow at a number of eastern monitoring bores.

3.3 Groundwater contributions to stream flow

To assess the potential contributions of alluvial groundwater discharge to stream flow volumes a mass balance approach was adopted. Available data were limited to upstream/ downstream flows, pH and electrical conductivity (EC) data, and borehole pH and EC data. Both data sets had time series data available. Of the 33 groundwater temporal data entries, complete data sets (data in all parameters at all locations) were present for 10. These data were further restricted to exclude two of the time entries where downstream flows were less than 65% of upstream flow, these two data points were considered not representative of general conditions due to the significant discrepancy between upstream and downstream flows.

Mass balance calculations were undertaken using available EC data as a proxy for Total Dissolved Solids (TDS). The simplified conceptual model adopted for the mass balance calculations is presented in Figure 12. The relative contribution of groundwater to the downstream discharge was calculated using Equation 1. The Groundwater EC/TDS value for each time period were adopted from the mean recorded value for groundwater bores BSBH08 – BSBH18 (mean pH 3.8). Bores BSBH01 to BSBH08 were noted to have pH values (mean pH 5.8) equivalent to or greater than the downstream values (mean pH 4.4) and hence inferred to have limited impact on stream water quality.

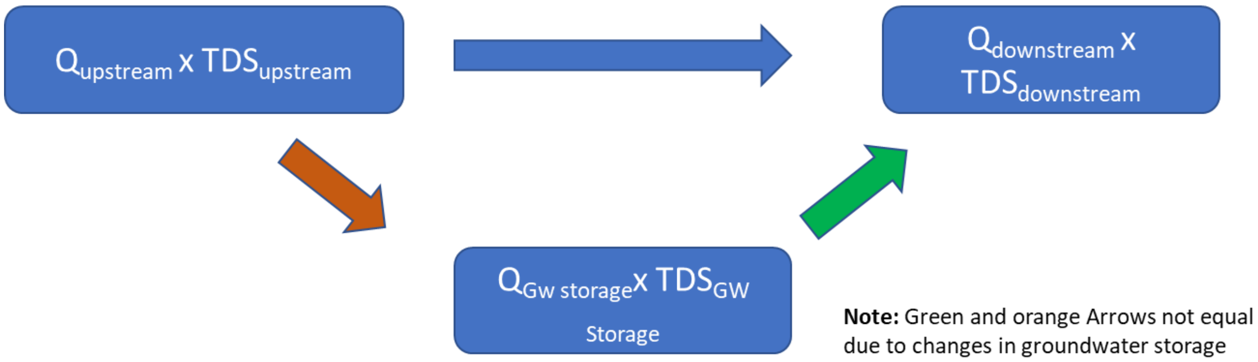

Figure 12 Conceptual Model of Groundwater/Surface Water interactions

Equation 1:

$$\frac{(Q_{Downstream} \times TDS_{Downstream}) - (Q_{Upstream} \times TDS_{Upstream})}{TDS_{Groundwater}} = Q_{Groundwater}$$

Where:

- $Q_{upstream}$ and $Q_{downstream}$ are the recorded flow at the upstream and downstream points, respectively;
- $TDS_{upstream\ and}$ $TDS_{downstream}$ are the recorded concentrations at the upstream and downstream points, respectively;
- $Q_{groundwater}$ is the groundwater flow to the stream; and
- $TDS_{groundwater}$ is the concentration of the groundwater.

Table 3-1 Calculated Groundwater flow to Stream

Date	Groundwater discharge to Stream flow ML/day	% of Downstream flow derived from groundwater
6/08/2019	0.30	5.7
5/05/2020	0.91	17.2
2/06/2020	0.11	3.8
7/07/2020	0.15	1.9
4/08/2020	0.09	5.0
8/10/2020	0.46	2.1
5/11/2020	0.10	11.2
1/12/2020	0.05	10.8
20/02/2021 (2/03/2021)*	0.18	28.5
1/06/2021	0.36	14.0
6/09/2021	0.42	3.5
24/11/2021 (7/12/2021)*	0.33	22.0
8/03/2022	0.54	45.0
2/06/2022	0.34	15.0
Geometric mean	**0.235**	**5.03**

* Note: date in brackets denotes the adopted chemical groundwater data used in calculation adopted due to data gaps in stream gauging station data on date of groundwater sampling.

These calculated data suggest that groundwater discharge to the stream contributes between 2% and 45% of the total discharge from the swamp. Relative discharge is noted to be generally lower during elevated stream flow periods and elevated during lower stream flow periods. These results of 0.24 ML/Day are broadly similar to the Jacobs groundwater-surface water modelling (Jacobs, 2019) which 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). The GHD groundwater-surface water coupled model (GHD, 2021) shows a more detailed assessment of groundwater contributions to streamflow. The result of the GHD model calibration indicate an average groundwater discharge to Boundary Creek flow of 0.16 ML/d.

When viewing the calculated percentage of stream flow derived from groundwater presented in Table 3-1, there appears to be a weak yet positive increase in groundwater contributions (0.00235%/day) since 2019. However, due to limited data points this correlation is very weak (R^2=0.31).

When viewing inundation extent image for the wet period predicted water depths (Figure 13) there appears to be three potential flow paths over which groundwater may contribute to stream flow. The combined length of these three flow paths is approximately 3,000 m with each flow path extending approximately 1,000 m.

If groundwater discharge is assumed to be constant along the length of the flow paths this returns an average groundwater inflow to surface water of 0.079 m^3/day per linear metre of creek. If discharge is assumed to be concentrated in the eastern portion of the swamp where groundwater levels are artesian, then a higher rate of 0.156 m^3/day per linear metre of creek are obtained.

The relatively low calculation of groundwater contribution per linear meter of stream length, and absence of any known flow focusing features within Big Swamp, negatively impact the potential viability of a PRB. It would be anticipated that the volume of water passing through a PRB would be within the same order of magnitude as that entering the steam. As such, a PRB 3m in length would likely be exposed to 0.47 m^3/day which is approximately 0.3% of the total mean daily groundwater discharge (235 m^3/day) to the stream.

The GHD model (GHD, 2021) also provides an estimate of groundwater discharge to the swamp (i.e. outside of the Boundary Creek alignment in areas of inundation and overland flow). Figure 13 corroborates this conceptualisation of the swamp having an upstream recharge area and a downstream discharge area.

These estimates are based on limited data and broad assumptions. Further works should be undertaken to understand the groundwater discharge in the swamp before progressing with remediation options that aim to treat groundwater discharge.

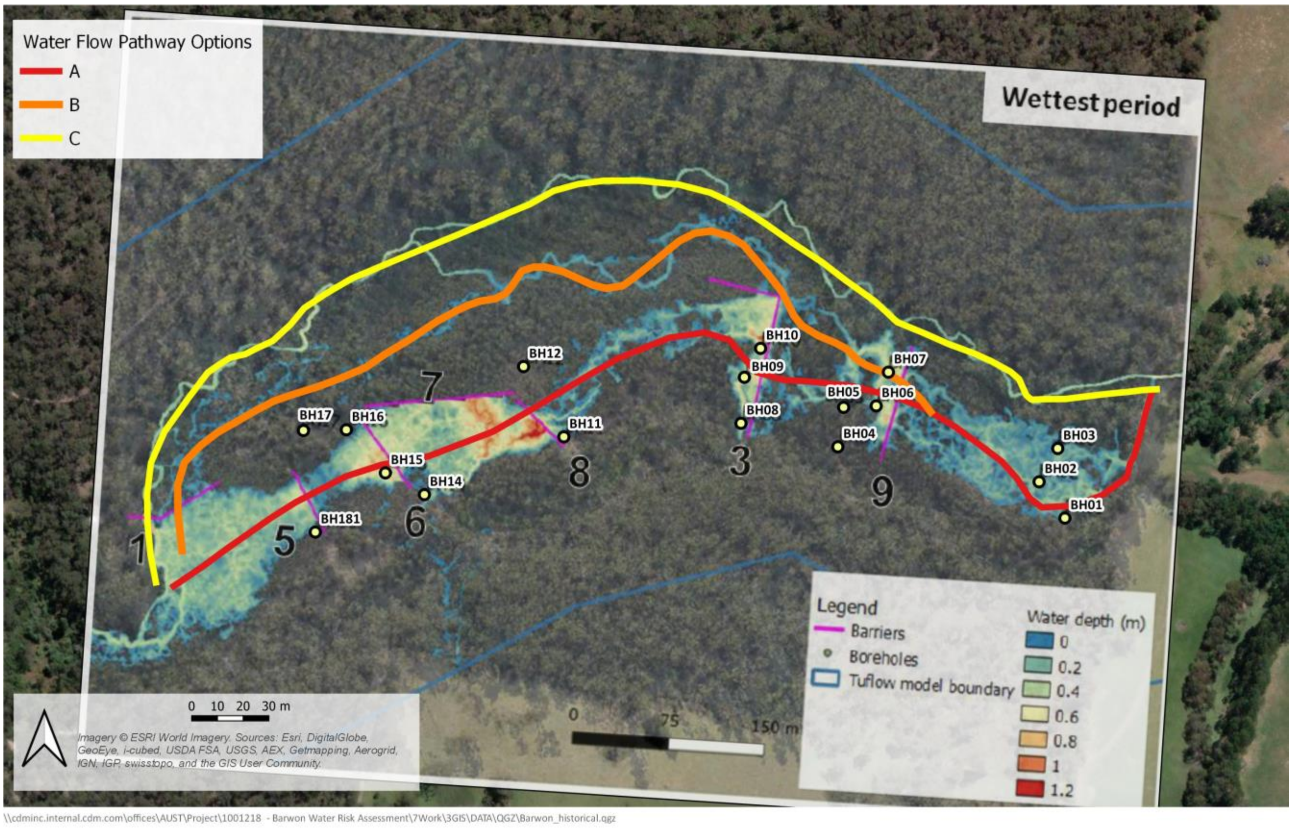

Figure 13 Inundation – Wettest Period (GHD 2021)

3.4 Groundwater Conditions Relative to PRB Assessment

From the review of hydrogeological site conditions in sections 3.1 to 3.3 above, the following are directly relevant to the re-assessment of PRB as a viable option to improve groundwater/surface water conditions and Big Swamp/Boundary Creek:

- Groundwater levels in the LTA have generally increased since cessation of groundwater pumping in 2016, which has resulted in positive influence in several groundwater bores in Big Swamp, as detailed in Section 3.2 above. As discussed in Section 3.2 above, there is evidence that Big Swamp may have reached a steady state, or maximum groundwater-controlled saturation, where modifications to the landscape have resulted in topographic highs in the landscape, which may never be re-saturated, regardless of ongoing groundwater recharge in the LTA. This is represented in Figure 6 above. The relevance of this to the installation of PRBs is as follows:
  - Groundwater levels may not increase further over-time. This would impact the location of PRBs and installation would be favoured in areas that are currently saturated.
  - Acid generation is likely to continue to some extent in the unsaturated areas of Big Swamp. This may impact groundwater that has been treated through a PRB, in that re-acidification of PRB treated water may occur.
- Groundwater discharges into Reach 3 of Boundary Creek account only for a small proportion of the total flow, with the following relevant calculations:
  - 0.3 ML/day (Jacobs 2019).
  - 0.16 ML/day (GHD 2021).
  - 0.05 to 0.91 ML/day, based on mass balance in Section 3.3, noting a geometric mean of 0.24 ML/day.

- Mass balance data indicate that an in-situ permeable reactive barrier that extends 3 m along the creek line would be expected to be able to treat up to 0.47 m^3/day of water or 0.3% of the predicted daily groundwater discharge (235 m^3) to the creek system.

PRB technology was excluded from the CDM Smith (2019) ROA as previous modelling approaches inferred groundwater to be only a small proportion of total flow (less than 0.3 ML/day). Whilst more recent estimations, based on mass balance equations (mean 0.24 ML/day), are similar to the previous estimation (0.3ML/day), the groundwater data above indicates potential increasing groundwater contributions over time. As such, a review of PRB technology in line with previous ROA assessment criteria and ranking is provided in Section 4, noting that Barwon Water are considering the installation of two small PRBs as part of contingency measures.

Section 4 Remediation Options Assessment – PRB

4.1 Technology Description

A permeable reactive barrier is a trench filled with reactive or adsorptive material (e.g., organic matter, limestone, zero valent iron, etc.) that is designed to intercept and treat impacted groundwater (Figure 14).

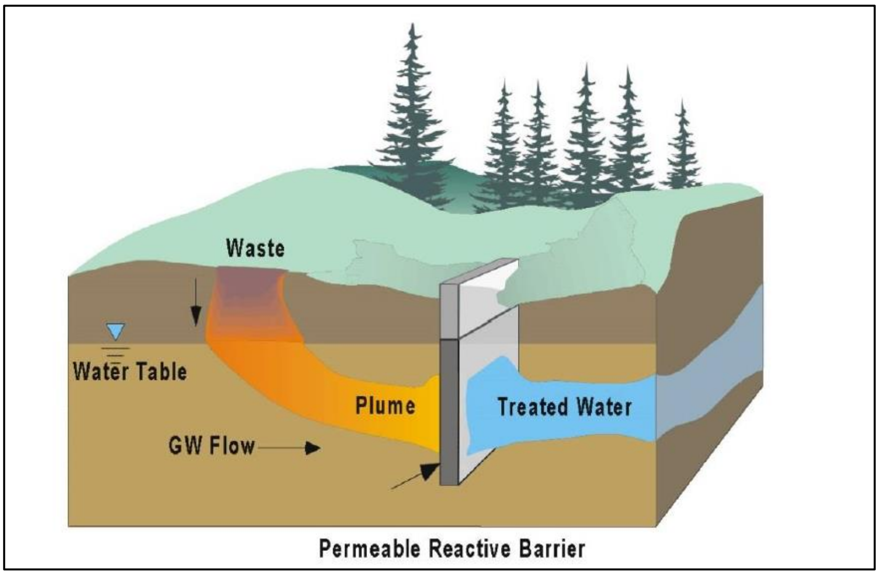

Figure 14 PRB diagram (US EPA, 1998)

For low pH groundwater impacted with dissolved heavy metals, a common approach is to construct a PRB using a combination of organic material (e.g., mulch, manure, bark, etc.) and limestone (e.g., crushed agricultural limestone, hydrated lime, etc.), supplemented with coarse sand and gravel. The organic material promotes bacterially mediated sulphate reduction, which results in generation of alkalinity and precipitation of dissolved metals in the form of sulfide precipitates within the barrier. The limestone serves to neutralise the pH of the groundwater.

The factors that affect the lifetime of PRBs are the mass of reactive material within the PRB, the pore space (and permeability) of the barrier and the residence time of the groundwater within the PRB. In addition, metal precipitation and substrate compaction can result in a decrease in porosity and permeability of the barrier. PRBs can range from 1-4 metres wide, with residence times ranging from a few days to a few months.

4.2 PRB Locations and Dimensions

Based on the variable topography within the vicinity of Big Swamp, smaller (shorter) PRBs are envisaged to be constructed at multiple key access points along the boundary of Big Swamp. These PRBs would be less than 10 metres in length (more likely 2-3 m in length) and up to 2 meters deep. The PRB width would likely be on the order of 1.1 to 1.5 meters wide, with final dimensions dependent on the residence time required to treat the low pH groundwater.

A concept plan showing the proposed location of two 3 m PRBs at BSBH15 and BSBH06 is shown on Figure 15 below. The concept locations have been chosen based on the long section provided in Figure 6, where groundwater is noted to be close or at the surface, where groundwater would pass through a shallow PRB trench (2m deep). These concept locations are also in the areas outlined by Barwon Water as being feasible locations based on existing access (circled on Figure 15 below).

Further work would be required to determine the optimal design and construction of PRBs. This would be conducted as part of a detailed design phase, where PRB is considered a viable option (further information in section 4.4 below).

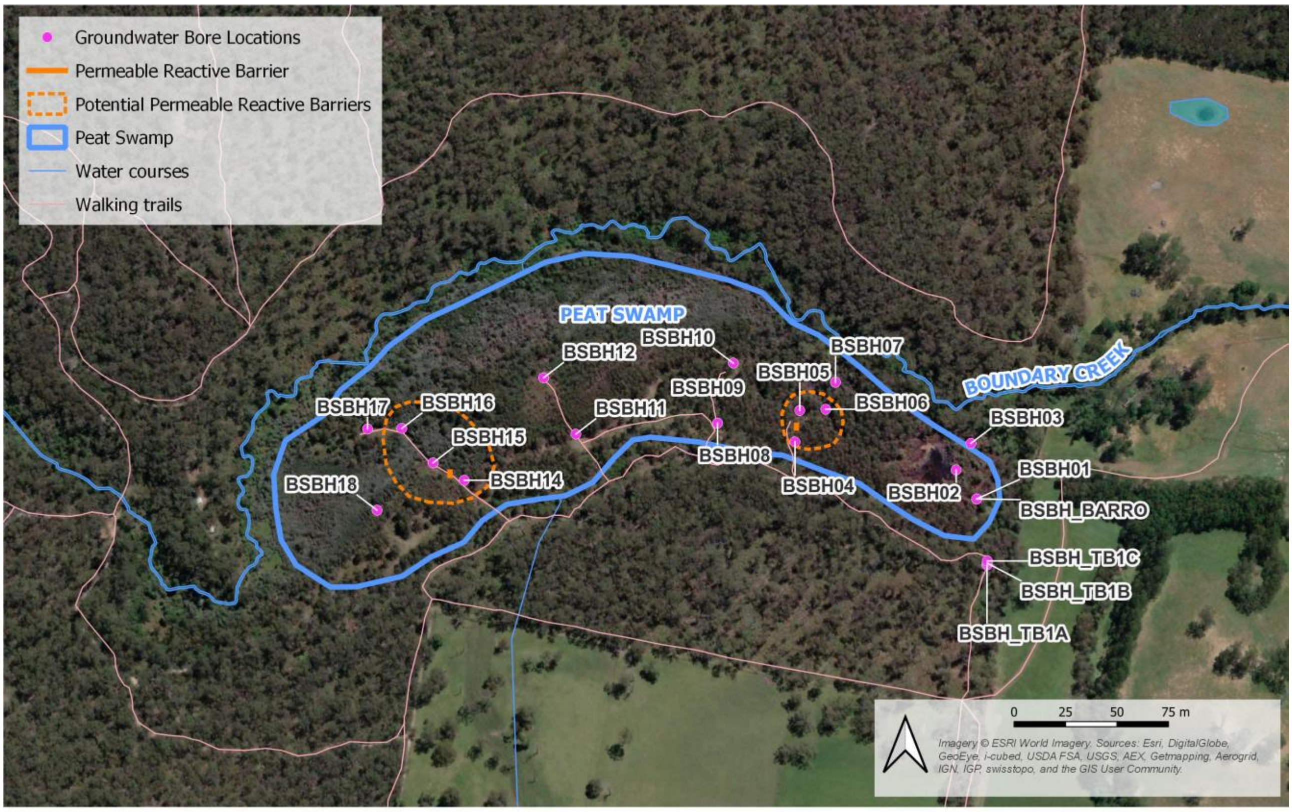

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Figure 15 Potential Locations for PRBs (PRB lines, as shown are 3 m in length)

4.3 Assessment Criteria

This section assesses the feasibility of installing and operating PRBs with respect to the remediation options assessment (ROA) criteria presented in Table 4-1 below. Relative indicators for each category assist with ranking the merits of the technology, ranging from 1 (low / least preferable) to 5 (high / most preferable). The ROA criteria below is consistent with that adopted from the existing ROA assessment (CDM Smith 2019).

Table 4-1 ROA Assessment Criteria

		Score		
Category	**Description**	**1 (poor)**	**3 (fair)**	**5 (good)**
A – Effectiveness	Assessment of the degree to which the technology will achieve the remediation objectives, considering the nature and extent of the contaminants and the site-specific geological and hydrogeological settings	Technology has not proven and demonstrated at scale or is unable to meet remediation objectives. Site specific conditions preventing or limiting effectiveness.	Proven effectiveness and within recommended ranges for chemicals to be treated. Pilot scale trials may be required to demonstrate applicability and develop detailed design.	Proven effectiveness and within recommended ranges for chemicals to be treated. Pilot scale trials not likely to be required prior to demonstrate effectiveness and develop design criteria.

		Score		
Category	**Description**	**1 (poor)**	**3 (fair)**	**5 (good)**
B – Implementability	Practical considerations associated with the logistics of designing, constructing, operating, maintaining, monitoring, and decommissioning the technology at the site	Complex engineering and design, large footprint (>2 ha), restricted access high level of administrative controls, high level of operation, maintenance, and monitoring, difficult to decommission.	Moderate level of engineering design required, feasible to construct, moderate level of operation, maintenance and monitoring required, feasible to decommission.	Proven technology with standard design, standard construction techniques, moderate level of operation, maintenance and monitoring required, feasible to decommission.
C – Cost	Feasibility level (-30% to +50%) cost of implementing the technology for a nominal 10-year timeframe	Capital cost > $5 M Operating costs > $100k/yr	Capital cost $1 to $5 M Operating costs $50k/yr to $100/yr	Capital cost < $1 M Operating 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.
E – Schedule	The timeframe required for the technology to meet the selected clean-up objectives	More than 2-years for design and construction. More than 5 years to realise relevant project objectives. No or minimal source reduction, long treatment timeframes (>10 years) envisaged.	Can be implemented in 1-2 years and operated for 5-10 years to realise project objectives. Some potential for source reduction potentially leading to shorten treatment timeframes.	Can be implemented in within 1-year and operated for less than 5 years to realise relevant project objectives. Substantial source reduction short treatment timeframes.
F - Sustainability	Assessment of resource usage, including air emissions, waste generation, water usage, energy consumption, carbon footprint, and generational equity	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.

4.4 Technology Assessment

This section assesses the feasibility of installing and operating multiple PRBs to intercept low pH groundwater at Big Swamp is provided in Table 4-2. The technology assessment is considered in conjunction with hydrogeological conditions in Section 3 above.

Table 4-2 PRB Technology Assessment

Category	Evaluation and Key Issues	Score
A – Effectiveness	PRBs are a proven technology, capable of neutralising low pH conditions. May require pilot testing to develop site-specific design criteria. PRBs constructed at or near locations of groundwater-surface water interaction do not address potential contaminant sources. Overall effectiveness will depend on size (length and depth) of the PRB, and the portion of impacted groundwater that the PRB is able to intercept and treat prior to discharge to surface water. Groundwater conditions relevant to the assessment of PRB is detailed in Section 3.	1 (poor)
B – Implementability	PRBs can be constructed using standard civil engineering equipment (excavators, loaders, trench support equipment, etc.). Reactive media are readily available and transportable to the PRB location. Access to the PRB construction areas may be limited or restricted, requiring disturbance of native vegetation to widen or construct access roads and working pads. Disturbed or damaged vegetation and native ecology will require rehabilitation. Longer length PRBs crossing variable topography will require more time to construct and will result in greater disturbance to native ecology.	5 (good)
C – Cost	Moderate cost to install. Low cost to operate. A preliminary cost table for PRB is provided in Appendix C.	3 (fair)
D – Stakeholders	Will require engagement with local community to describe the technology and the advantages and disadvantages. The local community is highly engaged with this project and keen to provide input on the objectives, implementation, operation and overall approach. The community preferences for natural recovery and ‘do no harm’ principal have been considered in the ranking. However, the installation of small PRB’s (2-3 m in length and 2 m deep), with small scale disturbance, has still achieved a likely ranking of fair, with the potential benefits of water treatment likely to align with stakeholder’s expectations.	3 (fair)
E – Schedule	PRBs can be constructed in a relatively short time frame (months), though longer PRBs and variable topography can affect the schedule. The ranking has considered a significant amount community and Stakeholder engagement prior to any installation works. So whist the PRB’s can be installed in a short amount of time, the design phase including community engagement is likely to take 1-2 years. This falls in the ‘fair’ ranking category. Long-term operability (>10 years) with ease of monitoring. Periodic replacement of reactive media will be required, and the frequency of replacement will depend on groundwater quality and flux.	3 (fair)
F - Sustainability	Low water and energy use during construction and operation. Low air emissions and carbon footprint during construction, primarily due to use of diesel-powered construction equipment. Long-term operability improves generational equity. Moderate waste generation if acid sulfate soils are disturbed and require off-site disposal. Vegetation damaged during construction activities will need to be repaired.	5 (good)

4.5 Feasibility and Ranking

Our current technology assessment for PRB, with consideration of the assessment criteria in Section 4.3 and Section 4.4 shows:

- Implementability and Sustainability is ranked **good**.
- Cost, Stakeholders and Schedule is ranked **fair**.
- Effectiveness is ranked **poor.**

The ROA scoring is largely positive (fair to good), however, the effectiveness is poor. The poor effectiveness is associated with installation of small PRBs of 2-3 m in length, which would result in treatment of low volumes of groundwater (proportionate to total groundwater volumes), prior to discharge into Boundary Creek (see also Section 3.3 and 3.4). The visual extent of 3 m PRBs at two locations can be visualised on Figure 15 above. Numerically mass balance data suggests that a 3 m PRB along the creek line would treat up to 0.47 m^3/day of water or 0.3% of the predicted daily groundwater discharge. This would have a negligible impact in reducing acidity and metal loads in Big Swamp and Boundary Creek.

By enlarging the PRBs, the effectiveness may be improved, where PRBs are significantly larger and/or span the length of Big Swamp, perpendicular to groundwater flow. However, based on our understanding of the community/Stakeholder goals and expectations, longer PRBs would not be possible given the significant disturbance to vegetation and the swamp itself. So larger PRBs may increase the overall effectiveness ranking: however, Stakeholders or implementatility may be reduced to a level (poor ranking), that impacts PRBs as a feasible option. The Stakeholder/community goals and expectations that could reduce the feasibility of larger PRBs include (but are not limited to):

- The do no harm principal.
- Preference for natural recovery.
- Risk based approach to assessment and remediation.

Overall, installation of two small PRBs at Barwon Water's specified locations (Figure 15) are currently considered to be principally feasible with consideration of cost, stakeholders, schedule, implementability and sustainability. However, the effect is negligible and there are unlikely to be any net benefits to Big Swamp and Boundary Creek with respect to reducing acidity and metal loads. With primary focus on the effect, the installation of two small PRBs (as shown in Figure 15) is not currently considered to be a feasible option for risk mitigation at the site. Further summary and recommendations are provided in Section 4.6 below.

4.6 PRB Summary and Recommendations

As detailed in Section 3 above, there is currently insufficient time series data (for bores located within Big Swamp), that represents different climatic regimes to adequately assess whether any further increases in water levels, would result in further re-saturation of swamp sediments and/or increases to the proportion of groundwater flow into Boundary Creek (in ML/day). Regardless of increased groundwater flow proportions and groundwater levels in the swamp, the effectiveness of two small PRBs across a small area (visualised on Figure 15) is likely to remain 'negligible'.

With this in mind, the following are recommended for further conceptualisation and consideration of PRBs as a remediation contingency:

- Consideration of potentially expanding the scope for PRB installation, so that the length is significantly increased to treat increased volumes of groundwater discharged to Boundary Creek. Or looking at the installation of a number of small PRB's in saturated locations of Big Swamp. Whilst the volume of groundwater able to be treated using PRBs increases with PRB length, this is not necessarily a linear function and further work (including review of additional time series data), would be required to establish the optimal length, design and location of PRBs.
- Further review of groundwater levels and recovery over time, with subsequent updates to the hydrogeological conceptualisation. At a minimum it is recommended that a further 6 months of groundwater and surface water data should be collected, prior to further review and updates to the conceptualisation of groundwater in the swamp.
- Further investigation and consideration of steady-state conditions in Big Swamp and re-saturation of sediments in topographical high points (between BSBH12 and BSBH09) as shown on the long section in Figure 6.
- Additional groundwater modelling to further assess groundwater discharge to Boundary Creek and validate the mass balance calculations for the proportion of groundwater contributing to surface water. The GHD groundwater model may be adaptable to assess this remediation option in more detail. The model was

constructed using data up to August 2020, and could be validated with the updated monitoring data prior to being used to assess groundwater discharge remediation options.

- Consideration of groundwater flow and pathways across the swamp, with relevance to PRBs. This can include tracer analysis in groundwater to further understand groundwater migration towards Boundary Creek. This would be important to understand for PRBs where dilution and other chemical processes associated with unsaturated acid sulphate soils, could re-acidify treated water.

Section 5 References

ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2018

Austral (2022) Upper Barwon River, Macroinvertebrate Sampling Repot 2019-2022, Austral Research and Consulting, June 2022.

Barwon Water (2022), Outcomes and Implications of the Upstream Treatment Investigation, Boundary Creek and Big Swamp Contingency Planning, Barwon Water, June 2022.

Barwon Water (2022) Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan – Quarterly Update, Barwon Water, June 2022.

Eco Logical Australia Pty Ltd (2019) Big Swamp Ecological Assessment, 21 November 2019

CDM Smith (2019), Boundary Creek and Big Swamp Remediation Options Assessment by CDM Smith, December 2019.

CDM Smith (2021), Big Swamp Success Target Assessment. Prepared for Barwon Water by CDM Smith, July 2021

GHD (2021), Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design Technical Modelling Report. Prepared for Barwon Water by GHD, April 2021.

Jacobs (2019), Groundwater and surface water modelling for Big Swamp. Prepared for Barwon Water by Jacobs, 26 November 2019

Appendix A Surface Water Quality Review

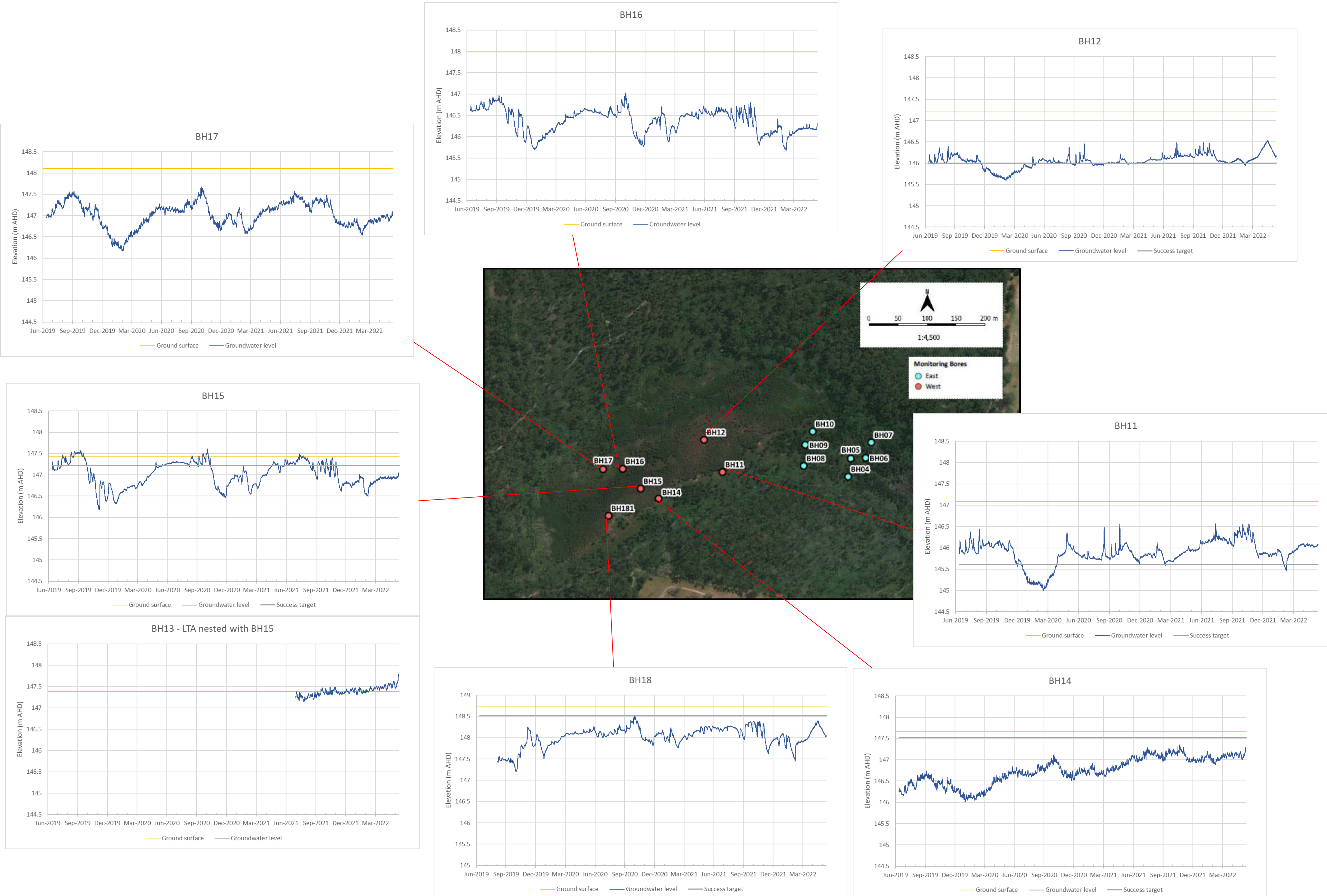
Table A1 – Review of Surface Water Quality Data for May and June 2022

Analyte	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Change Relative to Background (→, ↑, ↓)
Metals	**May 2022**			**June 2022**			
Aluminium	<0.01	1.8	2.1	<0.01	2	1.9	↑
Antimony	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Barium	0.016	0.032	0.032	0.013	0.028	0.027	↑
Beryllium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Boron	<0.02	0.03	0.02	<0.02	<0.02	<0.02	→
Cadmium	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	→
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Cobalt	<0.001	0.013	0.006	<0.001	0.012	0.005	↑
Copper	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Iron (OES)	1	35	43	1.3	40	43	↑
Iron (MS)	0.14	5.1	4.1	0.14	3	2.5	↑
Ferrous iron, as Fe	0.1	13	19	0.2	33	38	↑
Ferric - Soluble (by Difference)	0.9	22	24	1.1	7	5	↑
Lanthanum	<0.001	0.008	0.008	<0.001	0.007	0.006	↑
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Manganese	<0.001	0.041	0.029	<0.001	0.04	0.025	↑
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	→
Molybdenum	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Nickel	0.002	0.028	0.019	<0.001	0.025	0.014	↑
Selenium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Silver	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Strontium	0.07	0.04	0.028	0.066	0.045	0.029	↓
Thallium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Tin	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Titanium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Vanadium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	→
Zinc	<0.001	0.11	0.059	<0.001	0.1	0.048	↑
Inorganics							

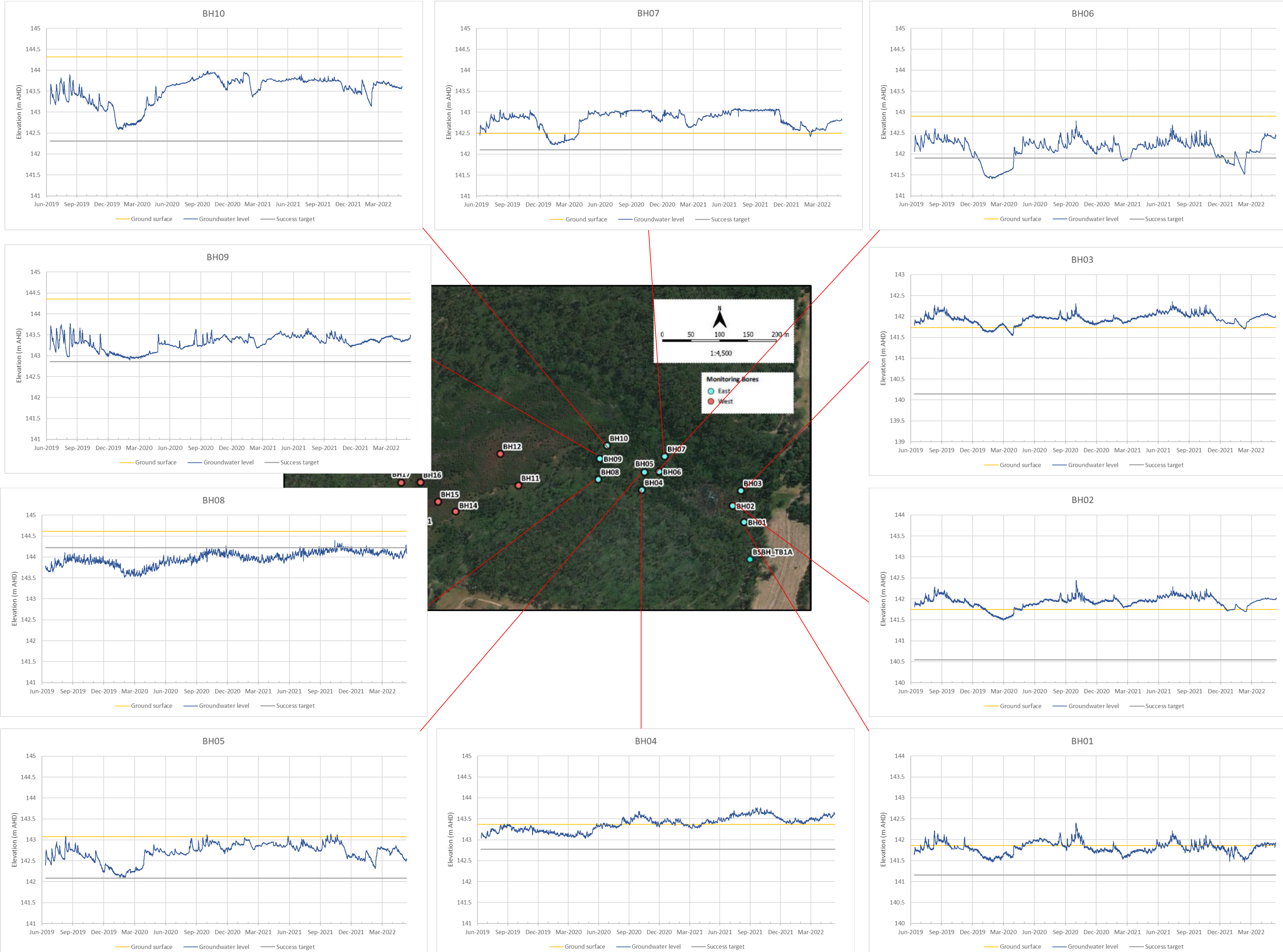
Analyte	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Change Relative to Background (→, ↑, ↓)
Dissolved Organic Carbon	6.1	6	4.8	7.7	4.8	4.4	↓
Total Organic Carbon	6.2	6	4.8	8	12	15	↑
Chemical Oxygen Demand (COD)	41	53	70	33	53	55	↑
Biochemical Oxygen Demand, 5 Day (BOD)	<2	<2	<2	<2	<2	<2	→
Dissolved oxygen Calc (Field)	9.9	8.1	8.7	11	10.1	5.3	↓
Total Dissolved Solids	190	350	310	200	320	310	↑
Total dissolved solids by calculation	230	460	420	250	410	360	↑
Electrical Conductivity (Field)	370	690	630	430	750	530	↑
Electrical Conductivity @ 25C	340	680	620	370	620	540	↑
Turbidity (Field)	4	22	28	16	41	37	↑
Temperature (Field)	12.6	13	12.9	7.9	9.2	9	→
			pH, Acidity and Alkalinity				
pH (Field)	6.5	3.9	5.3	6.7	4.3	5	↓
Acidity as Calcium Carbonate	36	120	114	11	61	76	↑
Bicarbonate Alkalinity as CaCO3	28	<2	<2	18	<2	<2	↓

Analyte	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Boundary Creek, upstream of Big Swamp (BCUSBS)	Boundary Creek at Yeodene (BCY)	Boundary Creek, downstream of Big Swamp	Change Relative to Background (→, ↑, ↓)
Carbonate Alkalinity as CaCO3	<2	<2	<2	<2	<2	<2	→
Hydroxide Alkalinity as CaCO3	<2	<2	<2	<2	<2	<2	→
Total Alkalinity as CaCO3	28	<2	<2	18	<2	<2	→
Cations							
Potassium	2.9	3.8	3.9	3.8	3.7	3.5	↑
Sodium	46	56	59	45	53	48	↑
Calcium	4.9	3.5	2.4	4.7	3.5	2.3	↓
Magnesium	7.1	5.7	5.3	7.2	6.1	5.2	↓
Anions and Nutrients							
Chloride	81	100	95	90	100	100	↑
Ammonia as N	0.04	1.2	1.4	0.08	1	1.1	↑
Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	→
Nitrate as N	0.09	<0.01	<0.01	0.12	<0.01	<0.01	→
Total Kjeldahl Nitrogen, as N	0.53	1.9	2	0.61	1.6	2.1	↑
Total Oxidised Nitrogen as N	0.09	<0.01	<0.01	0.12	<0.01	<0.01	→
Total Nitrogen as N (Calc)	0.6	1.9	2	0.7	1.6	2.1	↑
Sulphate	4	87	83	6	84	78	↑
Reactive Phosphorus as P	<0.005	0.006	0.005	<0.005	<0.005	<0.005	→
Phosphorus, total as P	<0.05	0.05	0.11	<0.05	<0.05	0.09	↑

Appendix B Hydrographs



BH16
BH12
BH17
BH15
BH13 - LTA nested with BH15
BH18
BH14
BH11
Elevation (m AHD)
Jun-2019 Sep-2019 Dec-2019 Mar-2020 Jun-2020 Sep-2020 Dec-2020 Mar-2021 Jun-2021 Sep-2021 Dec-2021 Mar-2022
Ground surface
Groundwater level
Success target
N
0 50 100 150 200 m
1:4,500
Monitoring Bores
East
West
BH10
BH09
BH08
BH07
BH05
BH06
BH04
BH181



BH10
BH07
BH06
BH09
BH03
BH08
BH02
BH05
BH04
BH01
Elevation (m AHD)
Jun-2019
Sep-2019
Dec-2019
Mar-2020
Jun-2020
Sep-2020
Dec-2020
Mar-2021
Jun-2021
Sep-2021
Dec-2021
Mar-2022
Ground surface
Groundwater level
Success target
0 50 100 150 200 m
1:4,500
N
Monitoring Bores
East
West
BH12
BH11
BH16
BH15
BH14
BSBH_TB1A

Appendix C Preliminary PRB Cost Table

Table C1 – Preliminary Cost Estimate for installation of two small Permeable Reactive Barriers.

Item	Task Description	Quantity	Unit	Unit Cost	Line Item Cost	Notes, Comments, Assumptions
1	Design, Specification, Tender, Contractor Selection	1	Lump Sum	$25,000	$25,000	Drawings, specifications, tender package, tender review, contractor selection, contracting
2	Pre-Field, Planning, Permitting	1	Lump Sum	$25,000	$25,000	Health and Safety Plan, Construction Environment Management Plan, permits
3	Mobilisation and Site Setup	1	Lump Sum	$20,000	$20,000	Equipment, sheds, amenities, vegetation clearance and work pad grading
4	PRB Trench Excavation and Construction (2 trenches)	2	Each	$25,000	$50,000	Excavator, 3-person crew, 5 days per PRB, trench shoring, PRB is >5m long x 2m deep x 1.1-1.5 m wide
5	Limestone Infill	50	Tonne	$150	$7,500	Assume 2.5 tonne/m3, locally sourced
6	Soil Disposal (incl sample, analyse, waste profile)	32	Tonne	$225	$7,200	Assume 1.6 tonne/m3 for 20 m3, load, transport, off-site dispose as Category C
7	Surface Reinstatement (2 PRB locations)	300	Sq. meter	$50	$15,000	Revegetation of PRB and surrounding work area
8	Project Management, Construction Supervision	1	Lump Sum	$25,000	$25,000	Project Manager, on-site construction manager
9	Construction Completion Report	1	Each	$10,000	$10,000	Construction quality assurance (CQA) and summary report
				TOTAL	**$184,700**	

Appendix D 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 preliminary review of permeable reactive barriers as a remediation contingency.

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