Detailed design of hydraulic barriers

Review of remediation success targets

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

01 July 2021

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Purpose

This document comprises Barwon Water's submission for the detailed design of the hydraulic barriers proposed to be constructed within Big Swamp as part of the preferred remediation strategy for Boundary Creek and Big Swamp. It also outlines a review of the remediation success targets as prescribed in the Boundary Creek, Big Swamp and Surround Environment Remediation and Environmental Protection Plan (REPP).

This document does not include the detailed design for an active treatment contingency measure or consideration of possible treatment of the groundwater or soil porewater contained within Big Swamp. These aspects will be addressed in the submission for the hydrogeochemical modelling and contingency measure detailed design which are due for submission to Southern Rural Water (SRW) by 31 July 2021.

Informing the process

The detailed design of hydraulic barriers and the review of remediation success targets has been informed by:

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

The feedback received from the RRG and their nominated experts, the ITRP and SRW has played an important role in shaping the detailed design of the hydraulic barriers and the review of remediation success targets.

Background

In June 2017, Barwon Water acknowledged that historic management of groundwater pumping had an environmentally significant impact in the Boundary Creek catchment. Reductions in flows caused by groundwater extraction coupled with a drier climate and supplementary flows not reaching the intended area, all contributed to the drying out of Big Swamp. This resulted in the activation of acid sulfate soils and ongoing release of acidic water to the lower reach of Boundary Creek.

In May 2018, Barwon Water established a community and stakeholder working group to participate in the design of a remediation plan for Boundary Creek and Big Swamp. As part of this process, Barwon

Water invited the working group to nominate their own technical experts to help support them in their discussions to shape the remediation plan.

Barwon Water's commitment to undertake remedial works was legally strengthened through the issuing of a Ministerial Notice under section 78 of the Water Act, 1989. This notice mandated the development and implementation of the Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP) by 01 March 2020.

The section 78 notice defined remediation to be the controls and actions that could be practicably carried out to achieve improved environmental outcomes. In order to align this with an accepted scientific definition for remediation, the REPP further expanded the definition to be "the controls and actions that could be practicably carried out to improve the ecological condition and function of areas confirmed to have been impacted by historical management of groundwater pumping at Barwon Downs, noting that this is likely to be different to the original condition due to the extent of change since European settlement."

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

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

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

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

- Continued delivery of a supplementary flow so that Boundary Creek is flowing all year round.
- Construction of barriers within the swamp to effectively distribute flow.
- Infilling of the existing fire trenches and the drain to allow the swamp to retain more water over the winter months.
- Prevention of the spread of some dry vegetation types so that wet vegetation species can recolonise.
- Collection of ongoing monitoring data to inform any changes needed so that the remediation plan can adapt to how the environment is responding.
- Assessment of contingency measures for implementation as required.

Objectives for remediation of Boundary Creek and Big swamp

Remediation has been defined in the s78 notice as 'the controls and actions that could be practicably carried out to achieve improved environmental outcomes for Boundary Creek, Big Swamp and the surrounding environment that has been impacted by groundwater pumping at Barwon Downs'.

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

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

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

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

In addition to developing an agreed definition of remediation for the REPP, a set of priorities to underpin remediation were also developed in consultation with the Remediation Working Group and their nominated experts during development of the REPP. The set of agreed priorities that were developed were based on the protection of assets with the highest ecological values as well as consideration of the level of effort required to not only remediate damaged reaches but realise the benefits of remediation. Priorities agreed to by the Remediation Working Group and the nominated experts were:

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

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

1. Maintain groundwater levels above the top of the non-oxidised sediments in Big Swamp (to prevent oxidisation of deeper sediments within the swamp).

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

3. Maintain at least minimum flows in Reach 3 of Boundary Creek all year round.

4. Manage potential formation of acidity downstream of Big Swamp, which may be triggered as a result of implementation of some remediation options (i.e. swamp inundation).

5. Preserve/improve the ecological values of Big Swamp and Boundary Creek. This objective is focused around addressing the changes to the vegetation assemblages within the swamp post the initial acidic event and fire. The result is a drying of the swamp, creating a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities.

6. Reduce the peat fire risk in Big Swamp.

Remediation strategy for Boundary Creek and Big swamp

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

An adaptive approach was recommended by all the experts and specialists involved in the remediation options assessment and they concluded that a combination of remediation options would be required to meet the vision and priorities and respond to outcomes from further monitoring and technical assessments.

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

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

- ***ongoing data collection to inform the adaptive monitoring approach*** *including monitoring or surface water flow, groundwater levels, water quality for both groundwater and surface water, vegetation monitoring, macroinvertebrate survey, etc.*
- ***additional data collection and testing to inform the feasibility of the other contingency options*** *(e.g. 'aerial liming', 'in-stream treatment' and 'limestone sand') which is particularly important for the 'in-stream treatment' option in consideration of its higher complexity and financial implications. Subsequent refinement of the geochemical model will inform the feasibility, risks and trade-offs associated with the need for additional treatment as a contingency to manage low pH events while the re-wetting strategy takes effect.*

The information presented in the following section relate to the detailed design of the hydraulic barriers proposed for installation as part of the above remediation strategy.

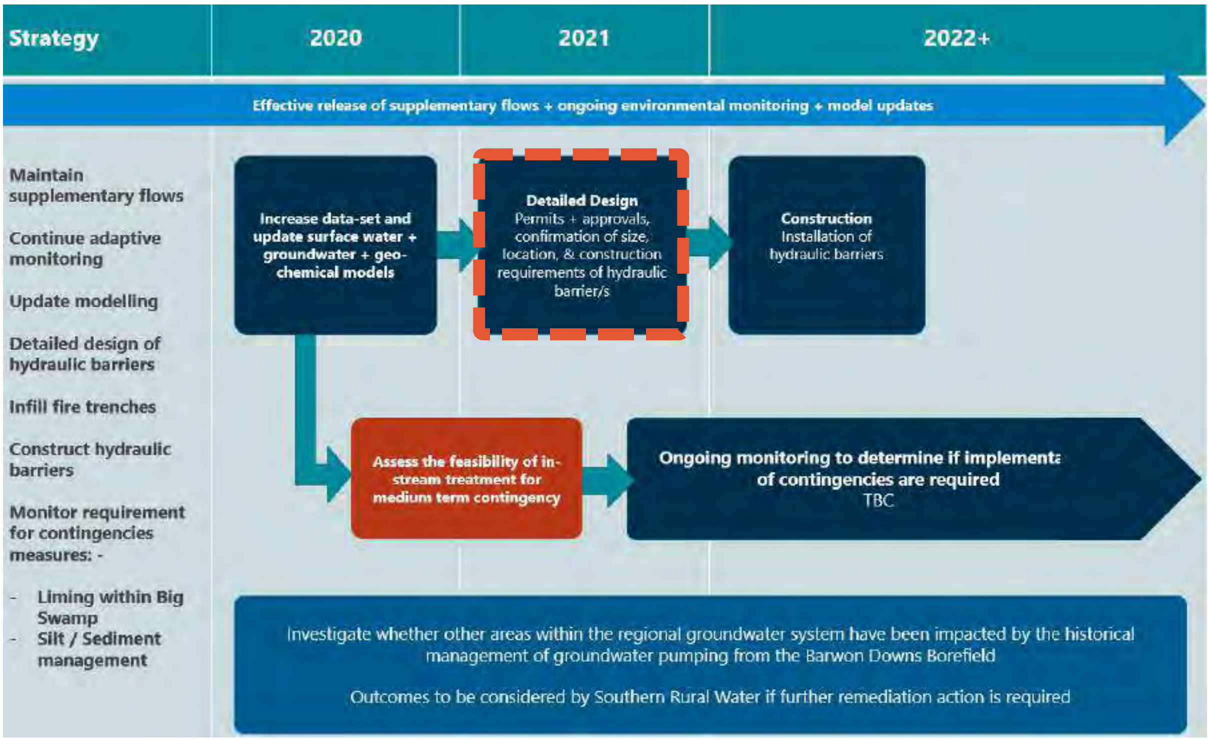


Figure 1: Timeframes for implementation of the proposed remediation strategy as presented in the REPP (Barwon Water 2020). Highlighted is the detailed design stage of implementation of which this document is a component.

Determining hydraulic barrier locations within Big Swamp

Following collection of additional groundwater level data for Big Swamp and surface water flows in Boundary Creek, Barwon Water was able to update the groundwater-surface water modelling for Boundary Creek and Big Swamp. The objective of this modelling was to confirm the concept of installation of hydraulic barriers to assist with achieving the objectives of remediation and determine the sizing and location of barriers to optimise the flow of water through the swamp. Detailed information on the groundwater-surface water model and the modelling outcomes is presented in Appendix A.

A number of different flow scenarios were modelled with different hydraulic barrier configurations and sizes to determine optimal barrier locations and configurations in order to:

1. Elevate groundwater levels across Big Swamp and minimise risk of further activation of acid sulfate soils by maintaining groundwater levels above the target levels in the monitoring bores located within Big Swamp required to limit further oxidation of sulfides within the soil profile.
2. Maintain a minimum surface water flow target of 0.5 ML/day in Boundary Creek at the Yeodene stream gauge.
3. Optimise the number and size of the barriers required to achieve the above objectives so as to minimise the construction footprint within the swamp

The modelling completed in December 2020 showed the installation of hydraulic barriers was able to maintain target groundwater levels within the swamp to prevent further acidification of soils and allow 0.5ML/day flow through Boundary Creek @ Yeodene stream gauge (a success target for remediation). And work towards achieving objectives of the remediation strategy.

Figure 2 and Figure 3 below shows the recommended barrier locations and configuration to achieve the desired objectives.

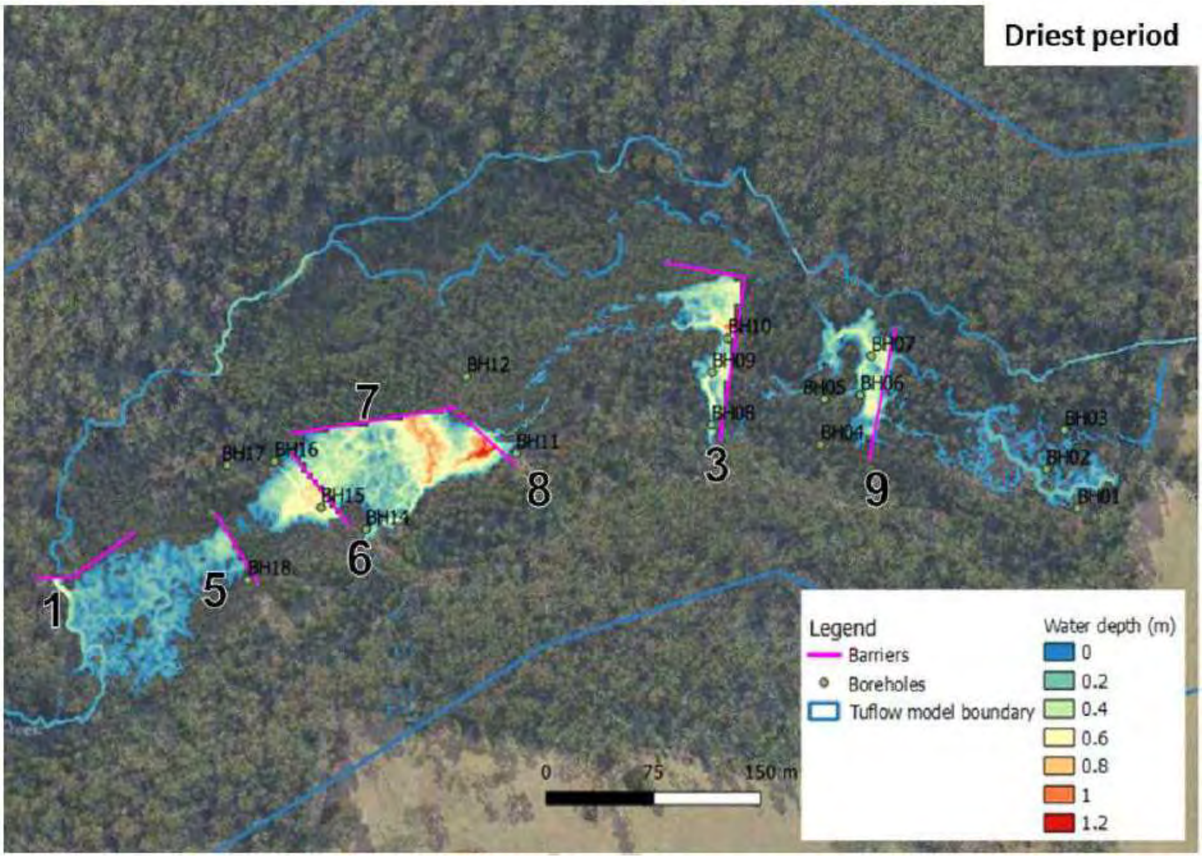


Figure 2: Recommended barrier locations – driest period

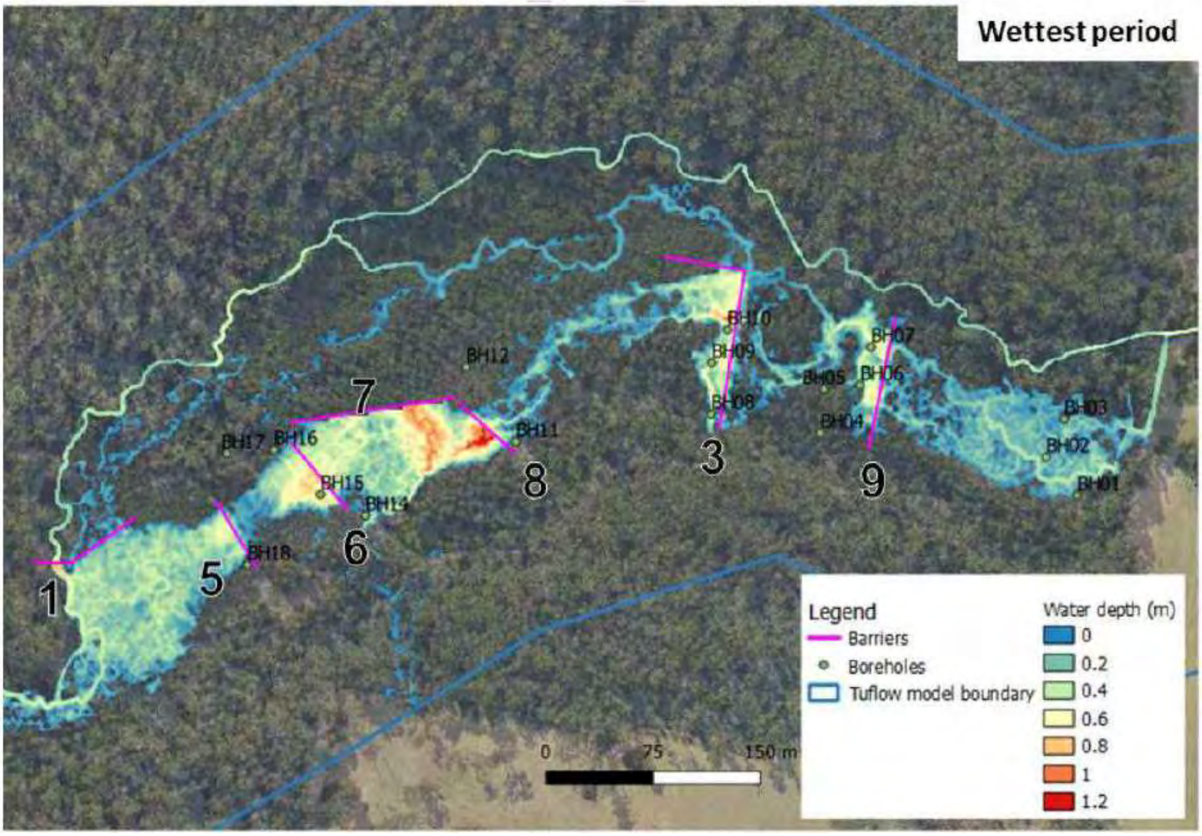


Figure 3: Recommended barrier locations – wettest period

Detailed design of hydraulic barriers

The detailed design of the hydraulic barriers was informed by the outcomes from the groundwater-surface water modelling which determined the size, location and configuration of barriers required to achieve the remediation objective of keeping groundwater levels above the target levels in the monitoring bores located within Big Swamp required to limit further oxidation of sulfides within the soil profile.

Also informing the design of the hydraulic barriers were the following key design requirements:

- Ability to meet hydraulic objectives – i.e. evenly distribute flow over the top of the barriers
- Minimising the construction footprint for installation of the barriers
- Minimising the requirement for removal of vegetation
- Minimising disturbance of acid sulfate soils within Big Swamp
- Utilising materials that can withstand the corrosive conditions within Big Swamp
- Allowing for removal of the barriers in the future if required

Basis of hydraulic barrier design and options assessment

The process for selection of the hydraulic barrier type consisted of an initial screening process followed by more detailed assessment of the remaining three options.

A broad range of options were identified and considered as part of the initial option screening process. These were then assessed based on their ability to meet the functional requirements of Hydraulics, Durability, minimising Potential Acid Sulfate Soil (PASS) disturbance, Seepage, Constructability, Vegetation Disturbance, and Rehabilitation (i.e future removal). Table 1 and Table 2 below provides the initial screening scores for each of the options assessed, where scores were assigned according to the following:

Table 1: Grading description

Grade	Description
4.0	Excellent
3.5	Very good
3.0	Good
2.5	Satisfactory
2.0	Fair
1.0	Poor
0	Fail

Table 2: Initial options screening matrix

	Assessment Criterea									
Option Description	Hydraulic	Durability	PASS distrubance	Certainty & Risk	Seepage	Constructability	Envronmental Disturbance	Rehabilitation	Weighted Score	Comment
Weighting	15%	5%	20%	10%	10%	15%	20%	5%		
Earth bank	1	3	1	2.5	2.5	1	1	3	**1.5**	Conventional solution, as suggested at project innitiation
Sand filled geotextile bag	0	2.5	2	1	1	2.5	3	3	0.0	Fails because the individual bags would leak at the joints
Sand filled geotextile tube	1	2.5	2	1	1	2	3	3	1.9	Would require custom bags, difficult to build to tolerance to achieve hydraulic criterea.
Rock Bank with PVC Pile Barrier	3.5	3.5	3	3	3	3	2	3	**2.9**	
Rock Bank with Geotextile Barrier and cut off	1	3	2	2	2	2	2	3	2.0	
Water Filled Coffer Dam	1	2	2	1	2	3	3	3	2.2	Lacks a cut off. Not clear how this could be done. Sincle size tube would require a fine tolerence on the foundation.
Precast concrete panels	2	1	1	2	2	2	1	1	1.5	Extensive excavation and backfill. Unclear how the joints would be sealed
Cast insitu concrete wall	2	1	1	2	2	1	0	1	1.2	Need coffer dams to build it.
PVC Sheet pile barrier	3.5	3.5	3	3	3	3	2	3	**2.9**	
Steel sheet pile	3.5	1	3	3	3	3	2	3	**2.8**	Option more expensive than PVC pile, so not considered further
H pile wall with planks (plastic or timber)	2	3	2	2	2	2	3	3	2.3	

The assessment scored the options with a sheet pile barrier the highest on the first four assessment criteria, with the majority of other options requiring installation of a membrane barrier to limit seepage. Irrespective of the form of membrane, the method of placement would involve significant trenching/backfilling, increasing the requirement for disturbance of the acid sulfate soils and increasing the construction footprint.

An additional advantage identified with the sheet pile barrier options is that the final crest level can be achieved with greater accuracy by cutting the pile after it has been placed. This provides greater control for achieving even distribution of the flow of water over the crest of the barrier, allowing greater spread of water across the swamp downstream of the barrier.

All other options present a significant challenge in achieving a consistent crest level for even distribution of flow, either through method of construction, barrier material, or propensity for settlement post construction given the soft sediment contained within the swamp.

Of the options considered, three were selected for more detailed assessment. These options were:

1. The conventional earthen bank. Whilst this scored poorly on most counts, it would superficially appear the most conventional approach, and is therefore discussed to highlight the potential issues and construction challenges involved.
2. The PVC sheet pile barrier and rock bank
3. The PVC sheet pile barrier

It is also worth noting that while the steel sheet pile scored reasonably well, it has a lower tolerance to the corrosive conditions, offers no advantages over the PVC pile option, scores slightly lower overall, and is more expensive. As such it was not considered for further assessment.

Detailed options assessment for hydraulic barriers

Earthen – Clay Barrier

Installation of earthen barriers was considered the most standard approach and the preferred option prior to completion of the detailed design assessment.

A typical design for an earthen barrier of 0.5m height is shown in Figure 4

Figure 4: Typical earth bank section

. It consists of an earth bank with rock protection on the crest and downstream face.

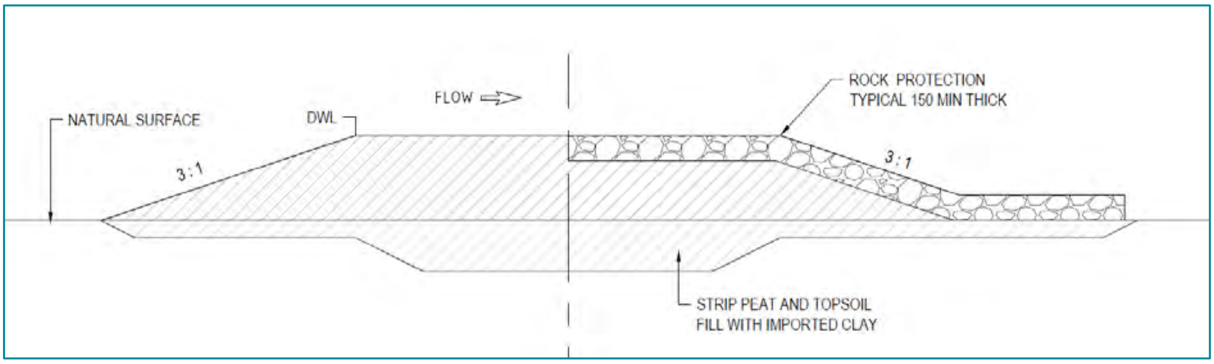


Figure 4: Typical earth bank section

The key issues that were identified with an earthen barrier included:

1. Stripping. The foundation needs to be stripped to remove all topsoil, tree roots, peat through to an impermeable surface and the thickness is unknown. All the stripped material would need to be removed and treated off site, due to PASS.
2. Volume of material. All material that is removed would need to be replaced with imported fill. Assuming 0.3 m depth, then this would double the quantity of material to be imported.
3. Lack of solid base. For construction of an impermeable bank, a solid foundation is needed to compact against. The lithological logs show most of the foundation is soft and unsuitable to build off directly. The usual methods of dealing with this are to place geotextile and rock to create a base, however this not appropriate under a water retaining bank.
4. Acid sulfate soils and PASS disturbance. Acid sulfate soils can be brought to the surface by stripping, excavation, and traffic movement. This option has a high proportion of all these elements. Compaction on a soft foundation risks pushing up the adjoining soil.
5. Large footprint. The footprint consists of the area immediately under the bank plus a cleared area 3 m on each side, to protect the water retaining bank from tree roots.
6. Wet foundation. Difficult to build if there is water in the swamp, without building a second coffer dam or draining the swamp.
7. Water Retention. Difficult to build a water retaining bank from earth that also acts as a weir, and requires rock protection. The rock protection is not water retaining, and the earth (clay) is susceptible to erosion. It can’t be built or maintained to the tolerance required to provide even distribution of flow over the crest and needs a hard crest to define the water level.

Based on the above, the use of earthen barriers was not considered a viable option for meeting the design and subsequently remediation objectives.

Cantilever PVC Sheet Pile Barrier

This option assumes insertion of a lightweight Poly Vinyl Chloride (PVC) barrier into the ground to sufficient depth to be able to withstand the depth and flow of water without supporting material. An indicative design is shown in Figure 5 and consists of a simple cantilever wall with rock beaching on the downstream side to dissipate flowing water for erosion protection. This serves two purposes, a working platform for pile installation, and erosion protection when water is flowing over the barrier.

The key factors considered in assessing the cantilever sheet pile barrier included:

1. Chemical resistance of piles. The PVC sheet piles are non-corrosive and resistant to acid except at high concentrations.
2. Structural strength. PVC piles have lower structural strength than steel. At the heights under consideration (conservatively up to say 1.5 m) the strength required is well within the capacity of available sections (in the order of 23 kN.m/m)
3. Deflection is greater than for steel. They need to deflect more to mobilize ultimate strength.

4. Geotechnical strength. The cantilever pile relies on the capacity of the supporting soil, which could be limiting given the soft substrate.
5. Seepage. PVC piles are frequently used for seepage cut off applications in levees and landfills. The interlocks can be sealed to reduce seepage if necessary.
6. Constructability. It is anticipated that they can be pushed or driven into the site soils. The most likely obstruction would be submerged trees. Several placement options are available if conditions are more difficult including pre-trenching or pre-driving a steel template.

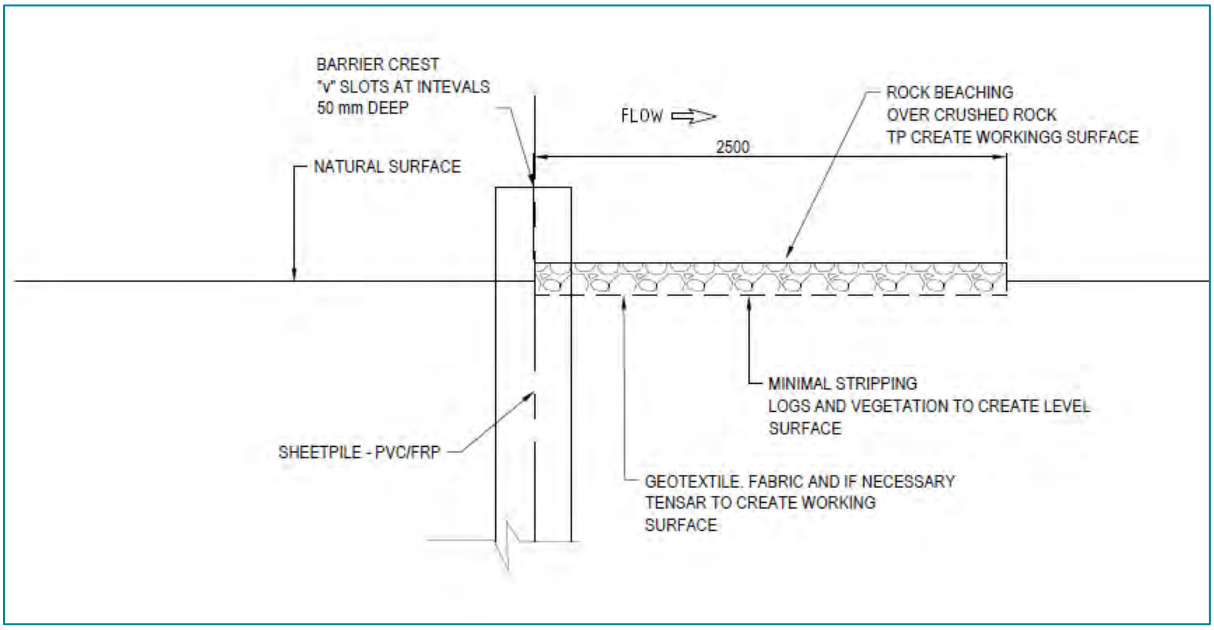


Figure 5: Cantilever – Sheet Pile Wall

Key disadvantages identified for the indicative cantilever sheet pile barrier design shown above included:

1. Lack of fire resistance. PVC piles are susceptible to fire damage, including small grass fires.
2. Possible damage by UV
3. Erosion protection may not be adequate for large drops, and the rock would need to be thicker
4. No access, or limited access in service, where the tailwater extends to the base of the wall
5. The platform does not provide good construction access in wet conditions, and it may be more difficult to place piles at the edge of the platform
6. The deflection of the sheet piles could be excessive and would increase the difficulty of maintaining the tolerance required for even flow over the crest

Rock bank – Sheet Pile Barrier

This option is similar to the cantilever wall and aims to rectify some of its deficiencies. The earth/rock bank on either side of barrier is provided to just below crest level of the barrier. This aims to provide fire protection, improve access, provide greater erosion protection, and reduce the sheet pile deflection. It also allows to the barrier to be inserted into the ground to a much shallower depth, which minimises the impediment to subsurface alluvial groundwater movement and allows for easier removal in the future should the barriers no longer be required.

The sheet piles would be used to provide a watertight barrier with minimal seepage while the embankment would provide structural support and erosion protection.

Compared to the Cantilever sheet pile barrier, the Rock bank sheet pile barrier was considered to have the following advantages:

1. Construction access is improved, particularly if there is water in the swamp
2. Operation and maintenance access would be better. It would allow pedestrian access across the structure when in operation, and depending on the length of pile protruding, may allow excavator or some vehicle access if required.
3. Embankment provides fire protection to the PVC sheet piles
4. Less visual impact and potential for the embankment to grow over compared to the cantilever pile. Covering the rock with topsoil would assist with this aspect if desired.
5. Improved erosion control due to reduce drop to rock beaching from the crest of the sheet pile barrier
6. Sheet pile deflection is significantly reduced, making it easier to achieve and maintain uniformity in the crest level and subsequently distribution of flow
7. Reduced site disturbance compared to the earthen barrier, but slightly higher footprint compared to the cantilever wall.

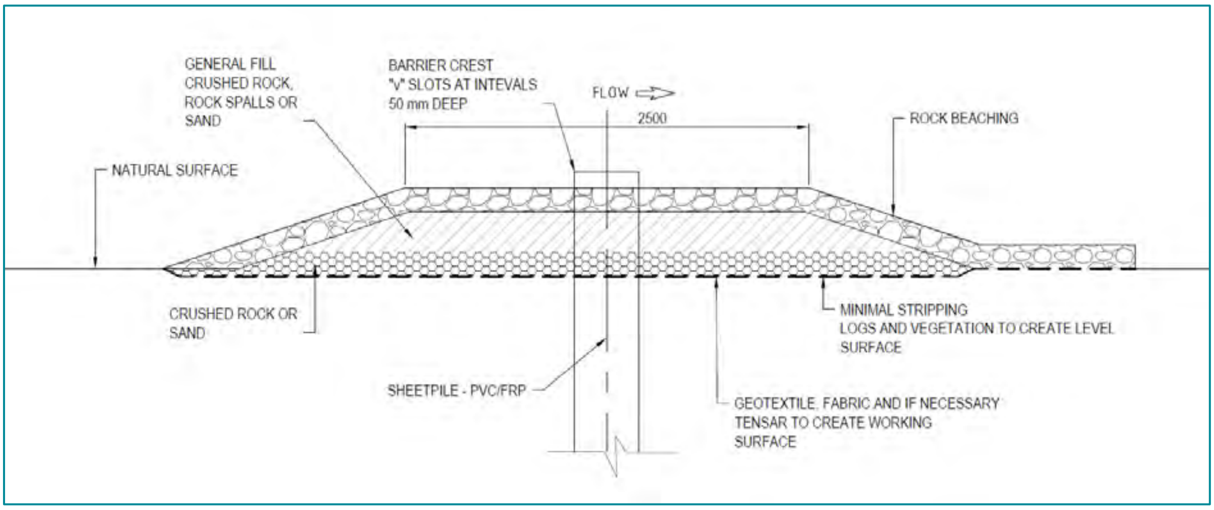


Figure 6: Rock bank with sheet pile cut off

Site conditions and geotechnical investigations

The geotechnical investigations considered in development of the detailed design for the hydraulic barriers included existing available geotechnical information and targeted onsite geotechnical investigations and subsequent interpretation of result and calculations pertinent to the hydraulic barrier options being considered.

The review of the existing investigations included previous borehole drilling operations and soil sampling completed within Big Swamp from 2014 through to 2019. Further investigations were also commissioned to inform the design and were carried out in April and May 2021. These investigations consisted of cone penetrometer tests and hand auguring to inform geotechnical design requirements. The conclusions drawn from this analysis are summarized below.

The cantilever sheet pile barrier option was found to have excessive pile deflection, and the depth of pile necessary to achieve geotechnical stability was excessive. This finding leads to the option being ruled out. A combined sheet pile and rock embankment option was subsequently adopted as the hydraulic barrier design solution.

The results of the geotechnical analysis concluded that the sheet pile barrier option satisfied the strength, stability, and seepage requirements, with embedment depths ranging from 1.0 to 4.0 m below ground surface level depending on height of the barrier above ground. The deflection and settlement of the sheet piles were no greater than 20 mm.

Summary of barrier option assessment

A range of hydraulic barrier options were considered and ruled out through a screening process based on the criteria developed in the functional requirements. Key factors considered in the assessment included:

1. The swamp soil and water conditions are aggressive to many materials including mild steel and concrete, and their use in barriers and the regulating structure is not recommended
2. Construction methods required to ensure water tight barrier whilst also minimizing the disturbance of acid and PASS soils are a challenge for most options
3. Ability to construct a uniform crest level to provide for even distribution of surface flow across the swamp was considered important, and this led to a low score for options which could not be built and maintained with a uniform crest level to allow for even distribution of flow over the barrier.

The conventional earthen barrier option was developed further and subsequently ruled out on points (2) and (3) above.

Structures based on a variation of PVC sheet pile were considered the most viable for meeting the functional requirements and minimising site disturbance and construction footprint. Based on the geotechnical requirements, coupled with the above, it was found that the rock bank PVC sheet pile barrier would provide the required stability whilst having a reduced the total depth of pile below ground and therefore this was adopted as the preferred barrier option.

In the final design the pile acts as a hydraulic barrier, which is structurally supported by the bank. The bank provides a method for gaining access into the swamp to incrementally install the barriers and ultimately remove them if required.

Hydraulic barrier design

As outlined previously, the size, location and configuration of the barriers was determined by the Groundwater – Surface Water Modelling for Boundary Creek and Big Swamp that was completed by GHD (2020). This information has formed the basis for the detailed design of the hydraulic barriers. Figure 7 below shows the barrier configurations from GHD (2020) with revised barrier labelling as outlined in Table 3. The barrier levels refer to the top of the barrier as determined through the groundwater surface water modelling. Most barriers are designed to overflow at the designated pool level, with the following exceptions:

- The north part of J4 is slightly higher, to assist redirection of flow
- The two barriers at the west of the swamp (J1 & J2) elevate the water as part of the scheme to regulate the distribution of flow between the Big Swamp and Boundary Creek and subsequently the pool level will dependent on the adjusted level set at the regulator in barrier J1.

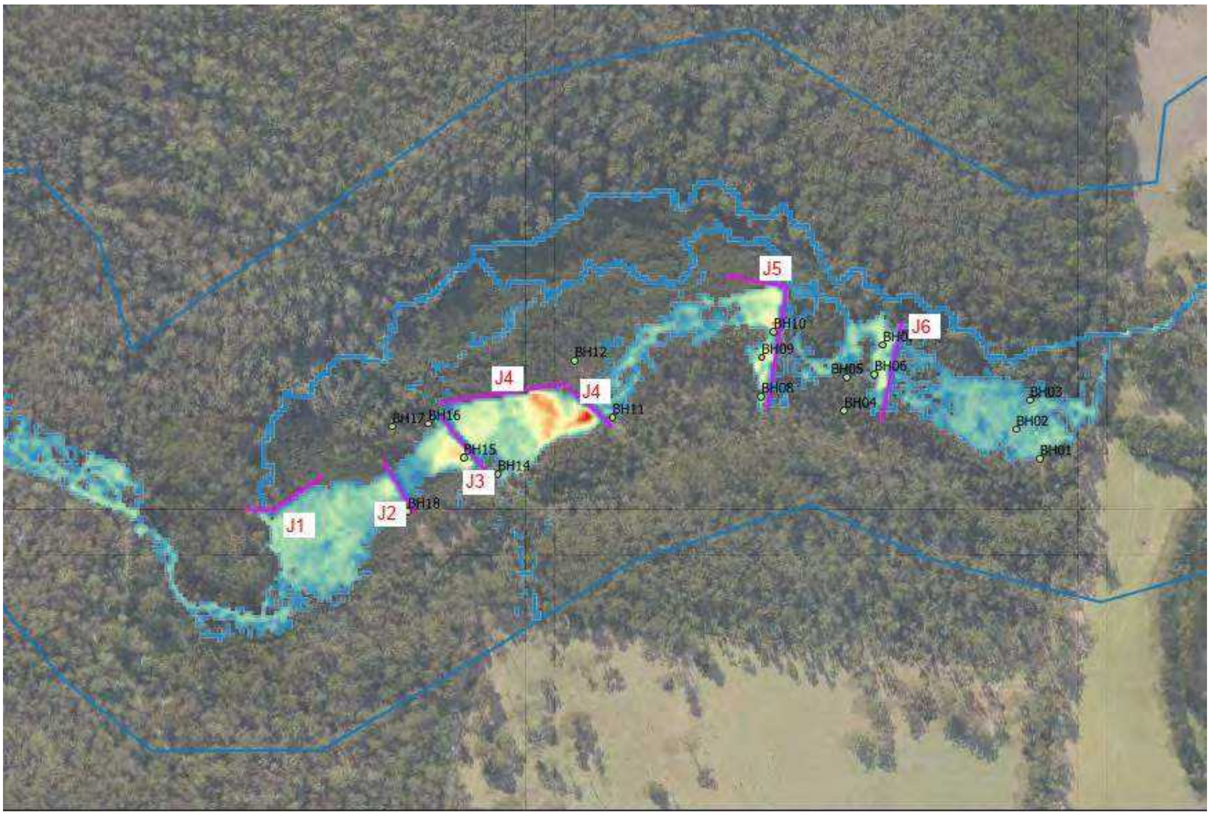


Figure 7: Preferred Barrier configuration (from GHD 2020)

Table 3: Barrier numbering and concept design levels

Previous number (GHD 2020)	Adopted Number	Concept Barrier Level (m AHD)	Concept Pool Level (m AHD)
1	J1	148.7	148.5
5	J2	148.7	148.5
6	J3	147.9	147.9
7	J4 – north	147.7	147.6
8	J4 – east	147.6	147.6
3	J5	144.9	144.9
9	J6	142.7	142.7

The alignments adopted for the detailed design align with those determined by the modelling as closely as practicable. The concept alignments aim to spread water evenly across the width of the swamp, to maximise the wetted area downstream, as well as upstream. As such the barriers alignment and configuration of the barriers was selected to maximise spread of water and are not necessarily the shortest path across the swamp. Attempts were made to refine the alignment to bring the barriers closer to the existing tracks and apply standard minimum radii at changes in direction, however this was done so as not to compromise on the lateral spread of water at the barrier.

Existing groundwater monitoring bores are to be retained undamaged and be relatively accessible from the barriers. Whilst it would be desirable for barriers to follow the cleared paths that link the monitoring bores to minimise any further clearing and disturbance within the swamp, this was not able to be achieved in all instances. The existing access tracks were built for the installation of the monitoring bores and were conceived prior to establishing the proposed embankment alignments. Where the bank is offset from the existing access tracks, typically slightly to the east of the cleared path, the design still gains some benefit in terms of minimising the require for further vegetation clearance.

The ends of the barriers have been designed to tie into higher ground so as to reduce the risk of outflanking of water around the ends of the barriers and undermine the objective of even distribution of water over the barrier. The barrier crest has also been designed to maximise the spread of water, and as such should not prematurely rise at the abutment with the higher ground.

Curved alignments have been designed with a minimum15 m radius which is the typical minimum radius for vehicle movement and hence construction practicality.

The sheet pile crest is designed 0.05 m higher than the pool level in most barriers. This allows for "V" notches to be installed at intervals across the crest, with the invert of the V to be set at the required pool level.

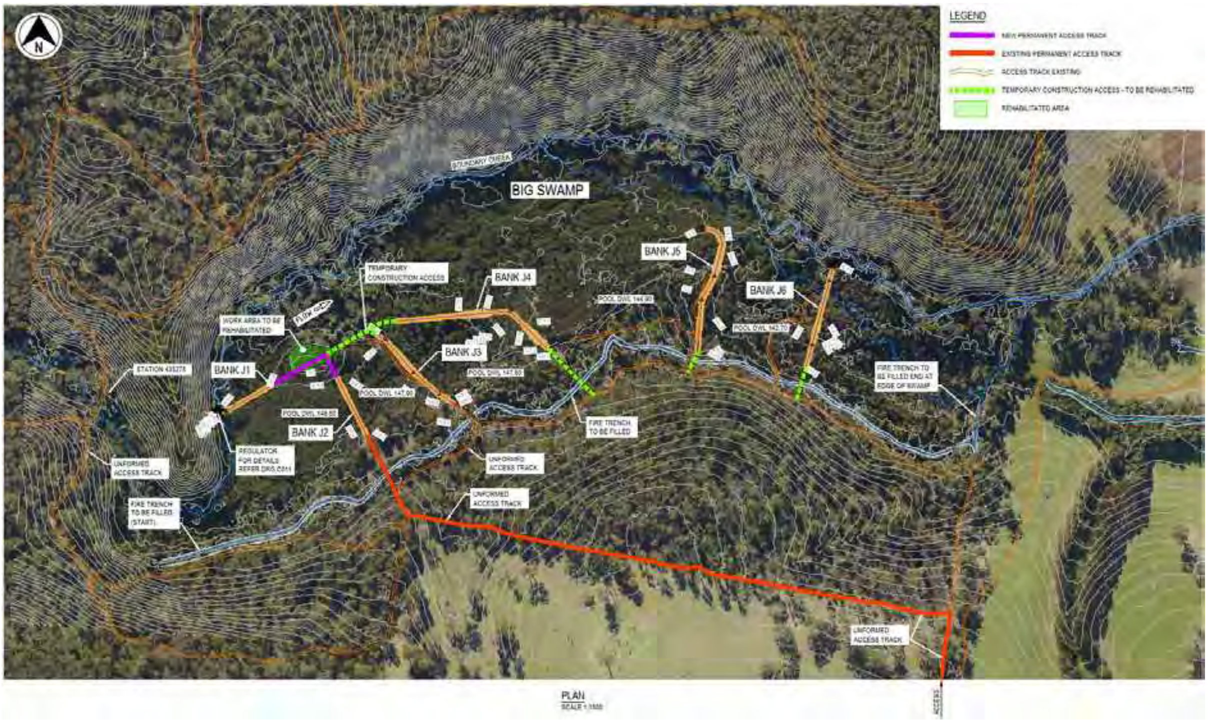


Figure 8: Plan view of barriers and construction access

The depth of sheet pile is determined by the geotechnical ground conditions. The sheet pile must be deep enough for the loading from the retained water but shallow enough to allow groundwater to pass underneath them. To accommodate this a novel structure has been designed where every second sheet pile is kept shallow to allow groundwater movement, while the deeper piles in between provide the barriers strength. Table 4 below provides the minimum and maximum depth requirements for these barriers based upon the height of the barrier at that point.

Table 4: Sheet pile depth schedule

SHEET PILE SCHEDULE				
HEIGHT (m)	MINIMUM EMBEDMENT DEPTH (m)	MAXIMUM EMBEDMENT DEPTH (m)	BANK	OTHER REQUIREMENTS
0 OR LESS DWL < NSL	1000	1500	J1 TO J6	EXTENDED PILES LATERALLY 3m MINIMUM INTO ABUTMENTS
0 - 300	1000	1500	J1 TO J6	
300 - 600	1500	2500	J1 TO J6	
600 - 900	1500	2500	J1 TO J4	
600 - 900	2000	3500	J5 TO J6	
900 - 1200	2000	3000	J1 TO J4	
900 - 1200	2000	4000	J5 TO J6	

PILE EMBEDMENT DEPTHS SHALL BE ALTERNATED TO ALLOW SUBSURFACE FLOW ie.MIN./MAX... ETC.
PILE DEPTH MAY BE ALTERNATED TO STRADDLE BURIED OBSTRUCTIONS.
HEIGHT "H" IS DEFINED AS THE MAXIMUM OF "DWL MINUS NSL" MEASURED OVER A LENGTH OF 4.5m CENTRED OVER THE POINT.

A long section of each barrier is provided in Figure 9 to Figure 15 below. These long sections provide the height of each barrier compared to ground level. The maximum barrier height is approximately 1.2m

Figure 9: Barrier J1 longitudinal section

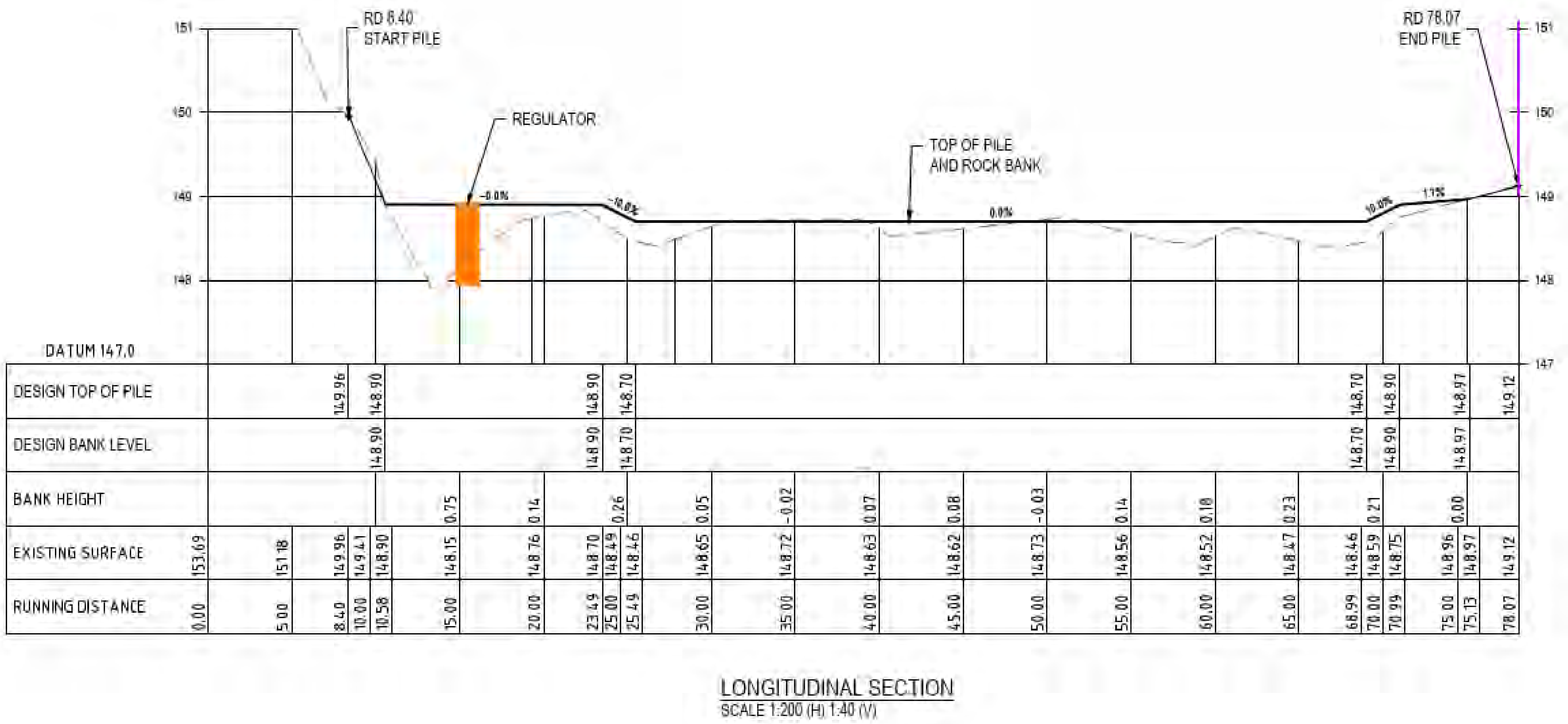


Figure 10: Barrier J2 longitudinal section

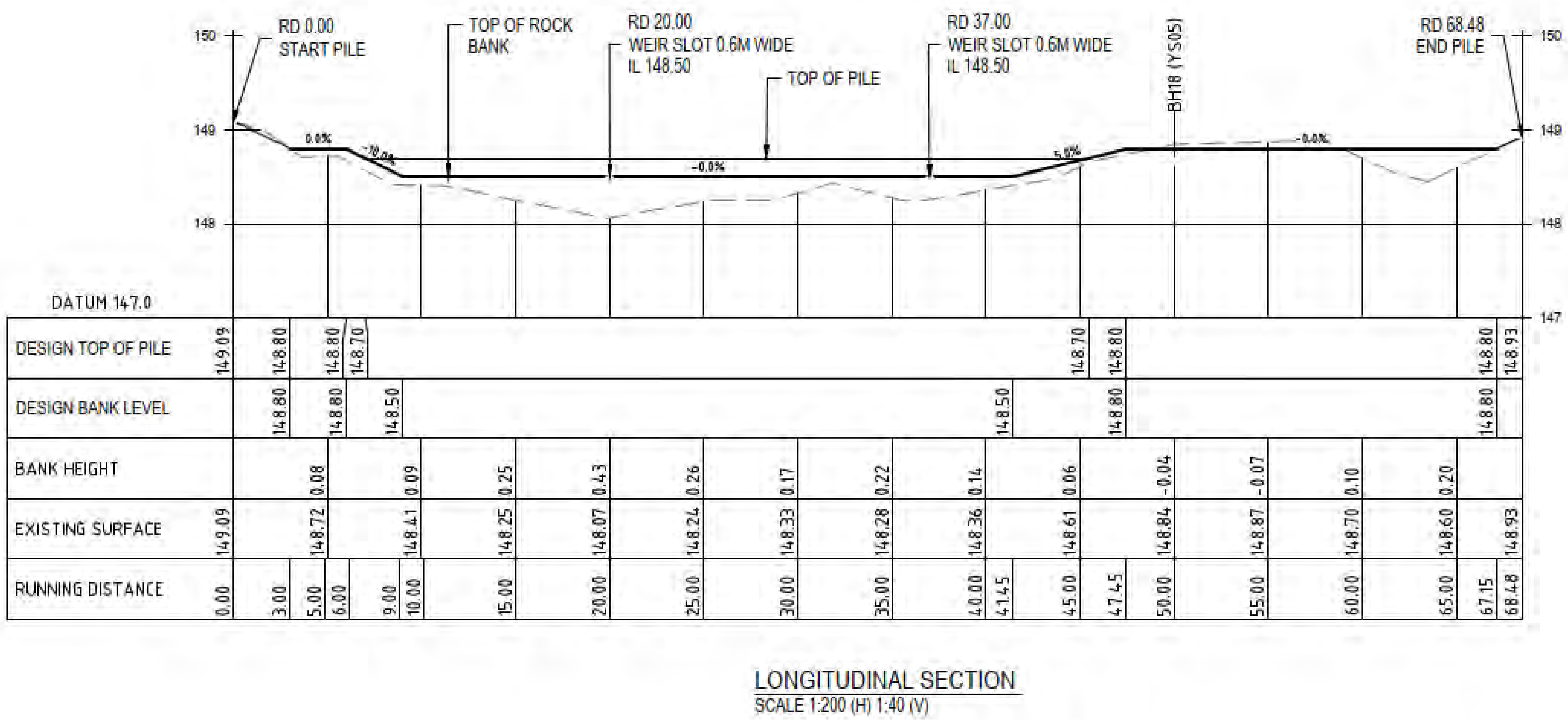


Figure 11: Barrier J3 longitudinal section

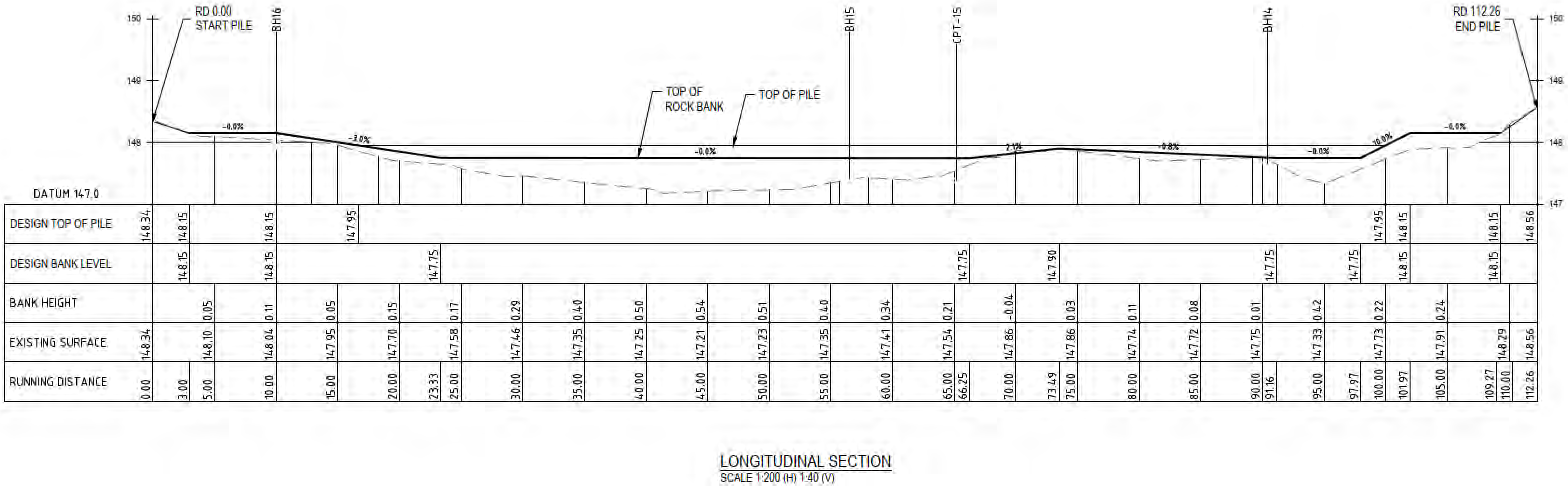


Figure 12: Barrier J4 longitudinal section (1/2)

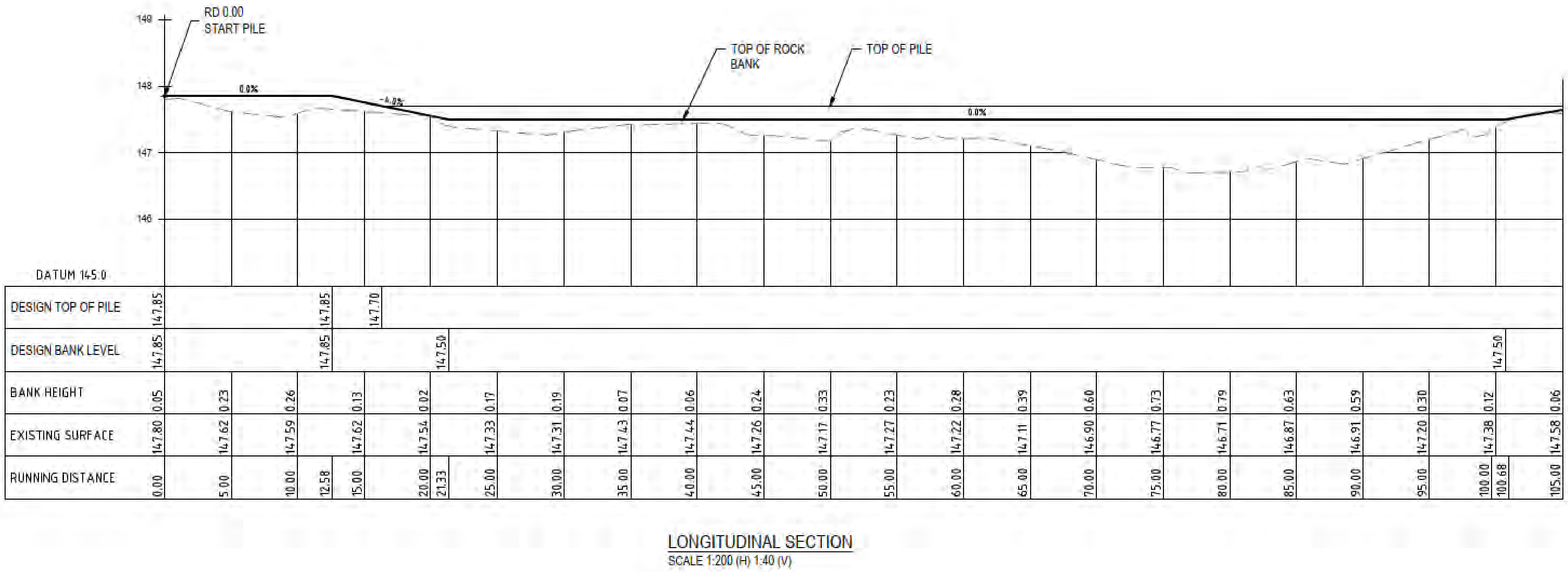


Figure 13: Barrier J4 longitudinal section (2/2)

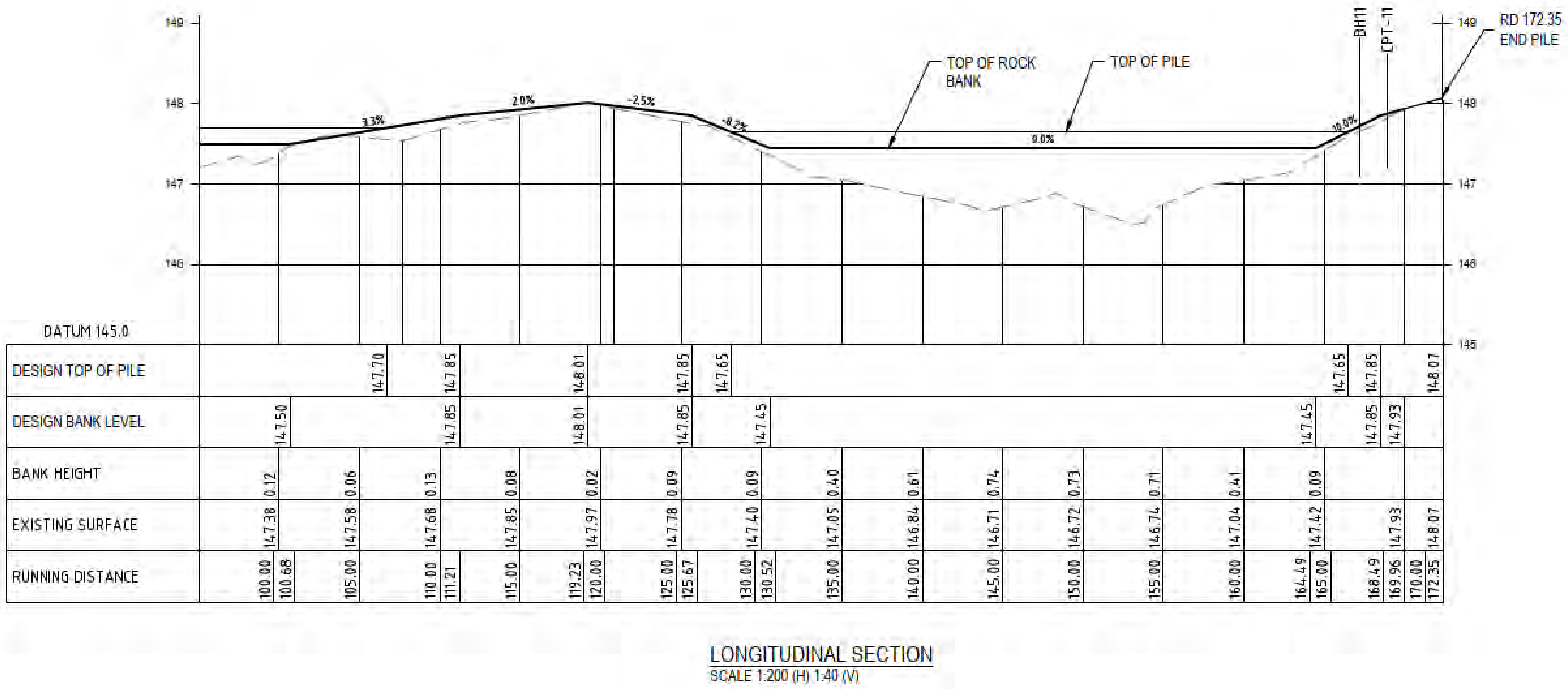


Figure 14: Barrier J5 longitudinal section

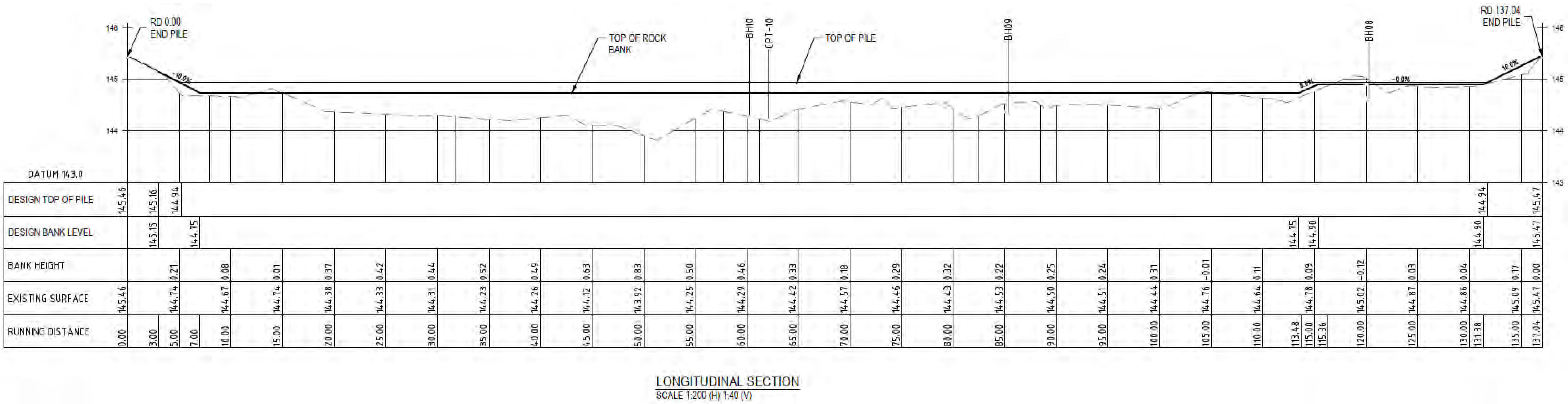


Figure 15: Barrier J6 longitudinal section

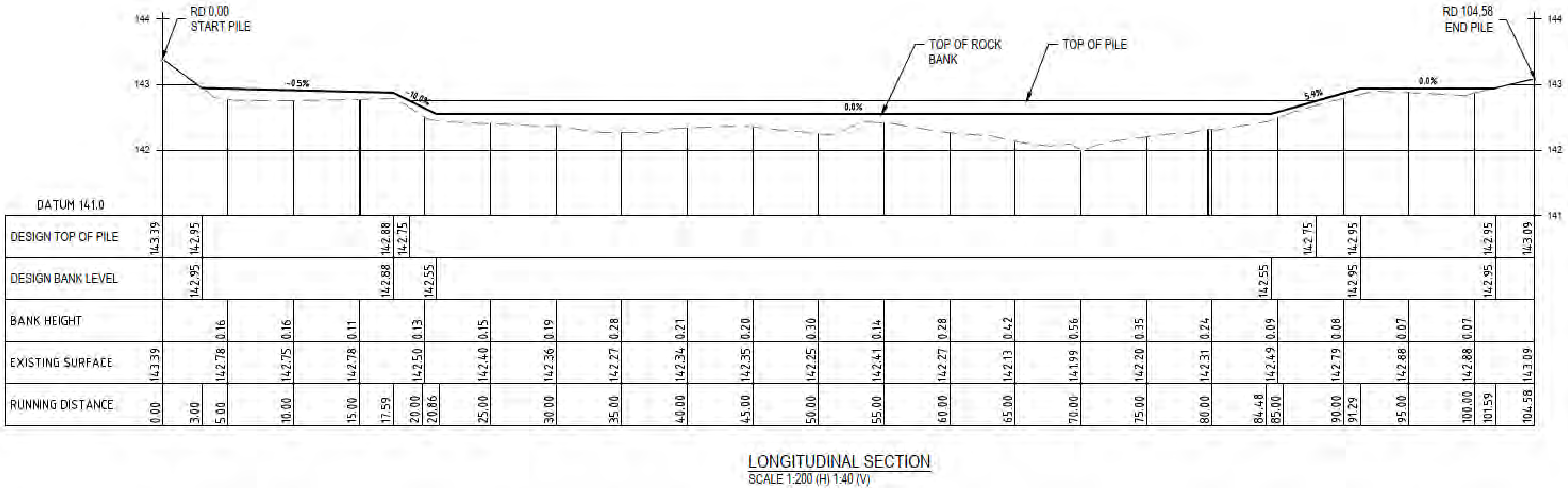
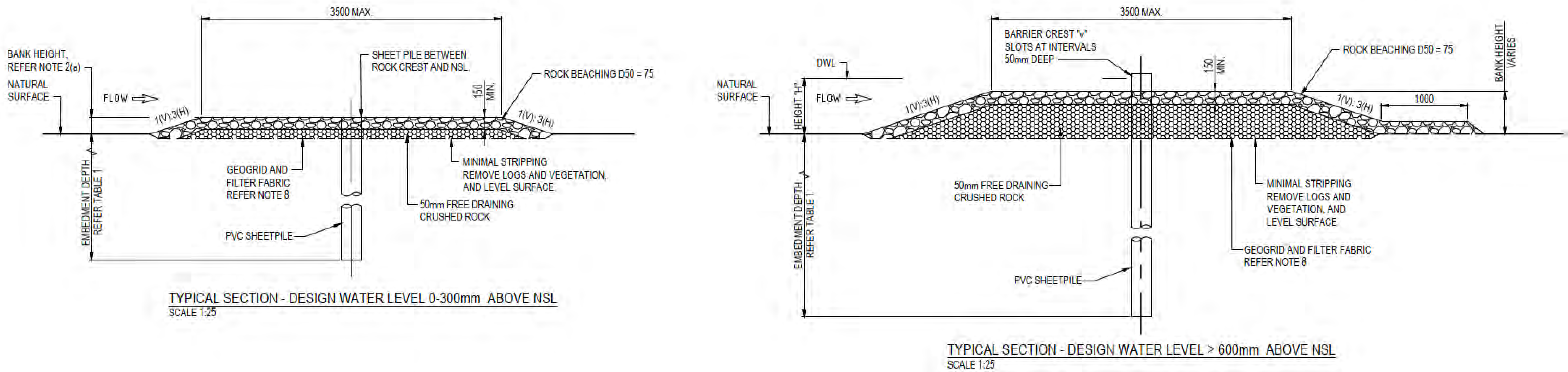


Figure 16: Typical cross sections of barrier design



Appendix B provides a full drawing set for the barriers.

Flow control regulator, fire trench filling and access

A flow control regulator is to be installed in Boundary Creek at Barrier J1. Its purpose is to raise the water level to enable the manipulation of the flow distribution between the northern channel of Boundary Creek and the swamp. This allows distribution of flow between the swamp and the creek and ensures flows are maintained in the creek channel during drier low flow periods. The regular is located immediately downstream of the first natural overflow.

The hydraulic behaviour of the creek and swamp can vary depending on flow conditions. Observations from a recent field inspection downstream of the regulator site indicated that there may be more cross connection between the two than the recent surface water model predicts. This reinforced the need for an adaptive management approach to optimize the flow distribution which will be aided by the regulator.

Regulator Design

The regulator gate is to be an adjustable overshot lay flat style gate. It will operate as a fixed structure most of the time with the flow split between the creek and swamp to be adjusted if necessary to suit flow and seasonal requirements.

The regulator support structure re is designed as a continuation of the sheet pile hydraulic barrier for barrier J1. Sheet pile is used as the upstream hydraulic barrier and structure walls with mass concrete is used to provide the required foundations to support the regulator gate.

The barrier designs have intentionally avoided the need to import substantial volumes of cast insitu concrete or the necessity to transport large volumes of materials into the swamp. The use of concrete has been minimised due to durability concerns with steel reinforced concrete and corrosive conditions within the swamp. However, whilst the conditions elsewhere in the swamp are considered poor for reinforced concrete, it was considered that in the upper reach the conditions are less aggressive based on the water quality data available and as such suitably specified concrete could be used in this application to provide the foundations required.

The gate is to be procured as a bespoke item to a generally standard design consisting of the following:

- Lay flat overshot gate designed for a 1.22 m wide opening and to be floor mounted
- Manual hand wheel operated actuator (lockable with Barwon Water padlock)
- Integral walkway and handrails for the width of the regulator supported by either the gate or walls
- Top beams and cross beam on the sheet pile walls.
- Adjustable fittings affect a watertight seal between the regulator sides walls and the upstream sheet pile wall
- All gate and steel components are to be stainless steel, grade 316.

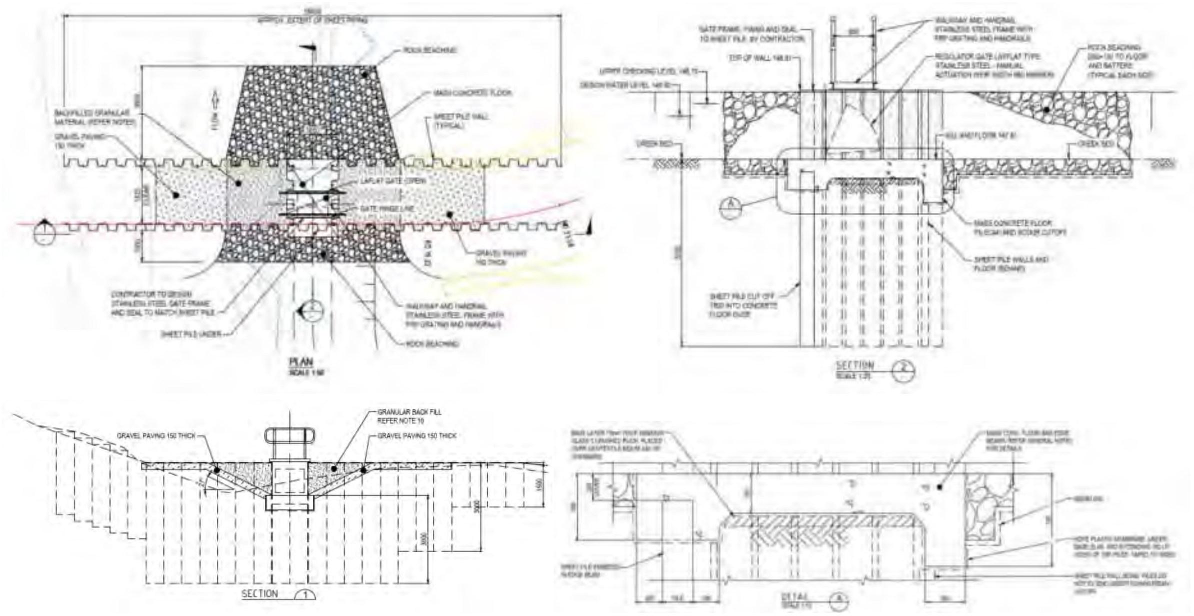


Figure 17: Regulator design

Infilling the Fire Trench

The primary objective of infilling the fire trench is to prevent it diverting surface runoff around the swamp and to reinstate the natural flow paths. The intent is that the inflow will contribute to maintaining a saturated environment in the swamp.

The fire trench was constructed to prevent the spread of a peat fire and this function is to be maintained once infilled. Therefore the organic peaty material in the spoil banks remaining from its construction is not considered a suitable fill material, and the trench will be filled with non-organic fill material.

The fill material and level of compaction will aim to reinstate permeability characteristics similar to the original material so that the flow of groundwater is not interrupted or diverted. During the construction of the fire trench, large trees were retained and therefore the infilling works will be undertaken so as to unnecessarily reduce their viability.

The fire trench will be filled over its entire length along the southern side of the swamp (refer to Figure 8 for location of the fire trench). At the eastern end, where the trench continues into the body of the swamp, it will be filled up to the edge of the swamp, to a point where it can be practically constructed without disturbing PASS soils or impacting water movement through the swamp.

Sections of impermeable fill may need to be installed intermittently to act as blockages to flow along the trench. These will be located in line with the access to each of the proposed hydraulic barriers.

Fill material will be a clean mineral fill, imported to site. It should be broadly similar to the existing material identified in the top 2 m of boreholes YS01, YS04, and TB01a, with the exception that it should not be organic or peaty. Appropriate material would be classified as Silt, Fine Sand, light Clay, and mixtures of these material classifications.

The surface area to be filled will be cleared by slashing, but not excavated. The clean fill would be placed over the top of this and filled to slightly proud of the original natural surface. Compaction would be by track rolling, but not so heavily compacted as to be impermeable water. Topsoil will then be placed over the top.

Existing spoil banks are to be breached at intervals to ensure free flow of surface drainage. The excess material may be spread as shallow topsoil over the filled fire trench, provided it is suitable quality and not containing Acid Sulfate Soils. The remainder of the existing soil banks are to be retained as unchanged. Generally they will only be altered where required.

Next steps for implementation of hydraulic barriers

The detailed design drawings and report will now be used to inform the relevant approvals required for construction and implementation. This includes all environmental approvals, works on waterways permits, cultural heritage assessments and approvals, planning permits, constructability reviews and agreement with relevant landowners. Subject to obtaining all relevant approvals and outcomes of the geochemical analysis and modelling, construction of the hydraulic barriers could commence over summer 2021/22.

Review of remediation success targets

Under the REPP, Barwon Water committed to reviewing and revising remediation success targets as appropriate following collection of additional data and completion of further technical work to ensure the success targets remain relevant and aligned to SMART principles - specific, measurable, achievable, relevant and time limited. Consistent with these SMART principles, it is important that the success targets are set at a level that is achievable by the controls and actions being implemented.

The interim success targets contained in the REPP were informed by the technical work undertaken to that point in time, along the vision, priorities and objectives that had been established for remediation in consultation with the Remediation working Group and their nominated experts.

All success targets needed to be achieved concurrently before remediation could be considered to have been successful, at which point and in accordance with the Section 78 Notice, Barwon Water must demonstrate to the satisfaction of SRW that the REPP has been implemented and that the measures and outcomes have been achieved as outlined in section 2.5 of the Section 78 Notice.

The success targets currently contained in the REPP are outlined in Table 5 below, with further detail on how they were developed available in section 6.5.1 of the Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan.

Barwon Water engaged the services of CDM Smith to undertake the review of the success targets, with the following sections providing a summary of the review undertaken in order to fulfil this commitment and respond to the relevant feedback received from SRW and the ITRP. Their full report is provided in Appendix C

The targets have been reviewed using the latest monitoring data and modelling. Any proposed revisions to existing success targets or new success targets will need to be submitted to SRW as a proposed amendment to the REPP for approval in accordance with the approved Governance Framework process before being formally adopted.

With regard to groundwater level success targets for Big Swamp, in their review CDM Smith assessed the more conservative targets that were used within the groundwater-surface water modelling undertaken by GHD, rather than those originally stated in the REPP. This was because these groundwater level targets had been informed by the sulfidic horizon (the upper most layer of acidic soils) at each bore site. Ensuring groundwater levels remain above this sulfidic horizon will help to prevent further oxidisation of acid sulfate soils within the swamp and therefore were considered more appropriate success targets to inform the modelling undertaken by GHD. Subsequently CDM Smith thought it more appropriate to assess these more conservative targets as opposed to those originally included in the REPP. Table 6 lists both the original groundwater level success targets and the revised groundwater level targets used to inform the modelling undertaken by GHD.

Table 5: Success targets currently contained in the REPP

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

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

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

Table 6: Big Swamp groundwater level targets below ground level (bgl)

Borehole Number	Original groundwater level success targets	Revised groundwater level target used to inform the GW-SW modelling
BH01	1.0m bgl	0.7m bgl
BH02	n/a	1.2m bgl
BH03	n/a	1.6m bgl
BH04	n/a	0.6m bgl
BH05	n/a	1.0m bgl
BH06	1.5m bgl	1.0m bgl
BH07	n/a	0.4m bgl
BH08	n/a	0.4m bgl
BH09	1.8m bgl	1.5m bgl
BH10	n/a	2.0m bgl
BH11	n/a	1.5m bgl
BH12	1.9m bgl	1.2m bgl
BH14	n/a	0.15m bgl
BH15	1.0m bgl	0.2m bgl
BH16	n/a	n/a
BH17	n/a	n/a
BH18	n/a	0.2m bgl

Objectives of the success target review

The objective of this review is to assess whether the current success targets listed in the REPP are effective and measurable targets, based on the current level of information for the study area. The review will aim to answer the following questions:

1. Do the Success Targets align with the expected changes to eco-hydrological processes as remediation actions take effect?
2. Are the proposed Success Targets measurable, such that the eco-hydrological processes can be monitored into the future and provide a measurable indication of remediation success?

3. Can the success targets be improved or additional success targets adopted

The scope of the assessment included:

- Obtain and review historic data and information to determine baseline conditions of Boundary Creek & Big Swamp (pre-impact)
- Review current site data and information for Boundary Creek & Big Swamp (post-impact)
- Review predictive (modelled) data to assess the change in the system as a result of proposed remediation approaches and control measures
- Evaluation of proposed control measures
- Evaluation of current success targets
- Preparation of a report detailing the process undertaken and the effectiveness and suitability of the success targets.

Review methodology

The following provides a summary of the process undertaken by CDM Smith for their review. More detail on the review methodology is provided in the CDM Smith report in Appendix C.

Conceptualisation

To inform their review, CDM Smith first conceptualised the system in relation to the Lower Tertiary Aquifer, the Quaternary Aquifer, Hydrology and Eco Hydrology (vegetation) to better understand how each of these components are impacting Boundary Creek and Big Swamp. The conceptualisation consisted of 4 steps as outlined below:

1) A description of the baseline condition (i.e. pre-millennium drought and pre-pumping) of the Success Targets, including;
   a. the baseline groundwater levels in the LTA and alluvial aquifer
   b. the baseline vegetation assemblages
   c. the baseline streamflow
2) A description of the current condition of the Success Targets, including;
   a. the current groundwater levels in the LTA and alluvial aquifer
   b. the current vegetation assemblages
   c. the current streamflow
3) Development of "Problem Statements" that detail the cause-and-affect processes that have driven the changes observed for the Success Target between the baseline and current periods
4) Consideration of whether there is adequate information to;
   a. support the Problem Statements
   b. predict the trajectory of the Success Targets

Evaluation of remediation strategy control measures

CDM Smith then assessed the relationship between eco-hydrological changes, remediation actions (control measures) and Success Targets to assess the effectiveness of the control measures in changing the trajectory of the Success Target, i.e. how do the control measures change the current condition of the swamp and how these changes respond relative to the success targets. This would also inform whether additional actions or control measures would be required to achieve the success targets and therefore remediation objectives.

Evaluation of remediation success targets

CDM Smith then used the outcomes of Step 1 and Step 2 to provide an overall assessment of the alignment of the individual Success Targets with the proposed remediation actions, and how well current data and monitoring will be able to track the eco-hydrological changes and associated Success Targets into the future.

This step was designed to ultimately provide a holistic appraisal of the suitability of the current Success Targets, and where appropriate identify:

- Which Success Targets align with the expected changes to eco-hydrological processes as remediation actions take effect
- Which Success Targets are measurable based on the current monitoring network
- Where data gaps occur that prevent the Success Targets from being measured over time and what actions could be undertaken to reduce these data gaps
- Consideration of additional success targets

Review Outcomes

Table 7 below provides a summary of the outcomes of the data review and conceptualisation process, and whether there is adequate information to support the problem statements and predict the trajectory of the success targets. Cross sections (West to East) across the swamp for baseline (pre-impact), post fire (2011) and current conditions of the swamp are presented in Figure 18, Figure 19 and Figure 20 respectively.

Based on the conceptualised knowledge of the area, CDM Smith determined the following:

- There is adequate information to support the conceptualisation of Big Swamp so that the problem statements can be justified and trajectory of success targets can be predicted
- There is an absence of baseline water level data for the QA, however, the presence of other information and data (i.e. LTA water levels, soil logging, Boundary Creek water quality and vegetation assemblages) supporting the swamp are sufficient to determine the likely baseline water levels within the QA
- There is a lack of data supporting the saturation of the surface soil of the wetland. Consideration should be made to utilise a combination of hand-held EM surveys, site

observations, and/or remote sensing data to monitor soil saturation and use these data to monitor for progress against the predictions made by the groundwater-surface water modelling undertaken by GHD.

- The most robust datasets in terms of historical records are LTA water levels, streamflow (Yeodene stream gauge) and Boundary Creek water quality

With regard to incorporation of additional success targets the following outcomes were identified and form the basis for recommendations regarding additional actions or monitoring:

Macro-invertebrate Success Target.

A measurable component of the health of a swamp are macroinvertebrates. However, it is understood that no baseline data for the swamp exist, with the possible exception of upstream and downstream monitoring, to evaluate the current condition and trajectory of the species.

It would be possible through literature review and or sampling similar swamps to determine a baseline species list and abundance, in line with the expected hydrology and vegetation of the swamp. Sampling bi-annually within the swamp could provide data on how effective remediation efforts are in enabling macro-invertebrate population to re-establish towards a defined local baseline.

It is therefore recommended that consideration be given to performing baseline studies to establish an expected trajectory of macro-invertebrates. Once this is established, metrics against species and abundance could be derived and used to set a Success Target.

Boundary Creek downstream of Big Swamp

It is acknowledged that the impact of groundwater pumping, millennium drought and acidification of the swamp will have had a negative impact on the values within the water way of Reach 2 of Boundary Creek. While no specific success targets for values within Boundary Creek are currently specified, existing success targets regarding the LTA, alluvial aquifer, pH and flows in Boundary Creek at the Yeodene gauge provide some measure of support for the values in the creek.

Site specific success targets for the creek at this stage are considered problematic, as the current condition of the creek is subject stressors that are not associated with the management of the swamp and the aquifers, for example, grazing, pugging and pollution from stock. Unless theses stressors are controlled and or managed, proposed actions or success targets will be difficult to achieve.

It is recommended that a waterway management plan is developed for the creek (noting this is outside the scope of this report) that aims to in general boost the resilience of the creek's values, by controlling erosion, stock access and weeds. Once this is in place, consideration can be given to whether additional onsite actions and or management is required and or appropriate.

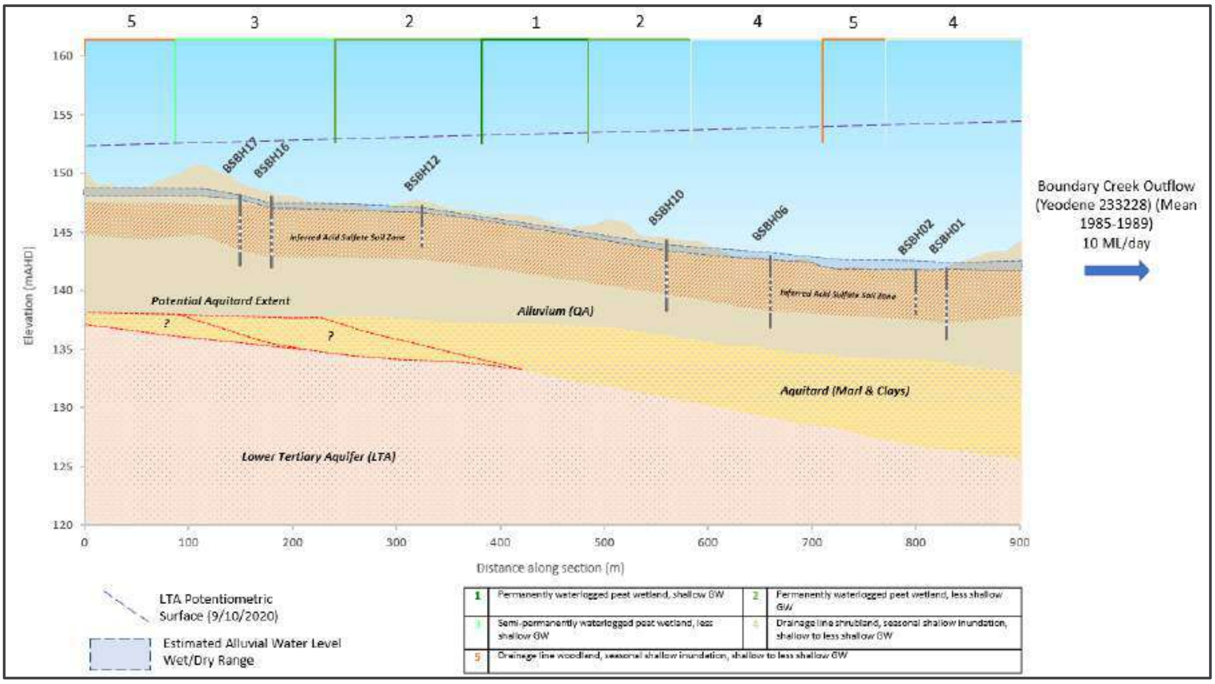


Figure 18: Baseline (pre-impact) conceptual cross section of Big Swamp (CDM Smith 2021)

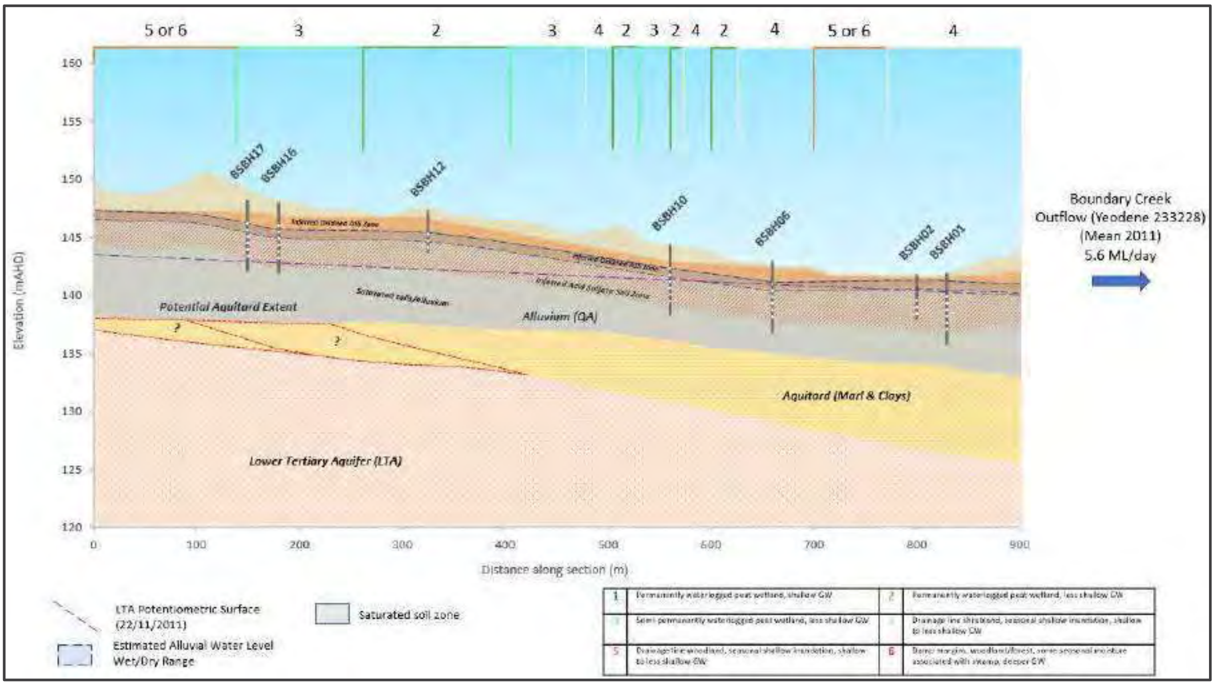


Figure 19: Post-fire event (2011) conceptual cross section of Big Swamp (CDM Smith 2021)

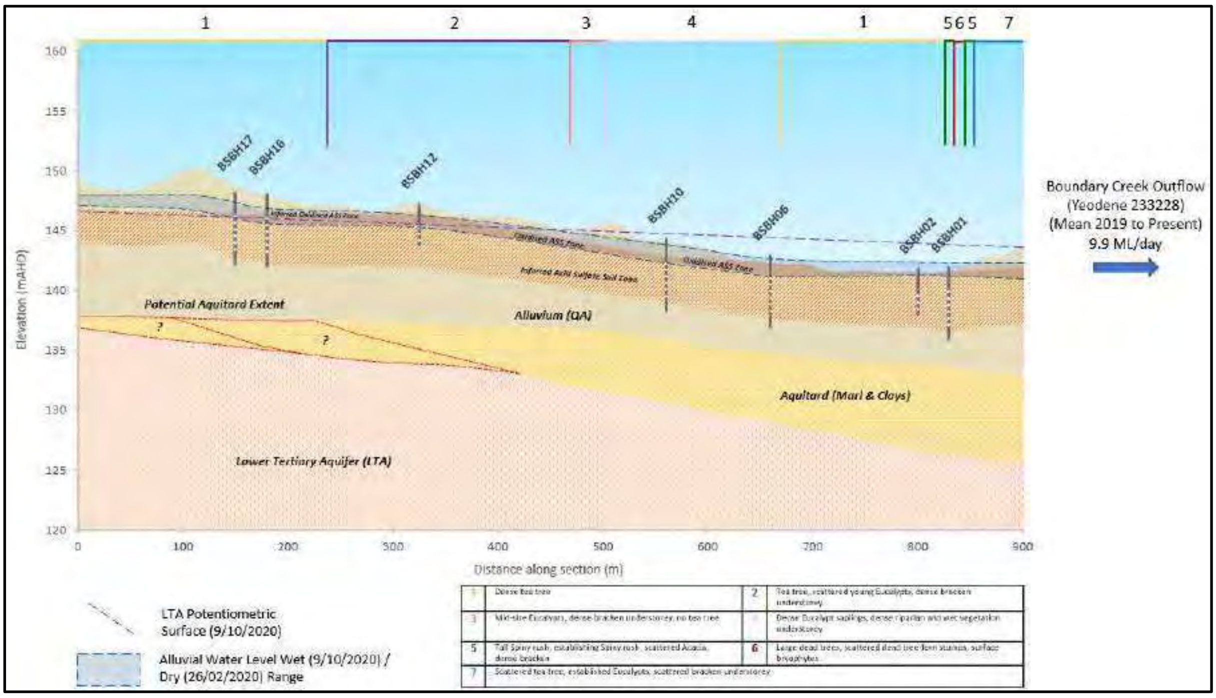


Figure 20: Current (post-impact 2019/20) conceptual cross section of Big Swamp (CDM Smith 2021)

Table 7: Summary of information used by CDM Smith to inform conceptualisation process (CMD Smith 2021)

Success targets assessed	Change to system	Problem statement	Adequate information to support problem statement (Y/N)	Adequate information to predict the trajectory of success target? (Y/N)
Recovery trend for groundwater levels in the LTA as measured in observation bores 64229, 64236, 82844,109131	Decreased water levels in the LTA and increased fluctuation in the water table surface (changes in soil saturation)	Groundwater abstractions coupled with drier climatic conditions (i.e. reduced recharge) have led to the decrease in water levels within the LTA	Y	Y
No further encroachment of terrestrial woodland into the swamp plain	Severe impacts on soil properties, surface microtopography, channel incision, decline in wetland vegetation and drying of perched aquifer has led to a collapse of the original wetland into a simplified/homogenised state, dominated by a handful of invasive native (woody) and exotic species	System now locked in a degraded state due to the above combination of impacts and will not likely recover unless there is intervention to restore hydrology (to the extent possible) and remove invasive plants to encourage wetland regeneration	Y	Y
No encroachment of Lowland Forest dominant species into areas of Damp Forest	To the extent that the drying of the swamp and fire encroached into areas of fringing damp vegetation, there has also likely been a similar mass yet patchy recruitment of Swamp Gum (and possibly other eucalypts) in this vegetation unit that similarly could have the effect of driving canopy closure.	This 'canopy thickening' process could serve to drive further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance) and will not recover unless there is intervention to restore hydrology (to the extent possible) and (where appropriate) possibly manipulate canopy structure to encourage understorey regeneration	Y	Y
No loss of structural or floristic diversity along the main channel and western end of the swamp	To the extent that the drying of the swamp and fire has also encroached into areas of fringing Drainage line Woodland vegetation, it is likely there has also been impacts of 'canopy thickening' and a drying out of the wettest sections that support some mesic specialist species	These impacts could drive even further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance) and will not recover unless there is intervention to restore hydrology (to the extent possible) and (where appropriate) possibly manipulate canopy structure to encourage understorey regeneration - especially those patches of mesic specialists	Y	Y
Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges	Severe impacts on soil properties, surface microtopography, channel incision, wetland vegetation destruction and drying of perched aquifer has led to a collapse of the original wetland into a simplified/homogenised state dominated by a handful of invasive natives (woody) and exotics and little or no regeneration of the original diversity of mesic specialists	System now locked in a degraded state due to this combination of impacts and will not likely recover unless there is intervention firstly to restore hydrology (to the extent possible), secondly to create a suitable ground level micro-environment (for seed/propagule dispersal and recruitment of mesic specialists), and thirdly actively reintroduce these wetland species should initial 'passive' strategies prove ineffective	Y	Y
Maintain monitoring bore water levels at individual bores within Big Swamp above target water levels: • BH01 – water level above 0.7m bgl • BH02 – water level above 1.2m bgl • BH03 – water level above 1.6m bgl • BH04 – water level above 0.6m bgl • BH05 – water level above 1.0m bgl • BH06 – water level above 1.0m bgl • BH07 – water level above 0.4m bgl • BH08 – water level above 0.4m bgl • BH09 – water level above 1.5m bgl • BH10 – water level above 2.0m bgl • BH11 – water level above 1.5m bgl • BH12 – water level above 1.2m bgl • BH14 – water level above 0.15m bgl • BH15 – water level above 0.2m bgl • BH16 – n/a • BH17 – n/a • BH18 – water level above 0.2m blg	Decreased water levels within the QA	Groundwater abstractions and swamp fires coupled with drier climatic conditions have led to a decrease in water levels within the QA at Big Swamp	Y	Y

Success targets assessed	Change to system	Problem statement	Adequate information to support problem statement (Y/N)	Adequate information to predict the trajectory of success target? (Y/N)
At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years	A reduction in average streamflow through Boundary Creek at Yeodene by around 3.4 ML/d from a flow of 10.6 ML/d circa 2002 to around 6 ML/d post 2002 Increased duration and frequency of flow cessation through Boundary Creek at Yeodene	Depressurisation of the LTA coupled with drier climatic conditions has led to decreased water levels within the QA which in turn has decreased average streamflow in Boundary Creek due to less water being gained from the QA	Y	Y
Annual median pH equal to or greater than 6.5 at Boundary Creek at Yeodene stream gauge (stream gauge 233228) maintained for a period of 2 years	A sharp decrease in average pH from Boundary Creek decreasing from a median of 6.5 circa 1990 to a median of 3.8 post 2000	Groundwater abstractions coupled with drier climatic conditions has led to drawdown of water levels in the QA and exposure of ASS to oxygen leading to the generation of acid rock drainage and a decrease in the pH of Boundary Creek	Y	Y

Evaluation of remediation strategy control measures

Table 8 presents a summary of the CDM Smith assessment of the effectiveness of the remediation actions and control measures for achieving the remediation success targets. The summary includes an assessment of the linkages between the control measures and the success targets as well as detailing the suitability of the control measures in achieving the Success Targets. From the assessment of the control measures CDM Smith concluded the following:

- All the control measures are considered suitable to achieve the success targets
- For every success target to be realised, all control measures (excluding control measure No. 6) will need to be implemented, i.e. construction of hydraulic barriers alone will not improve the condition of the swamp and is dependent on receiving supplementary flows, infilling of fire trenches/ agricultural drains as well as undertaking additional works to prevent the encroachment of dry vegetation species into the swamp
- The implementation of the barriers may reduce peak Boundary Creek flows at Yeodene stream gauge and prolongs periods of low to no flow during the dry period
- There is likely an adverse effect cause to the ecohydrology success targets by implementation of the hydraulic barriers due to the level of inundation in the swamp (i.e. more than 30
- Based on the interdependencies there is a sequence in which the success targets will be reached, therefore, the timing of reaching success targets needs to be considered appropriately and in accordance with each success targets influence on others (e.g. ecohydrology success targets cannot occur until the full effectiveness of inundation from the barriers is obtained)

A cross section (West to East) across the swamp showing the predicted remedial environment (in approximately 10 years' time) is presented in Figure 21, while Figure 22 shows the predicted vegetation pattern following implementation of remediation actions.

Table 8: Summary of outcomes from evaluation of effectiveness of remediation outcomes in achieving current success targets (CDM Smith 2021)

Control measure	Effect on success target								Control measure suitable? (Y/N)
	Recovery trend for groundwater levels in the LTA	No further encroachment of terrestrial woodland into swamp plan	No encroachment of Lowland Forest dominant species into areas of Damp Forest	No loss of structural or floristic diversity along the main channel and western end of the swamp.	Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges	Maintain monitoring bore water levels at individual bores above target water levels	At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	
1. Continued delivery of supplementary flow to Boundary Creek to maintain 0.5 ML/day in Reach 3 of Boundary Creek all year round	May provide increased recovery trend due to recharge of LTA from supplementary flow	Encroachment of invasive natives and exotics has already occurred and their continued dominance is unlikely to be impacted by this control measure alone	Encroachment of invasive natives and exotics has already occurred and their continued dominance is unlikely to be impacted by this control measure alone	This supplementary flow will assist in maintaining wetland vegetation in the main channel but will likely require additional measures to be achieved	Flow through Boundary Creek and swamp required to maintain swamp vegetation such as ferns and sedges, although additional measures may be needed	Current supplementary flows assist in maintaining majority of eastern monitoring bores above target water levels	Surface water modelling indicates increases to supplementary flow is effective in increasing the flow at Yeodene stream gauge, however, flows greater than the maximum daily allowance may need to be released in order to meet the success target 100% of the time	Potential to indirectly reduce the pH downstream of Big Swamp through increased 'wetting' of the QA and reduction in the amount of ASS exposed	Yes, control measure considered vital in providing flow to inundate swamp
2. Construction of hydraulic barriers	Potentially may increase recharge to underlying HSUs from increased inundation	Encroachment of invasive natives and exotics has already occurred and the barriers will be only partly effective in reversing this process	Encroachment of invasive natives and exotics has already occurred and their continued dominance will likely not be impacted (by this control measure)	The barriers will have minimal impact on this target	Encroachment of invasive natives and exotics has already occurred and the barriers will be only partly effective in reversing this process	Maintains all monitoring bore water levels above target water levels except BH18 and reduces the variability in water levels across all monitoring bores	Reduces peak Boundary Creek flows at Yeodene stream gauge and prolongs periods of low to no flow during the dry period	Inundation of the swamp will lead to increased water levels within the QA and decreased variability in water levels preventing the exposure of ASS and acidification of the water downstream of Big Swamp	Yes, control measure may require additional refinement to allow for water levels within BH18 to rise above current water level target
3. Infilling of existing fire trenches and agricultural drain	N/A	Encroachment of invasive natives and exotics has already occurred and their continued dominance will not be impacted (by this control measure)	Encroachment of invasive natives and exotics has already occurred and their continued dominance will not be impacted (by this control measure)	The infilling will have minimal impact on this target	The infilling will have minimal impact on this target	Increases water level flow through the swamp increasing ponding and thereby water levels within the QA, however, reduces water levels within the southern and northern portions of the swamp. Note the effect of this control measure alone, i.e. without barriers is unknown	Likely reduces the flow of water through the channels and Boundary Creek as a result of greater water flows being diverted through the swamp area and losing to the QA	Potential to indirectly reduce the pH downstream of Big Swamp through increased 'wetting' of the QA and reduction in the amount of ASS exposed. However, this is not supported by modelling.	Yes, necessary to prevent further erosion and channelisation in big swamp while providing greater flow of water though the swamp.
4. Prevention of encroachment of dry vegetation classes (e.g. Swamp Gum) in Big Swamp to provide suitable conditions for wetland species to recolonise disturbed areas.	N/A	Will reverse the encroachment process (esp. trees and larger shrubs)	Will reverse the encroachment (canopy densification) process (esp. trees and larger shrubs)	May partly contribute to maintaining diversity in this area	May partly contribute to increasing diversity (ferns and sedges)	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further may assist in preventing further decline in QA water levels	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further leaving additional water within the Swamp system which may induce groundwater gaining to Boundary Creek	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further may assist in preventing further decline in QA water levels and thereby less exposure of ASS	Yes, control measure considered vital to prevent further decline in swamp terrestrial ecology
5. Ongoing data collection to inform the adaptive monitoring approach	No direct effect, however, considered crucial in measuring the success of the target and the effectiveness of other control measures in changing the eco-hydrological environment								Yes
6. Additional data collection and testing to inform the feasibility of the other contingency options	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Suitable as a contingency measure, however, does not provide any effect on current success targets

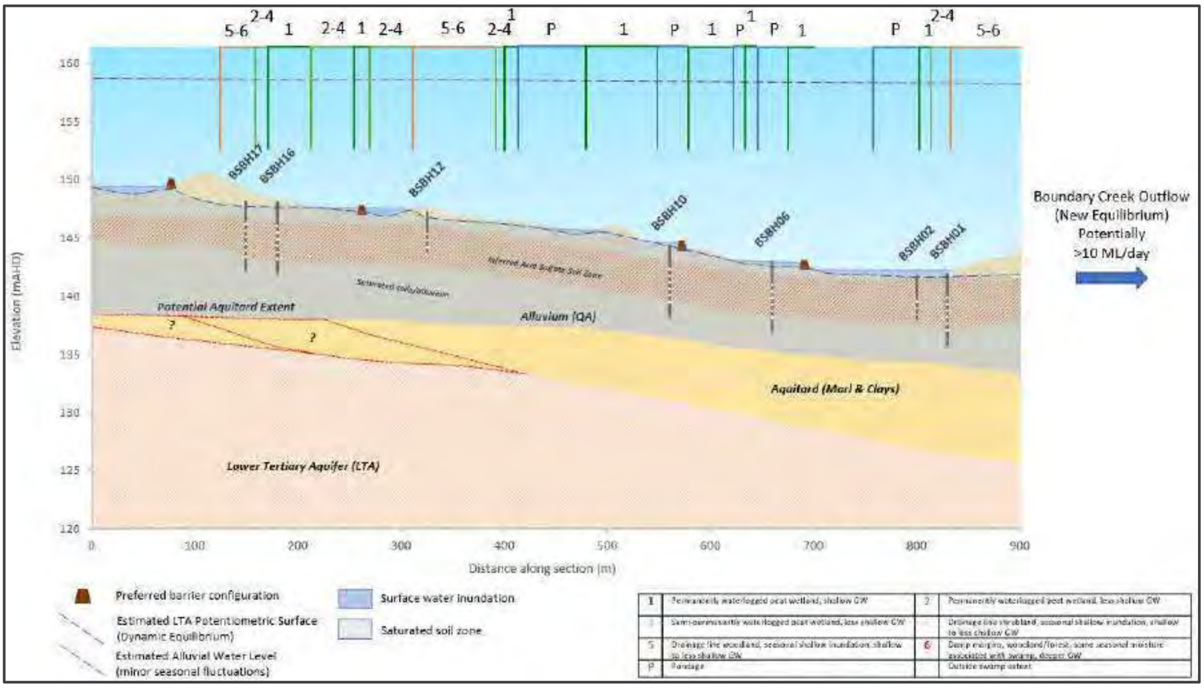


Figure 21: Conceptual cross-section of Big Swamp post remediation (CDM Smith 2021)

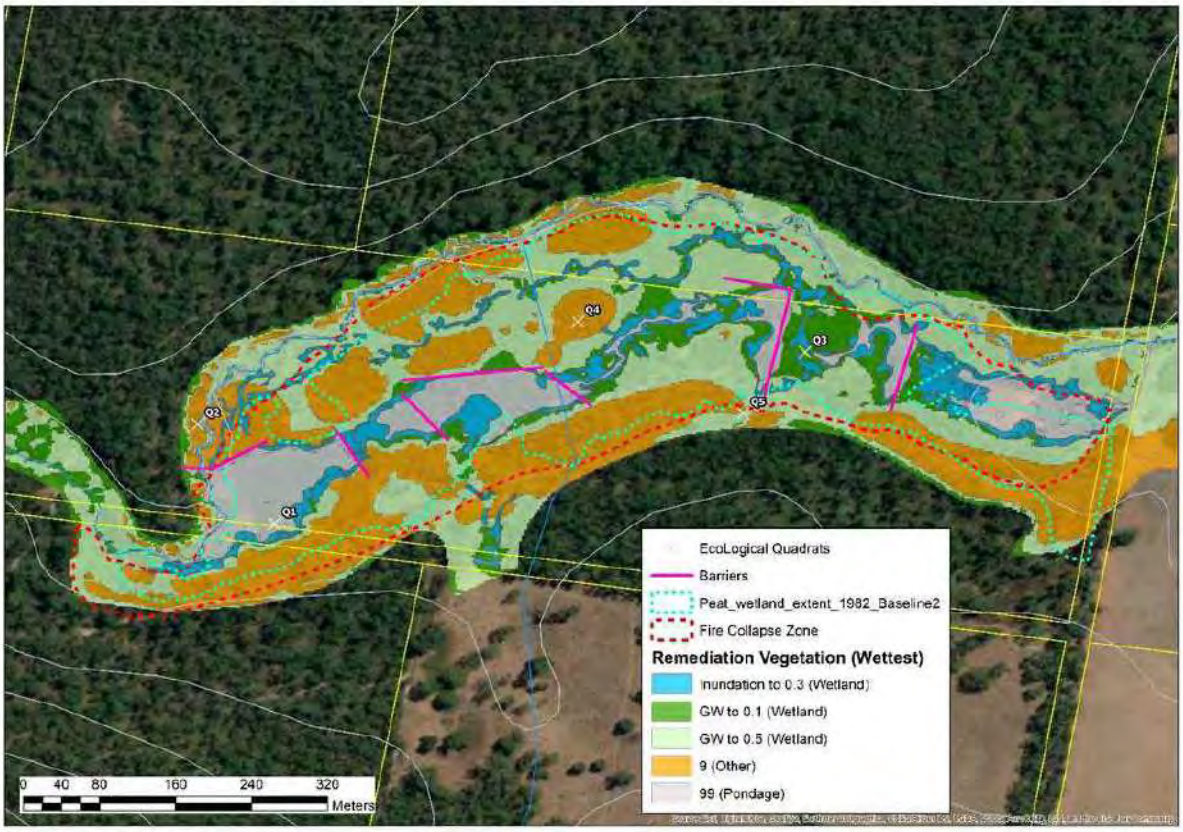


Figure 22: Predicted vegetation pattern following implementation of remediation actions (based on inundation extent for wettest period) (CDM Smith 2021)

Evaluation of remediation success targets

Recommendations

Each of the targets have been evaluated against the conceptual understanding, available data and completed investigations. Based on the outcomes of the review undertaken, Table 9 summarises the revised remediation success targets, along with CDM Smith recommendations for additional monitoring to assist in increasing the conceptual understanding of Big Swamp and allow for the effective implementation and measurement of the proposed success targets.

CDM Smith have also recommended giving consideration of the following:

Monitoring and Evaluation Vegetation

The proposed success targets for vegetation are aligned with the predicted area of groundwater depth <50 cm, and how relevant species and inundation occurs within that zone. Monitoring transects need to be aligned with the zones of future depth to water table, as well as to transitional zones between existing vegetation units. It is recommended that a review of current location of transects occur to identify the most suitable locations that cover the areas where expected hydrological and species change coincide. In addition, it is possible to calibrate high resolution remote sensing data (i.e Sentinel 2, 5 metre resolution) to the current vegetation units (using field based transects), and use the time series capacity (every 5 days) to spatially map changes in eco-hydrogeological zones. The advantage of the remote sensing approach is that it provides a very efficient (time and cost) way of providing a time series measure of the success targets, that can be supported by annual field-based assessments. The outcome would be a direct linkage between changes in vegetation and changes in the sub soil saturation.

Monitoring and Evaluation Soil Saturation and soil carbon

The assessment of the eco-hydrogeology of the swamp has identified that a critical component of successful remediation is the establishment of a suitable root zone hydrology and soil characteristics. There is a lack of data on the saturation of the surface soil of the wetland and how this may act to provide a suitable root zone environment for the establishment of mesic specialists. If a suitable root zone is not developed through the remediation actions, then success targets pertaining to specific vegetation may not occur, irrespective of all other success targets.

Consideration should be given to proposing a new success target focused on:

- Root zone conditions. It is fundamentally associated with the realisation of the modelled future depth water table and extent of surface inundation, as this process equates to a saturated root zone. What is unclear is how effective the modelled shallow water table zones, groundwater <50cm, are at saturating the root zone.
- Soil carbon accumulation. A feature of the pre-impacted swamp and a necessary requirement of the root zone environment for swamps species is a top soil that is high in organic matter (as opposed to surface organic trash). This organic matter is a component of peaty wetland soil structure and water holding capacity that especially mesic species require. As discussed, the fire event would have burnt and or removed this organic material, it is anticipated that the re-hydration and establishment of preferred wetland species will to some degree begin the accumulation process of carbon.

A combination of hand-held EM surveys, site observations, soil sampling along set transect and/or remote sensing data to monitor soil saturation and soil carbon could be used to confirm soil saturation is occurring and that soil carbon is being accumulated. This data would also be effective in a semi calibration assessment of the model predictions.

Macro-invertebrate Success Target.

A measurable component of the health of a swamp are macroinvertebrates. However, it is understood that no baseline data for the swamp exist, with the possible exception of upstream and downstream monitoring, to evaluate the current condition and trajectory of the species.

It would be possible through literature review and or sampling similar swamps to determine a baseline species list and abundance, in line with the expected hydrology and vegetation of the swamp. Sampling bi-annually within the swamp could provide data on how effective remediation efforts are in enabling macro-invertebrate population to re-establish towards a defined local baseline.

It is therefore recommended that consideration be given to performing baseline studies to establish an expected trajectory of macro-invertebrates. Once this is established, metrics against species and abundance could be derived and used to set a Success Target.

Reach 2 Boundary creek

It is acknowledged that the impact of groundwater pumping, millennium drought and acidification of the swamp will have had a negative impact on the values within the water way of Reach 2 of Boundary Creek. While no specific success targets for values within Boundary Creek are currently specified, existing success targets regarding the LTA, alluvial aquifer, pH and flows in Boundary Creek at the Yeodene gauge provide some measure of support for the values in the creek.

Site specific success targets for the creek at this stage are considered problematic, as the current condition of the creek is subject stressors that are not associated with the management of the swamp and the aquifers, for example, grazing, pugging and pollution from stock. Unless theses stressors are controlled and or managed, proposed actions or success targets will be difficult to achieve.

It is recommended that a waterway management plan is developed for the creek (noting this is outside the scope of this report) that aims to in general boost the resilience of the creek's values, by controlling erosion, stock access and weeds. Once this is in place, consideration can be given to whether additional onsite actions and or management is required and or appropriate.

Data collation and analyses

In addition to the recommendations that are related to specific targets, the ongoing monitoring and evaluation requires the development of two specific pieces of work. One is in regards to the water balance in the swamp and the second is in regards to effectively assessing the monitoring data and how these data relate to achieving the success targets. The works are:

1. Development of a wetland water budget. This will involve estimates of groundwater evapotranspiration, rainfall recharge, hyporheic exchange (i.e. bank storage scale), vertical and horizontal fluxes in/out of Big Swamp. This will provide an ongoing monitoring tool to assess the achievement of the success target. The water budget should be temporally developed in a format

such that as new data is collected the overall shift in water in, outs and consumption within the wetland is determined at least bi-annual scale.

2. In addition, a graphical interface could be developed that shows the current tracking of success targets spatially and through time. This interface provides a single portal by which Barwon Water are able to review and present the outcomes of future monitoring of success targets. The interface may also provide a report card style assessment of how well success targets are tracking, providing a high-level risk appraisal regarding Barwon Waters requirements.

Next steps

In line with the REPP Governance Framework and following consideration of feedback received from SRW, ITRP and RRG, the revised success targets will need to be submitted as proposed amendments to the REPP and accepted by SRW prior to being formally adopted.

Table 9: Summary of recommended success targets, additional monitoring and control measures

Functional Group	Current success target	Recommended success target	Additional monitoring and control measures
Lower Tertiary Aquifer	Recovery trend for groundwater levels in the LTA	Recovery of regional LTA hydraulic heads such that vertical hydraulic gradients between LTA and overlying HSUs reach stable hydraulic gradients (i.e. at nested observation bores to be identified through the surrounding environment investigation)	Continued monitoring of hydraulic heads to confirm recovering hydraulic head trends Based on the outcomes of the Surrounding Environment Investigation, identify locations of nested monitoring bores for comparison of vertical hydraulic gradients between LTA and overlying HSUs (at varying distances from the borefield to show spatial distribution of relative vertical hydraulic gradient stabilisation)
		LTA bores immediately to the west of the swamp (109113, 109132, 109131) to have hydraulic heads greater than 150 mts (elevation of western edge of the swamp) and LTA bore TB1c, greater than 143 mts (elevation of the eastern edge of the swamp) Recovering LTA hydraulic heads in vicinity of Big Swamp (i.e. BH01-PB, TB1c, 109113, 109132, 109131) to be higher and remain higher than the surface elevation of the swamp within 10 years.	Continued monitoring of LTA hydraulic heads further develop understanding of relationships between LTA, shallow groundwater systems and environmental values Detailed groundwater mass balance and revision of hydrogeological conceptualization of Big Swamp using multiple lines of evidence (i.e. first principles) to better establish context for role of LTA in supporting the shallow groundwater system and alluvial success targets, analysis may include: • Comparison of LTA hydraulic heads in the vicinity of Big Swamp with shallower HSUs to better establish the 3-dimensional relationships between LTA recovery and the shallow groundwater system • Evaluation of Boundary Creek losses (Reach 2) using multiple approaches to constrain differencing error between flow gauges (e.g. seasonal differential flow gauging with ~250 m spacing & development of flownets comparing LTA heads to creek stage) to better characterize the role of recovering LTA hydraulic heads on Boundary Creek flow into Big Swamp • Development of multiple hydrostratigraphic cross-sections to represent spatial and temporal variability of shallow groundwater system
Quaternary Aquifer	Maintain monitoring bore water levels at individual bores above target water levels	Maintain monitoring bore water levels at individual bores above target water levels: • BH01 – water level above 0.7m bgl • BH02 – water level above 1.2m bgl • BH03 – water level above 1.6m bgl • BH04 – water level above 0.6m bgl • BH05 – water level above 1.0m bgl • BH06 – water level above 1.0m bgl • BH07 – water level above 0.4m bgl • BH08 – water level above 0.4m bgl • BH09 – water level above 1.5m bgl • BH10 – water level above 2.0m bgl • BH11 – water level above 1.5m bgl • BH12 – water level above 1.2m bgl • BH14 – water level above 0.15m bgl • BH15 – water level above 0.2m bgl	Undergo analysis of geology at individual bores to determine the individual bore response to inundation and possible reconfiguration of the hydraulic barriers to increase the water level within BH18. BH18 is currently not modelled to reach target in GW-SW model. The current barrier configuration elevates the ponding level around BH18 as high as practically feasible (GHD 2020). To achieve the target the barrier heights would require a significantly higher barrier and create excessive ponding in adjacent areas. As such it has currently been excluded as a success target but will continue to be monitored.
Ecohydrology	No further encroachment of terrestrial woodland into the swamp plain	No further encroachment of terrestrial woodland into the swamp plain (Units 1 to 4) with a target of zero tree cover on the swamp plain (vegetation units 1-4)	Active removal of trees (mostly Swamp Gum regrowth) from across the 'swamp plain' (Units 1 to 4) (cutting, removal and poising as needs be) irrespective of rehydration extent (metric = cover of trees on swamp plain (units 1-4) should be zero). Also mass tree recruitment likely episodic linked to conditions immediately following fire (ash bed and generally dry soil surface) – this is unlikely to happen again on any significant scale as long as soils not exposed. Prevention of further encroachment by re hydrating the swamp, reducing the surface environmental suitability for woodland species encroachment
	No encroachment of Lowland Forest dominant species into areas of Damp Forest	No encroachment of Lowland Forest dominant species into areas of Damp Forest (Unit 6) through maintaining canopy cover at 10-30%	Active monitoring of canopy cover and as required thinning of trees from Unit 6 (Damp margins Woodland/Forest with mostly Swamp Gum regrowth) to encourage understorey recovery and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery (metric = maintain %cover of canopy at 10 to 30%) Establishment of suitable canopy cover and maintain suitable micro conditions
	No loss of structural or floristic diversity along the main channel and western end of the swamp	Establishment of suitable canopy cover of between 10-30% in vegetation unit 5 to maintain the diversity and abundance of mesic specialist species	Active monitoring of canopy cover and as required thinning of trees from Unit 5 (Drainage line Woodland with mostly Swamp Gum regrowth) to maintain understorey condition and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery (metric = maintain %cover of canopy at 10 to 30%) Maintenance of adequate flows along the main channel currently supporting Unit 5 (Drainage line Woodland) (define levels?? metric = Say 2 to 20 ML/Day) Monitor the diversity and abundance of mesic specialist species in Unit 5 (e.g. Blechnum nudum, Todea Barbara, Carex fascicularis, Melaleuca squarrosa, Lobelia beaugleholei) and consider active recovery works if local populations are threatened. Other rare mesic specialist species within this system that could be considered for monitoring and active recovery works include: Cardamine tenuifolia, Eucalyptus brookeriana. If populations of the remaining rare or threatened species (Monotoca glauca, Bossiaea cordigera, Pterostylis lustra) recorded in similar habitat nearby are found within the swamp and associated section of Boundary Creek, these too could be considered for monitoring and active recovery works as appropriate.

Functional Group	Current success target	Recommended success target	Additional monitoring and control measures
	Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges	Rehydration of the area covered by vegetation Units 1 to 4 of at least 54% to allow an increase diversity of understory species within the swamp plain, with a focus on ferns and sedges.	Rehydration of the soil profile across as much of the original swamp (Units 1 to 4) is possible using the strategically placed bunds/weirs. This reinstates a water regime at the land surface and in the soil profile that is consistent with that for 'Riparian Fern Scrub' (where rehydration involves waterlogging with fresh water for at least > 6 months and duration of inundation up to 6 months and water depth is very shallow <30 cm;. Frood and Papas 2016). As per **Error! Reference source not found.**; **Error! Reference source not found.** in Appendix C; modelled at ~54%. Micro-environment: shading from trees and taller invasive shrubs; cut and remove regrowth trees (and larger shrubs); possibly also slash bracken and dense lower vegetation to provide recruitment space and opportunity; No soil disturbance At least within the rehydrated zones, active regeneration of as many mesic specialists (in as many of the most diverse lifeforms – Forbs, Ground/Tree Ferns, Aquatic Herbs, Rushes and Sedges) as possible (metric = diversity of mesic specialists lifeforms and species) aiming for a combined cover of >50% (metric = combined cover of mesic specialist lifeforms and species) and active reduction/removal of weeds and other native ruderals (including trees like Swamp Gum). If natural regeneration of at least some species in each lifeform category do not spontaneously regenerate, then measures should be taken to actively reintroduce them.
Hydrology	At least 0.5 ML/day flow maintained at Boundary Creek at Yeodene stream gauge maintained for a period of 2 years	At least 0.5 ML/day flow maintained at Boundary Creek at Yeodene stream gauge maintained for a period of 2 years.	Revisit the success target based on continued monitoring data once other success targets have been realised
Hydrochemistry	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	Revisit the success target based on continued monitoring data once other success targets have been realised

Appendices

Appendix A

Big Swamp Integrated Groundwater-Surface Water, Modelling for Detailed Design, Technical Modelling Report

Barwon Water

Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design

Technical Modelling Report

April 2021

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1. Introduction

1.1 Purpose of this report

Big Swamp is a peat swamp located along Boundary Creek, which forms a tributary of Barwon River. The swamp comprises of pyritic sediments that form potential acid sulfate soils where the soils are waterlogged. The reduced flow along Boundary Creek due to a combination of drier climate, groundwater extraction from the Barwon Downs borefield and ineffective regulation of passing flow has led to the lowering of the water table in Big Swamp and activation of acid sulfate soils.

The Remediation and Environmental Protection Plan (REPP) developed for Boundary Creek, Big Swamp and surrounding environment outlines remedial works to stabilise the acidification process and improve the water quality of Big Swamp. These include controlled release of supplementary flow and construction of a series of hydraulic barriers to improve surface water connectivity across the swamp. In order to inform the detailed design of the remediation system, surface water and groundwater modelling is required to quantify the potential effectiveness of different flow regimes and barrier configurations on maintaining the water table in Big Swamp. This report details the findings of integrated surface water – groundwater modelling undertaken to meet this objective.

1.2 Modelling methodology

1.2.1 Modelling objectives

The overarching objective of the modelling is to inform the detailed design of the preferred remediation strategy of the Boundary Creek and Big Swamp system, specifically the hydraulic barrier configurations, supplementary flow regimes and their potential effectiveness in maintaining the water table within the swamp and flow downstream of the swamp.

The achieve this intended model use, the modelling is required to:

- simulate the existing hydrological and hydrogeological processes that are critical to understanding the effectiveness of the remediation strategy, including:
  - the extent, depth and duration of surface water inundation and associated effects on shallow groundwater levels.
  - rainfall recharge and evapotranspiration dynamics and influence of climate on the shallow groundwater system.
  - inter-aquifer connection, such as the rate and direction of leakage to/from the underlying Lower Tertiary Aquifer.
- simulate the interaction between the hydraulic barriers and surface water – groundwater systems, including changed extent, depth and duration of surface water inundation and associated effects on groundwater levels.
- simulate the interaction between Boundary Creek and groundwater, including the effect of supplementary flow regimes on maintaining flow within the swamp and immediately downstream.

The modelling detailed in this report has been commissioned to address specific design related questions such as the number, location and height of barriers that may be required to effectively redistribute surface water flow through a swamp that has a dimension of approximately 250 m by 800 m. The performance of the remediation strategy is also assessed against target groundwater levels set at monitoring bores that are located in close proximity to each other, with spacing as little as 25 m. This means the modelling must be of local scale, with fine grid resolution in critical areas and sufficiently flexible parameterisation to capture subtle spatial variability and associated uncertainty.

1.2.2 Modelling process

The integrated modelling described in this report has been undertaken in accordance with the staged approach of the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). A project inception and model planning meeting was convened at the start of the project to clarify the scope, objectives and expectations of the modelling. This was followed by the conceptualisation, model design and construction, calibration, predictive modelling and uncertainty analysis. The report has been structured to reflect this staged approach, with each chapter aligned with the key stages of the modelling process.

1.3 Scope and limitations

This report: has been prepared by GHD for Barwon Water and *may only be used and relied on by Barwon Water for the purpose agreed between GHD and the Barwon Water as set out in section 1.2 of this report.*

GHD otherwise disclaims responsibility to any person other than Barwon Water arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (in various sections). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Barwon Water and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

2. Hydrological and Hydrogeological Conceptualisations

2.1 Purpose of conceptualisation

The general hydrology and hydrogeology of the Boundary Creek catchment and Big Swamp have been documented extensively in prior studies completed by Barwon Water (Jacobs, 2016, 2018a, 2018b, 2019a, 2019b, GHD, 2019). The purpose of hydrological and hydrogeological conceptualisations presented in this section is specific to the needs of the modelling that is the subject of this report and include targeted discussions on:

- Key updates to the existing hydrological and hydrogeological knowledge base, informed by additional data collected and findings from relevant scientific studies that have become available since the earlier studies were completed.
- Features of conceptual model that are of importance to the key model predictions of interest, and hence for strategically informing the design and attributes of the numerical models, including:
  - Hydrostratigraphy of Big Swamp, to inform model structure such as model mesh, layering and material properties.
  - Key hydrogeological processes and their significance, to inform model boundary conditions and sink/source terms. In particular, the elements of the hydrology and hydrogeology have not been sufficiently developed to date given the acid generation-specific objectives of the modelling.
  - Hydrogeological response time, to inform temporal discretisation (stress periods) and flow processes (saturated/unsaturated flow).
  - Inter-aquifer connection and the potential influence of piezometric head changes in the underlying Lower Tertiary Aquifer (LTA).

2.2 Hydrological conceptualisation

The hydrology has been conceptualised in terms of the hydrological processes at a catchment level, and the interactions between catchments, as shown in the following figures.

Catchment interactions

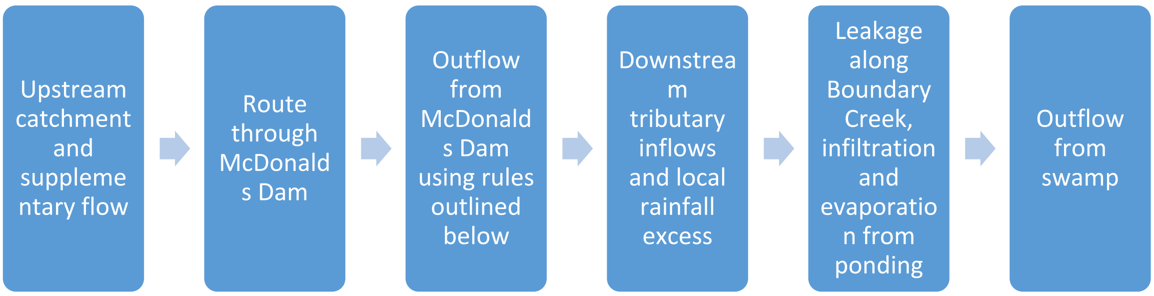


Figure 2-1 Surface water flow conceptualisation

The rules for routing through McDonald's Dam depend on the magnitude of flow, and whether or not it is the harvesting (filling) period for the dam. The decision tree for this is presented in Figure 2-2 below.

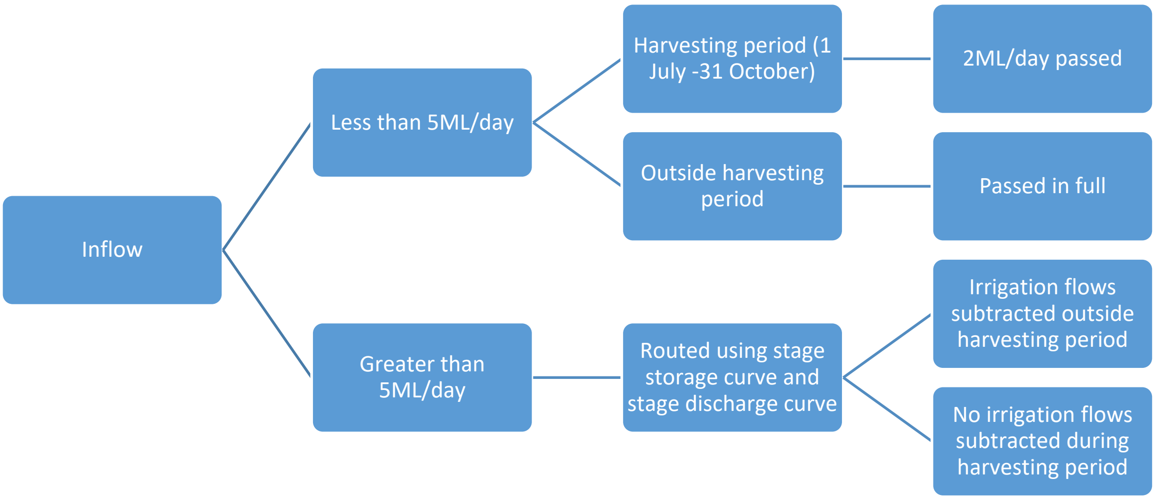


Figure 2-2 **Routing rules through McDonald's Dam**

Hydrological processes within the catchments in the hydrological model

The mechanisms by which flow is generated in the GR4J hydrological model are illustrated in Figure 2-3 following. The model consists of a production store (soil moisture) and routing store. The routing store determines the groundwater exchange, and therefore the total streamflow from the combined direct and routed flow components.

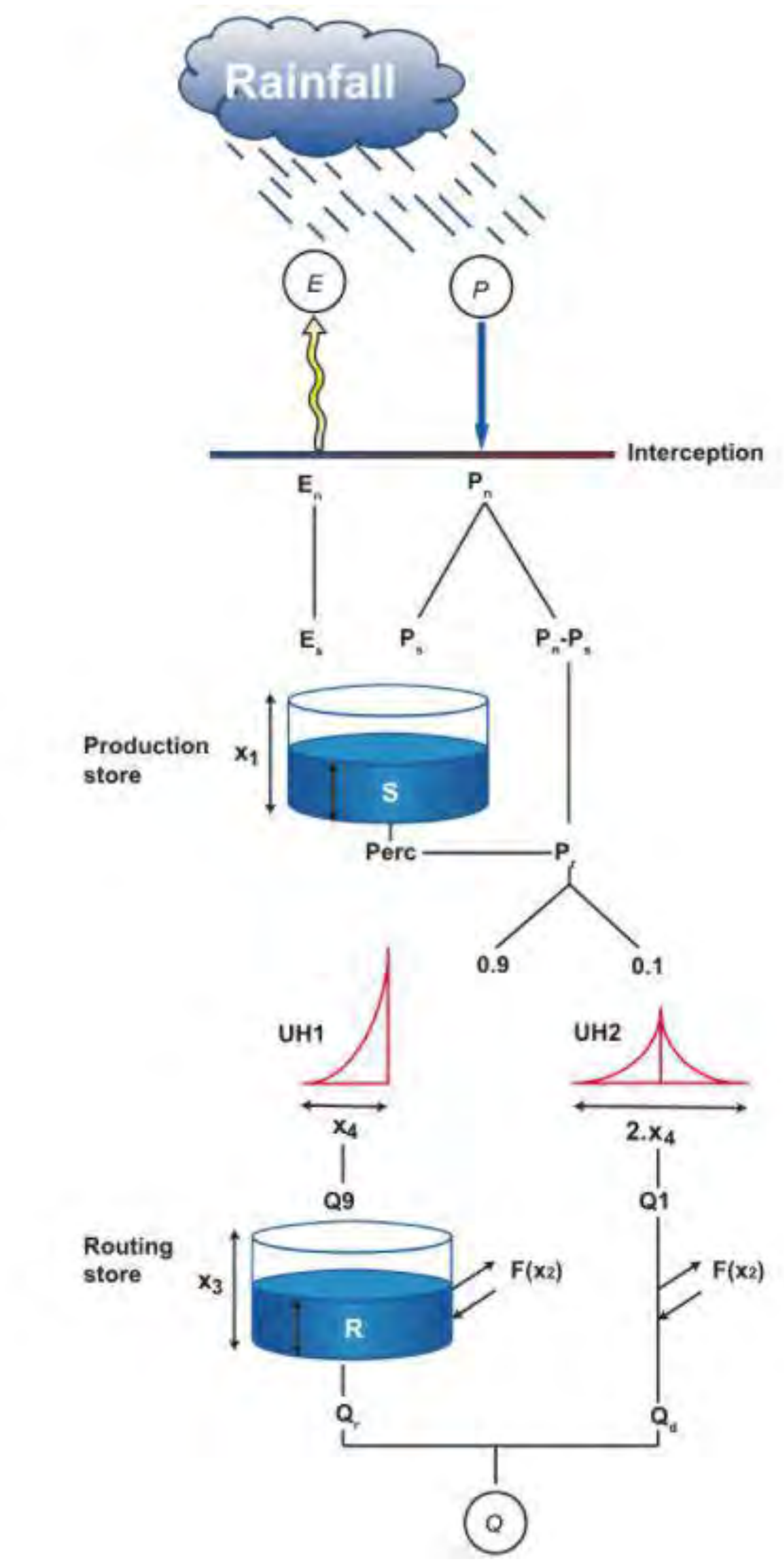


Figure 2-3 GR4J model schematic (from E-Water Source)

Hydrological processes within the hydraulic model domain

The mechanisms by which flow is generated or removed in the hydraulic model domain are illustrated in Figure 2-4.

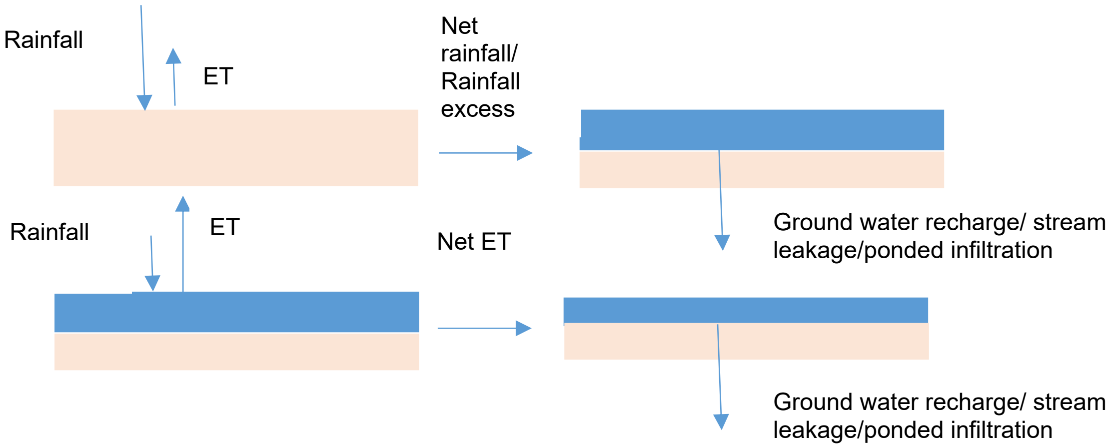


Figure 2-4 Hydrological conceptualisation in the hydraulic model

There are three methods available within TUFLOW to infiltrate water on the 2D surface into the sub-surface. These are Green-Ampt, Horton and Initial Loss/Continuing Loss. The models are used to represent hydrological losses particularly when rainfall is applied directly to the 2D surface and runoff is generated. The infiltration module used, and the parameters selected, are important calibration parameters. The hydraulic conductivity, in conjunction with the initial moisture content, which would be the parameters that are most focused on. The hydraulic conductivity appears to affect the runoff volume throughout the event whereas the initial soil moisture has a limited impact at the beginning of the event before soils become saturated and results converge.

2.3 Hydrogeological conceptualisation

2.3.1 Big Swamp hydrostratigraphy

Aquifer geometry

Big Swamp is located within a narrow alluvial aquifer system, comprising channel-filled sediments associated with Boundary Creek. The width of the alluvial aquifer, as mapped in published geological maps (as sediments of Quaternary age), generally aligns with the topographic valley which is incised into the underlying older strata comprising the Gellibrand Marl (a regional Middle Tertiary Aquitard) and Mepunga/Dilwyn Formation (Lower Tertiary Aquifer). According to published geological maps, the stratigraphic contact between the Gellibrand Marl and Mepunga/Dilwyn Formation occurs approximately in the middle of Big Swamp, traversing in roughly north to south orientation.

Drilling in 2019 confirmed that the alluvial aquifer (hereafter referred to as the Quaternary Aquifer) underlying Big Swamp consists of clay, silt and sand of at least 6 m in thickness. The full thickness of the Quaternary Aquifer (QA) across the swamp is currently not known, although drilling of a nested monitoring site at the downstream end of the swamp indicated predominantly clay formation to a depth of around 26 m. At this location, three nested bores were constructed by Jacobs (2016) at depths of 11.7 m (TB1a), 19 m (TB1b) and 36 m (TB1c). According to Jacobs (2016), bores TB1a and TB1b are constructed in the QA and Middle Tertiary Aquitard (MTD) respectively, although this boundary is not well defined due to similarity in their lithology (potentially demarcated by around 1 m thick coarse sand at 13 m). At depth of 26 m, a coarse sand layer of at least 10 m in thickness was encountered. This defines the top of the Lower Tertiary Aquifer (LTA) within which bore TB1c was constructed.

Drilling records from the state database indicate several bores further upstream of Boundary Creek that were drilled near the creek line to depths ranging from around 15 to 30 m using the mechanical auger drilling method. These bores include 109130, 109143 and 109128 (from upstream to downstream), which are part of the State Observation Bore Network (SOBN) and are indicated to be constructed in the Dilwyn Formation (see Figure 2-12). Lithological logs are not available from these sites, although the information recorded at the time of drilling indicates that these bores were drilled to 17.5 m, 24 m and 30 m. According to Jacobs (2016), bore 109130, furthest upstream, is screened from 8 to 15.5 m, and bore 109143 is screened from 11.5 to 17.5 m. This information suggests that the QA is likely to be <8 m in the upstream reach of Boundary Creek, near McDonalds Dam, and increases in thickness downstream, consistent with the depositional setting of a typical alluvial system.

The FEFLOW groundwater model developed by Jacobs (2019a) assumed a constant nominal thickness of 10 m for the QA along the entire length of the model domain. However, it is more likely that:

- the QA gradually increases in thickness along the length of Boundary Creek and Big Swamp, from less than 8 m adjacent to McDonalds Dam to potentially 14 m in the downstream end of the swamp where the nested monitoring site exists.
- the thickness of QA tapers off towards the edge where it pinches out against the bedrock (LTA/MTD), more consistent with a typical geometry of channel-filled alluvial aquifers.
- the width of the QA at Big Swamp is wide enough to include the nested site TB1, where Jacobs (2016) indicates the QA is at least 12 m in thickness (based on the TB1a bore depth). The QA currently represented in the FEFLOW model does not extend this far.

While a rectangular block of uniform thickness may be considered a reasonable approximation of average geometry, a more realistic representation of the aquifer geometry is considered warranted in this study to better account for the expected changes in aquifer transmissivity and storage along Boundary Creek and towards the edge of the aquifer (see Figure 2-5).

Hydrogeological properties

A key feature of the available data pertaining to aquifer and aquitard hydraulic properties is that they are derived from slug tests, which are generally considered to be of low reliability. Data from other tests such as pumping and packer tests are considered more reliable, but these are not available for this study. The slug test data discussed in this section are therefore useful in broad terms, but their low reliability means wider parameter bounds may be ultimately required during model calibration to adequately replicate the observed hydrogeological response.

The QA comprises predominantly of clay, with minor silts and discrete lenses of sand (which can be up to 3 m along the basal level in some bores). Hydraulic conductivity derived from the analysis of slug tests is variable, ranging from 0.02 to 1.4 m/d with a geometric mean of around 0.2 m/d. There appears to be little relationship between the hydraulic conductivity values derived from slug testing and abundance of sand or clay in a particular bore. This can be seen in Figure 2-6, which summarises the key information from each monitoring bore. For example, low hydraulic conductivity of 0.13 and 0.05 m/d was estimated at BH14 and BH16 respectively despite the presence of 2.5 and 3.2 m of sand and clayey sand respectively. Conversely, the highest hydraulic conductivity of 1.4 m/d was estimated at BH06 comprising predominantly of silty clay.

The implication is that spatial variability in hydraulic conductivity exists within the QA but this cannot be readily associated with a particular lithological material. This means the model should be parameterised to allow spatial variability, albeit without explicit representation of discrete sand and clay lenses as separate model layers which is not feasible based on the lithological data available. As further discussed in Section 2.3.2, the data available from the monitoring bores within Big Swamp capture the net response of the QA at the location of the bores and as such, the groundwater model should be discretised and parameterised at a resolution appropriate for simulating this observed net response (after accounting for the resolution required to satisfy numerical accuracy).

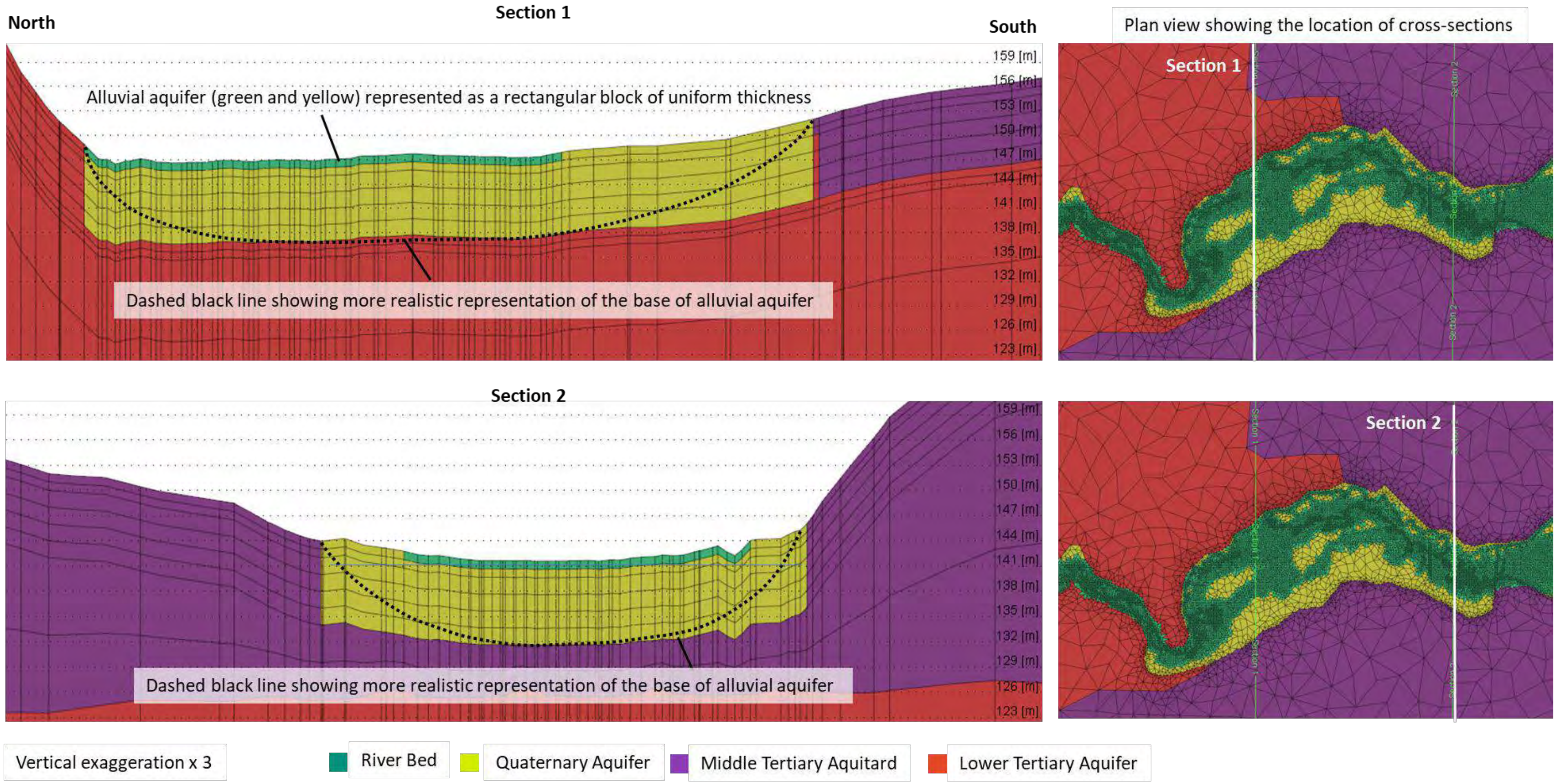
Jacobs (2016) completed slug testing in several bores constructed within the broader Boundary Creek catchment. One of the bores constructed within the QA had a hydraulic conductivity of up to 4.7 m/d (bore Tb2b) and indicates the potential for locally elevated hydraulic conductivity to exist within the QA (e.g. local sand lens). The analysis of data at two bores (A2 and A3) constructed within the MTD downstream of Big Swamp indicates low hydraulic conductivity ranging from 1.8×10^{-5} to 8×10^{-3} m/d. The calibrated hydraulic conductivity of the MTD in the existing FEFLOW model is 7.6×10^{-3} m/d, towards the upper end of this range, although data collected in areas further away from Big Swamp indicates hydraulic conductivity of up to 0.3 m/d (Jacobs, 2016).

For the LTA, slug testing was completed only on bores further to the west of Boundary Creek, with hydraulic conductivity ranging from 9.2×10^{-5} to 0.11 m/d (Jacobs, 2016). Where the bores are shallow and the sand/gravel is abundant, the hydraulic conductivity is generally towards the upper end of this range. The calibrated hydraulic conductivity of the LTA in the existing FEFLOW model is 1.45 m/d, greater than the range reported by Jacobs (2016) from slug testing and is considered to reflect the understanding of hydraulic conductivity from other regional studies. Given the presence of sand at TB1c, high hydraulic conductivity is plausible in the upper part of the LTA in the area of Big Swamp.

Key findings:

- The nominal 10 m thickness assumed in the existing FEFLOW model is considered simplistic and should be modified to account for the thickening of the aquifer along Boundary Creek and Big Swamp, with the aquifer geometry modified from the rectangular block currently assumed to a more realistic channel-filled geometry with some adjustments to its width.
- The QA in the model should be parameterised to allow spatial variability in hydraulic conductivity; however, explicit representation of discrete lenses of clay and sand as separate model layers is not necessary due to the lack of correlation between hydraulic conductivity and sand/clay abundances as well as the discrete nature of lithologic units rendering layer-based representation unsuitable.

Figure 2-5 Big Swamp alluvial aquifer representation in FEFLOW model



Item	BH17
Ground level (mAHD)	148.10
Screen top (mbgl)	1.90
Screen bottom (mbgl)	4.90
Min DTW (mbgl)	0.53
Max DTW (mbgl)	1.94
Average K (m/d)	0.05
Clay thickness (m)	2.00
Silt thickness (m)	0.80
Sand thickness (m)	3.2

Item	BH16
Ground level (mAHD)	147.99
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	1.02
Max DTW (mbgl)	2.29
Average K (m/d)	1.79
Clay thickness (m)	4.10
Silt thickness (m)	0.40
Sand thickness (m)	1.5

Item	BH12
Ground level (mAHD)	147.20
Screen top (mbgl)	1.90
Screen bottom (mbgl)	3.40
Min DTW (mbgl)	0.81
Max DTW (mbgl)	1.60
Average K (m/d)	0.82
Clay thickness (m)	2.20
Silt thickness (m)	NA
Sand thickness (m)	1.2

Item	BH10
Ground level (mAHD)	144.31
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	0.41
Max DTW (mbgl)	1.73
Average K (m/d)	1.26
Clay thickness (m)	4.40
Silt thickness (m)	1.60
Sand thickness (m)	NA

Item	BH05
Ground level (mAHD)	143.08
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	0.00
Max DTW (mbgl)	0.99
Average K (m/d)	0.05
Clay thickness (m)	3.90
Silt thickness (m)	2.10
Sand thickness (m)	NA

Item	BH07
Ground level (mAHD)	142.50
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	-0.56
Max DTW (mbgl)	0.28
Average K (m/d)	0.02
Clay thickness (m)	5.50
Silt thickness (m)	0.50
Sand thickness (m)	NA

Item	BH03
Ground level (mAHD)	141.74
Screen top (mbgl)	2.50
Screen bottom (mbgl)	4.00
Min DTW (mbgl)	-0.53
Max DTW (mbgl)	0.20
Average K (m/d)	0.03
Clay thickness (m)	2.40
Silt thickness (m)	1.60
Sand thickness (m)	NA

Item	BH09
Ground level (mAHD)	144.36
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	0.59
Max DTW (mbgl)	1.46
Average K (m/d)	1.31
Clay thickness (m)	1.80
Silt thickness (m)	4.20
Sand thickness (m)	NA

Item	BH06
Ground level (mAHD)	142.90
Screen top (mbgl)	1.90
Screen bottom (mbgl)	4.90
Min DTW (mbgl)	0.29
Max DTW (mbgl)	1.49
Average K (m/d)	1.44
Clay thickness (m)	4.50
Silt thickness (m)	1.50
Sand thickness (m)	NA

Item	BH18
Ground level (mAHD)	148.72
Screen top (mbgl)	1.50
Screen bottom (mbgl)	3.00
Min DTW (mbgl)	0.52
Max DTW (mbgl)	1.58
Average K (m/d)	NA
Clay thickness (m)	3.00
Silt thickness (m)	0.20
Sand thickness (m)	NA

Item	BH15
Ground level (mAHD)	147.42
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	-0.15
Max DTW (mbgl)	1.24
Average K (m/d)	0.15
Clay thickness (m)	6.00
Silt thickness (m)	NA
Sand thickness (m)	NA

Item	BH14
Ground level (mAHD)	147.67
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	0.82
Max DTW (mbgl)	1.65
Average K (m/d)	0.13
Clay thickness (m)	1.50
Silt thickness (m)	2.00
Sand thickness (m)	2.5

Item	BH11
Ground level (mAHD)	147.09
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	0.65
Max DTW (mbgl)	2.09
Average K (m/d)	0.35
Clay thickness (m)	4.80
Silt thickness (m)	0.30
Sand thickness (m)	0.9

Item	BH08
Ground level (mAHD)	144.62
Screen top (mbgl)	1.90
Screen bottom (mbgl)	4.90
Min DTW (mbgl)	0.51
Max DTW (mbgl)	1.11
Average K (m/d)	0.10
Clay thickness (m)	3.70
Silt thickness (m)	0.30
Sand thickness (m)	2.0

Item	BH04
Ground level (mAHD)	143.37
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	-0.03
Max DTW (mbgl)	0.34
Average K (m/d)	0.09
Clay thickness (m)	0.80
Silt thickness (m)	4.70
Sand thickness (m)	0.5

Item	BH02
Ground level (mAHD)	141.75
Screen top (mbgl)	2.20
Screen bottom (mbgl)	3.70
Min DTW (mbgl)	-0.54
Max DTW (mbgl)	0.26
Average K (m/d)	0.08
Clay thickness (m)	2.50
Silt thickness (m)	1.20
Sand thickness (m)	NA

Item	BH01
Ground level (mAHD)	141.86
Screen top (mbgl)	2.00
Screen bottom (mbgl)	5.00
Min DTW (mbgl)	-0.35
Max DTW (mbgl)	0.40
Average K (m/d)	0.21
Clay thickness (m)	3.80
Silt thickness (m)	2.20
Sand thickness (m)	NA

Legend

Groundwater bore

Paper Size ISO A3

0 20 40 60 80

Metres

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

Barwon Water
Big Swamp Modelling for Detailed Design

Project No. 12536659
Revision No. B
Date 12/10/2020

Big Swamp Bores: Bore Details

FIGURE 2-6

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Print date: 08 Apr 2021 - 18:01

Data source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020; . Created by: bsmyth (tworth)

2.3.2 Hydrogeological processes and response

The objective of the proposed remediation strategy is to maintain the water table within the Big Swamp QA to the required target levels to prevent activation of acid sulfate soils. In order to simulate the effectiveness of this remediation strategy, the groundwater model must be capable of simulating the processes that control the water table elevation i.e. the inflow and outflow components of the QA water balance that control the volume of shallow groundwater. The critical hydrogeological processes are:

- Recharge processes, such as surface water inundation and rainfall-recharge that maintain the water table; and
- Discharge processes such as evapotranspiration and aquifer through-flow, which influence the rate of drainage of shallow groundwater.

Recharge processes

Figure 2-7 compares the depth to water hydrograph of some of the representative monitoring bores against the stream flow data from upstream gauge 233275A. Also highlighted on the hydrographs are distinct flow events and associated spikes observed in groundwater levels. The hydrographs indicate that:

- the groundwater level in the QA rises rapidly following an increase in stream flow, which is expected given the depth to water table preceding some of the high flow events are less than 1 m. This means the unsaturated zone preceding most flow events is generally small, resulting in minimal “lag” in the water table response. Within the context of modelling, this implies that the simulation of unsaturated flow processes (and corresponding high vertical grid resolution in the top 1 m) is unlikely to be critical for replicating the rapid response/water table fluctuation to stream inundation events. This is also relevant under predictive conditions, given that the remediation strategy is designed to maintain the water table to generally within 1 m of ground surface. This has an important implication for modelling, as the simulation of unsaturated flow processes and corresponding vertical grid resolution can add a significant computational burden and run time.
- While there is short term (high frequency) variability, the onset of rise in groundwater level can be delineated into a total of 21 distinctive flow events for the period of monitoring data. For each flow event, the time it takes for the water table to reach peak elevation ranges from 2 to 8 days with an average of around 4 days. This provides a useful indication of the length and number of stress periods required to adequately simulate the seasonal water table response in the groundwater model i.e. at least 40 stress periods for a monitoring period of 14 months. The implication is that the model would need to be designed to accommodate potentially a large number of stress periods, in order to simulate flow/inundation events under a range of possible future conditions and to enable progressive updates of the model, if required, as additional data become available. A level of simplification, where this is immaterial to the outcome of modelling (for example, neglecting unsaturated flow), would be necessary for the model to simulate the seasonal dynamics over an extended period.
- Due to the rapid water table response, the water table fluctuation method can be applied to derive indicative infiltration (recharge) rates associated with each flow event. Assuming specific yield ranging from 0.05 to 0.1 (based on the porosity used in Jacobs’ FEFLOW model), the infiltration rate is estimated to range from 2 to 18 mm/d.

The hydrographs indicate a period of low flow from December 2019 to April 2020, which is accompanied by a gentle decline in the groundwater levels followed by a rise. There are spatial differences in the timing of this groundwater level response, which are further examined in Figure 2-8. The figure shows the stream level at downstream gauge 233276A steadily declines over this period, reaching close to zero in February 2020, while the stream level at the upstream gauge is maintained at around 0.1 m above gauge zero. The same trend is also seen in the flow data, indicating a net loss (stream leakage) along the length of the swamp (note the stream levels are used in this figure instead of flow to more clearly show the peak levels, which are truncated at 12 ML/d for flow). This means Boundary Creek continues to act as a losing stream during drier periods and this is supported by the elevation along the creek line (based on the processed DEM), which is generally above the groundwater elevation in the adjacent bores.

Figure 2-8 shows that the onset of the rising trend in upstream bores BSBH16 and BSBH17 is earlier and more pronounced than the trend seen in downstream bores BSBH07 and BSBH10, potentially reflecting earlier/more stream leakage in the upstream end. This suggests that time-varying stage along Boundary Creek (and appropriate temporal discretisation) would be necessary in the groundwater model to reflect spatial variability in leakage during dry periods and associated response in the QA.

There are also spatial differences in the range of seasonal variations in the groundwater level. Figure 2-9 shows an example of groundwater contours for wet and dry periods and the difference between the two contours. This spatial difference can also be inferred from Figure 2-9, based on the difference between the minimum and maximum depth to water. In general, the range of seasonal variation is greater closer to the alignment of Boundary Creek (northern boundary of the swamp) and decreases further downstream. An area of negative difference is centered on a shallow bore BSBH18 and this is due to anomalously low water levels recorded at this bore up to October 2019.

In addition to surface water inundation, rainfall recharge provides an additional source of inflow into the QA. Figure 2-10 shows that hydrographs generally follow the cumulative departure from mean daily rainfall trend, although this is expected as surface water inundation is also climate (rainfall) driven. For the period from June 2019 to August 2020, the most significant fluctuations generally appear to be caused by surface water inundation; however, it is not apparent from hydrographs alone the extent to which diffuse recharge has contributed to the maintenance of the water table. For example, the extent to which diffuse recharge over preceding months has influenced the water table prior to the onset of surface water inundation events (such as the early onset of the rising trend seen at bore BSBH16 in Figure 2-8). This is important because inflow due to rainfall recharge can accumulate in aquifer storage over time, which could influence how the water table responds to inundation events of different extent and duration under different climatic conditions. From the point of view of modelling, both recharge processes would need to be incorporated as time-varying source term to allow their relative importance to be examined, particularly in the context of the effectiveness of the propose remediation strategy that relies on the maintenance of stream flow.

Discharge processes

Following each inundation event, the groundwater level in Big Swamp declines. The initial decline is typically rapid, reflecting lateral drainage within the QA under high hydraulic gradients. The rate of lateral drainage slows down as the hydraulic gradients reduce across the swamp. During the dry period from December 2019 to March 2020, when stream leakage is limited, the groundwater levels in the monitoring bores are observed to fall to levels below the elevation of Boundary Creek. This means discharge processes continue to lower the water table, most likely as a combination of lateral drainage (aquifer through-flow) and evapotranspiration.

Swamp vegetation depends on groundwater stored in swampland sediments and during the summer months, significant evapotranspiration losses could be expected from the water table aquifer. It is possible that during extended dry periods, the hydraulic gradients would become flatter and evapotranspiration becomes an increasingly important discharge process as vegetation access shallow groundwater to meet its water requirements.

In addition to climate-driven hydrological processes described above, changes in piezometric heads within the underlying LTA influence fluxes into and out of the QA in Big Swamp. This component of the water balance is discussed further in Section 2.3.3.

Data resolution

The hydrographs presented in this section are obtained from bores that have a screen length of 3 m with the gravel pack typically extending 0.5 to 1 m above and below the screen interval. This means the data currently available provide the net response of shallow groundwater within the upper 6 m of the QA and do not provide indications of any subtle vertical differences that may occur within this depth interval (if any). It follows that the model calibrated to these data should be designed to simulate the net response, which would not benefit from high numerical resolution in the vertical direction i.e. multiple model layers of 1 to 2 m in thickness, as assumed in the existing FEFLOW model. An exception would be for simulating the potential effect of hydraulic barriers if they are keyed into the QA, where additional layers would be required to simulate the interference with shallow groundwater.

Key findings:

- Water table responds rapidly to surface water inundation events, with minimal lag (i.e. <4 days) indicating limited unsaturated flow effects due to generally thin unsaturated zone. This provides the opportunity to simplify the groundwater flow problem into saturated flow only, providing considerable numerical efficiency gains.
- Stress periods ranging in duration from 2 to 8 days would be necessary to simulate the seasonal dynamics of shallow groundwater.
- Boundary Creek acts as a losing steam and there are spatial differences in the timing and magnitude of water table response to seasonal flow events. Time-varying stage would be necessary to simulate variable leakage along Boundary Creek during dry periods.
- It is difficult to discern the relative effect of stream inundation and rainfall (diffuse) recharge processes based on the currently available data. The groundwater model would need to simulate both of these processes as time-varying source terms to examine their effect under a range of climate conditions.
- Discharge processes include aquifer through-flow (lateral drainage) and evapotranspiration, which would need to be incorporated into the model.
- Monitoring data provide indications of net groundwater response within the upper 6 m of the QA. This means a high vertical resolution (multiple model layers) is not necessary to simulate this net responds; however, additional model layers would be required to simulate the partial penetration of flow barriers as part of predictive modelling of future remediation strategy.

Figure 2-7 Bore hydrographs and stream flow

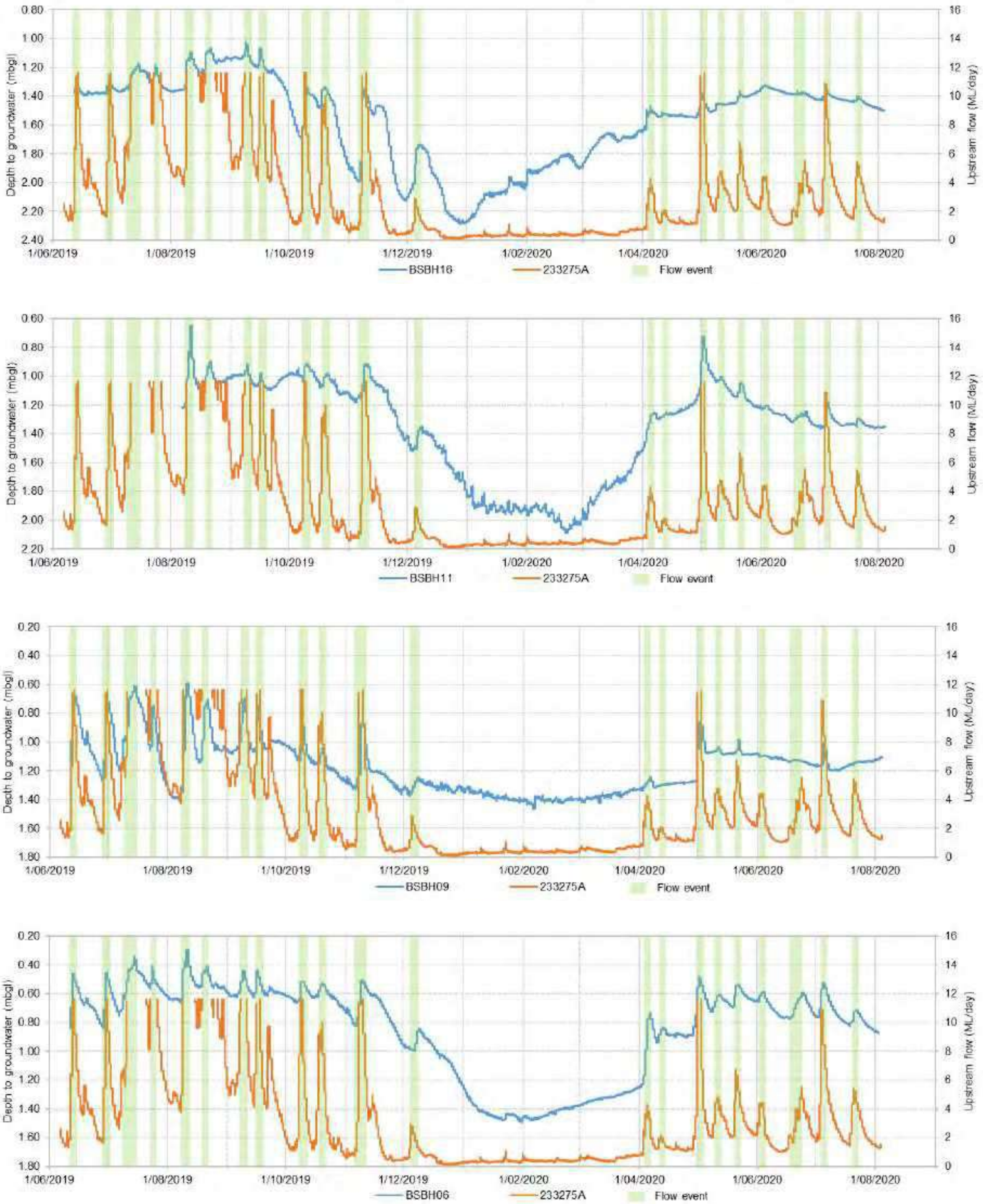
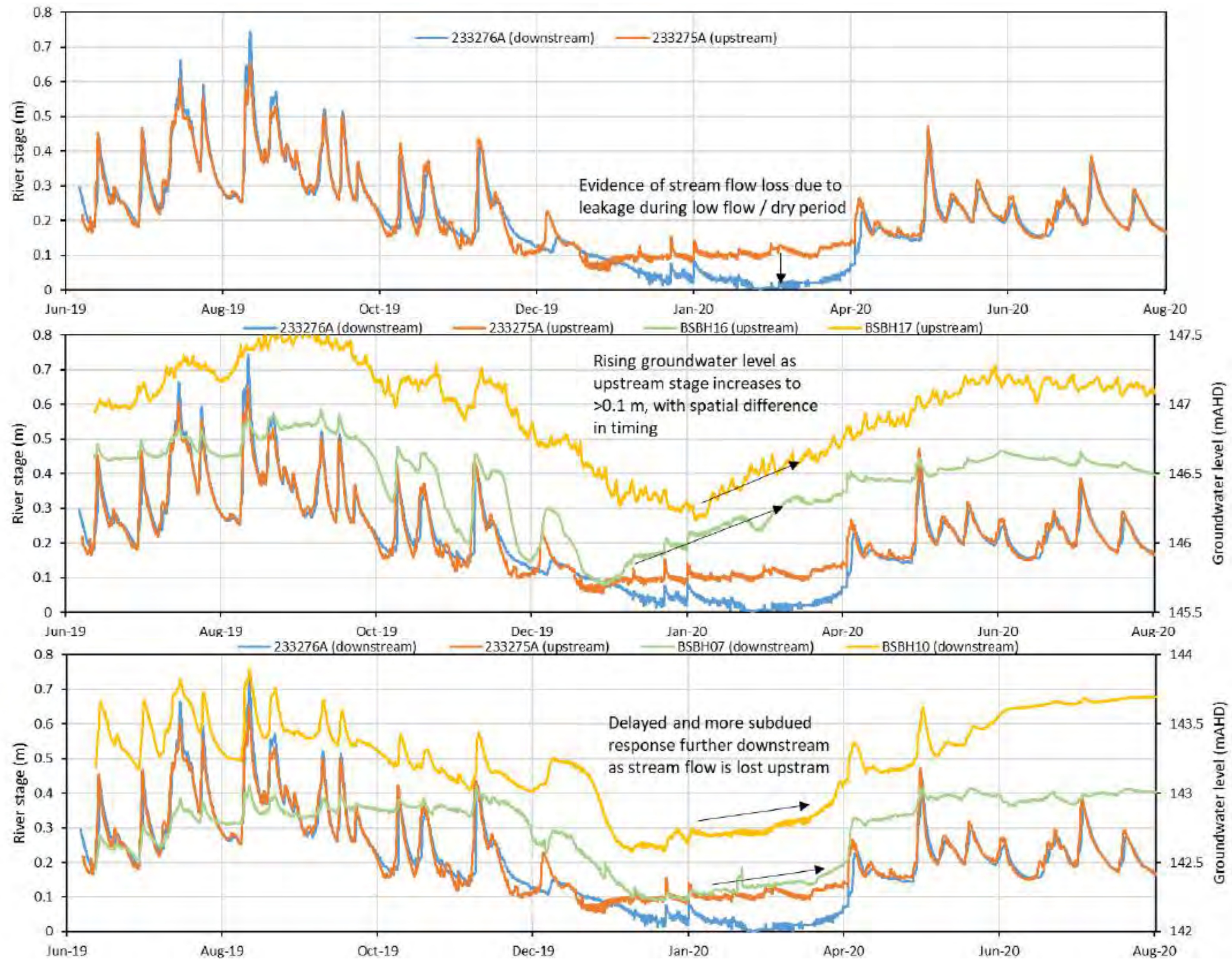
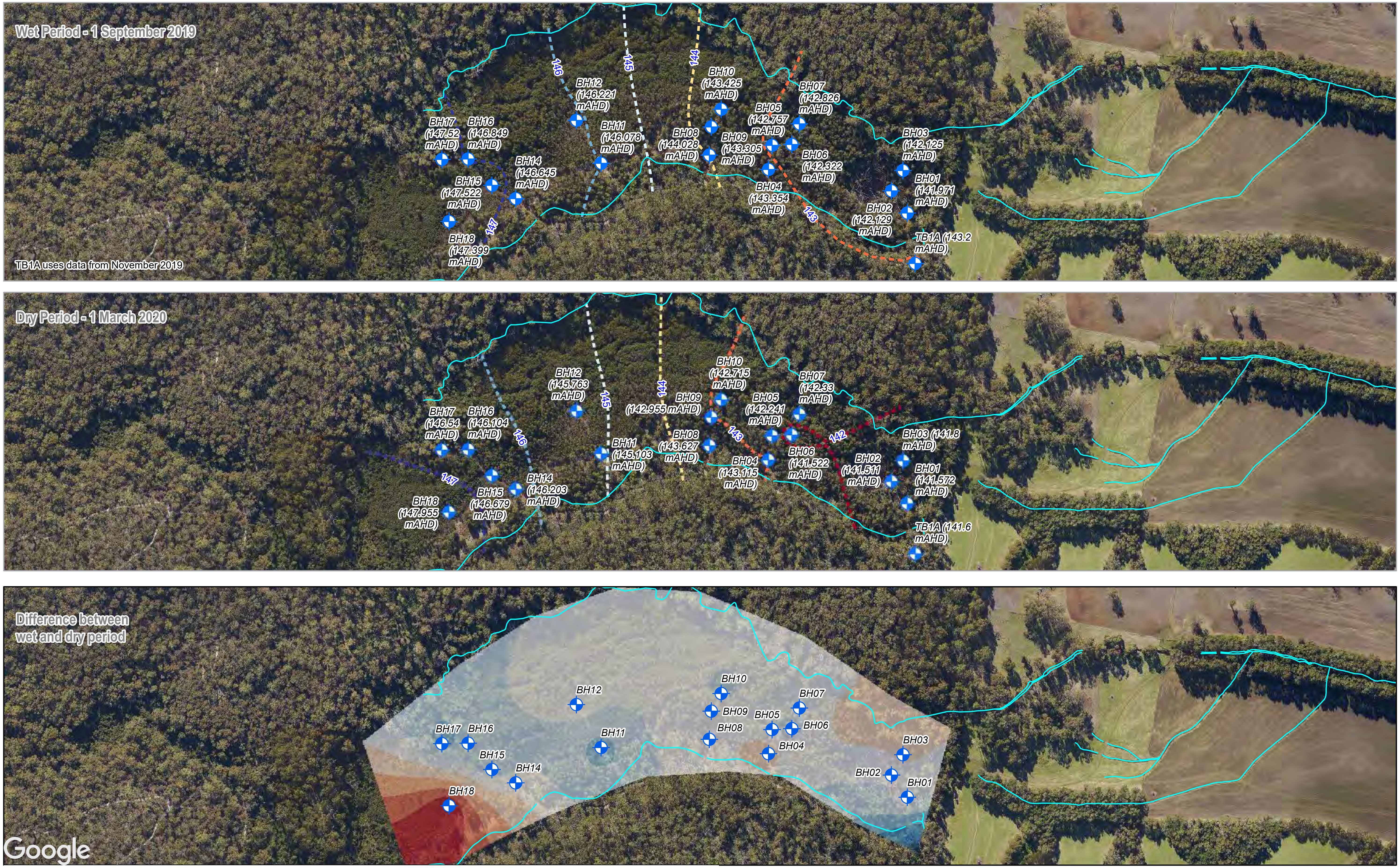


Figure 2-8 Stage hydrographs and upstream and downstream response





Legend

- Watercourse
- Groundwater bore (RWL in mAHD)

Groundwater contour (mAHD)

- 142
- 143
- 144
- 145
- 146
- 147

Difference between wet and dry RWL (m)

- -0.6 - 0.4
- -0.4 - -0.2
- -0.2 - 0
- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6

Paper Size ISO A3

0 50 100 150 200

Metres

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Wet (Sept 2019) and dry (March 2020) groundwater contours

Project No. 12536659
Revision No. C
Date 12/10/2020

FIGURE 2-9

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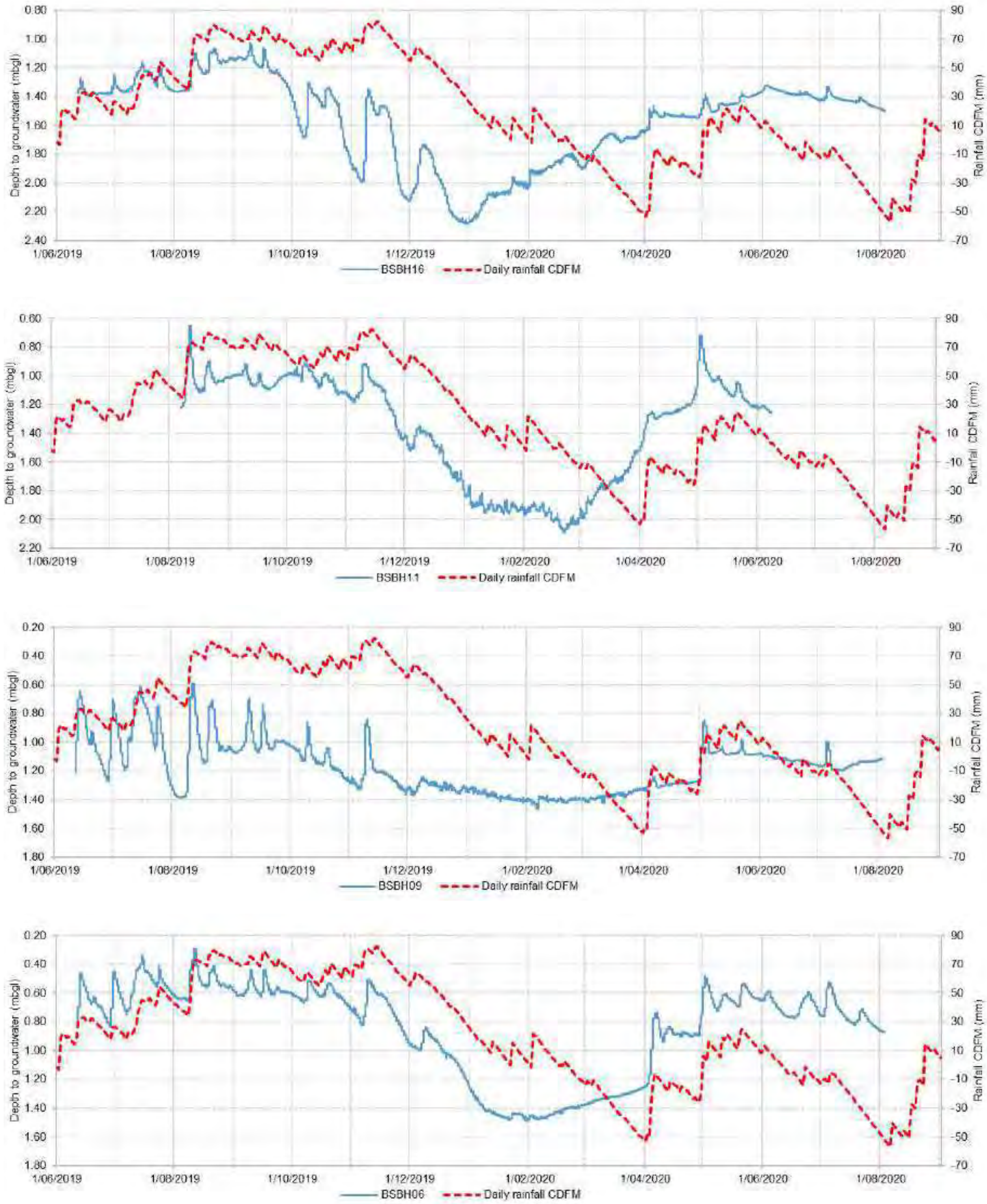
Print date: 08 Apr 2021 - 17:56

Data source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, groundwater contours, 2020; . Created by: bsmyth (tworth)

Figure 2-10 Bore hydrographs and cumulative departure from mean rainfall



2.3.3 Inter-aquifer connection

The LTA (Mepunga/Dilwyn Formation) is a regionally extensive aquifer that outcrops at surface predominantly in an area known as Barongarook High, where the aquifer has its main recharge zone. As discussed in Section 2.3.1, the LTA becomes confined by the MTD approximately in the middle of Big Swamp.

Prior to the commissioning of the Barwon Downs borefield and drier recent climatic condition, groundwater within the QA along Boundary Creek and Big Swamp would have been replenished by a combination of recharge from rainfall and surface water inundation and through-flow and baseflow from the LTA, with the natural water table likely to have fully intersected the QA. At the downstream end of Big Swamp, the upward leakage from the LTA may have been limited by the presence of the MTD, with through-flow from upstream providing an important component of flow into the QA underlying the swamp.

Extraction of groundwater from the Barwon Downs borefield and reduction in recharge due to drier climate have resulted in the lowering of groundwater levels within the LTA, reaching a depth of around 15 m below ground surface in 2010 along the upper reaches of Boundary Creek (based on the groundwater levels in bores 109128 and 109130, upstream of Big Swamp). Assuming a typical thickness of 10 m for the QA along the upstream reaches of Boundary Creek, the water table within the unconfined portion of the LTA potentially became disconnected from the base of QA. Following the cessation of pumping, the groundwater levels have gradually recovered to around 8 m below ground level, albeit still lower than the near surface levels measured in 1997 (however, the 1990s were a very wet climatic period compared to the subsequent 20 years of the 2000s). This means there currently remains a net downward hydraulic gradient from the QA to the LTA along Boundary Creek, and potentially in the upstream end of Big Swamp, which limits the contribution of aquifer through-flow into the QA underlying Big Swamp.

There is limited data on the groundwater level in the LTA at Big Swamp. Figure 2-11 presents the hydrographs of the nested monitoring site TB1 in the downstream end of Big Swamp. The groundwater level in the confined LTA is consistently above the groundwater level in the QA and MTD, indicating an upward vertical hydraulic gradient. However, the declining trend observed in the QA and MTD during the dry period indicates that upward vertical leakage from the LTA is likely to be limited by the low hydraulic conductivity of the MTD and is insufficient to maintain the water table in the QA, which is more strongly influenced by the surface water inundation events and subsequent discharge processes. The hydrographs also show that the vertical hydraulic gradient between the QA and MTD is seasonally variable. The artesian condition within the LTA is supported by bore 109112, located further downstream of Big Swamp, which currently has an artesian groundwater level of around 5 – 7 m above ground i.e. a greater artesian head where the LTA is deeper and confined by thicker MTD (the depth of bore 109112 is 292 m).

There are currently no bores monitoring the groundwater level in the LTA at the upstream end of Big Swamp. As discussed in Section 2.3.2, the bores in the upstream end of Big Swamp show a net declining trend during the dry period and this suggests that the groundwater level in the LTA is either close to or below the minimum groundwater level in the QA (or leakage from the LTA is insufficient to offset discharge via though-flow and evapotranspiration).

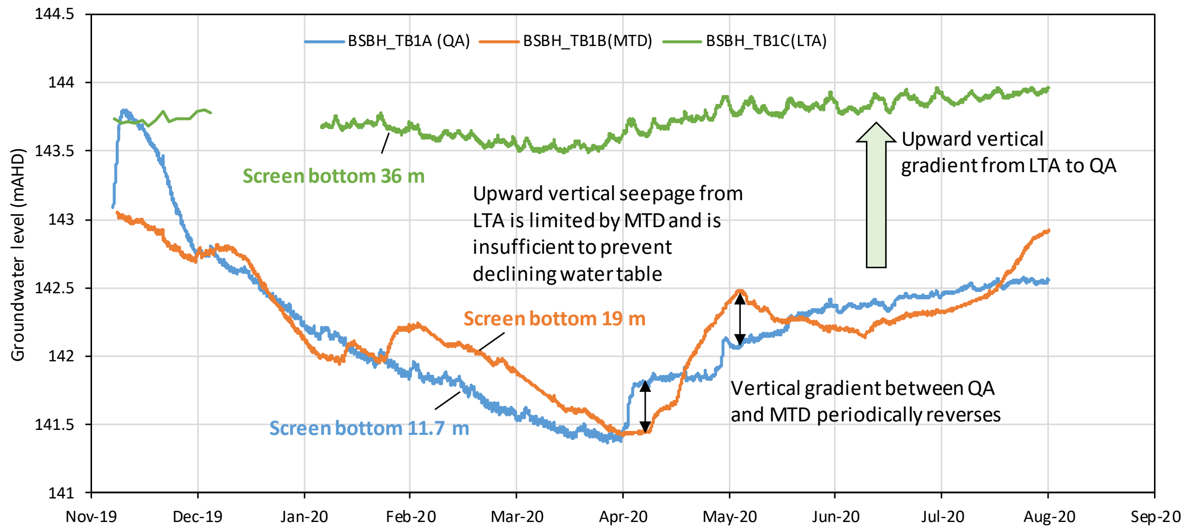
Figure 2-12 presents the location of bores in the LTA and interpreted contours of groundwater level in the LTA (Mepunga/Dilwyn Formation) for 2010 and 2020. Also included in the figure are hydrographs of key bores constructed in the LTA near Boundary Creek and Big Swamp. The interpreted groundwater contours and flow directions are broadly consistent with those derived from previous studies, which generally follow the topographic gradient along Boundary Creek. The horizontal hydraulic gradient between upstream bores 109130 and 109128 varied from around 0.0021 to 0.0051 since 1988, with an average of around 0.0037. The upper end of the range corresponds to periods of higher groundwater levels, such as the current condition and around 1996 prior to the Millennium Drought. The horizontal hydraulic gradient between bore 109128 and TB1C, located at the downstream end of Big Swamp, is around 0.0035 based on the recent data. The contours and hydraulic gradients suggest that the current groundwater level in the LTA could be around 146 mAHD in the upstream end of Big Swamp, similar to or slightly lower than the minimum groundwater level measured in the QA bores nearby. Given the direct connection between the LTA and QA at the upstream end of Big Swamp, the QA is likely to be losing to the underlying LTA following each inundation event i.e. downward leakage represents a component of discharge from Big Swamp after each inundation event. During extended dry periods, the groundwater level in the QA could potentially fall until it either equilibrates with the groundwater level in the surrounding LTA or induce an upward leakage from the LTA into the QA.

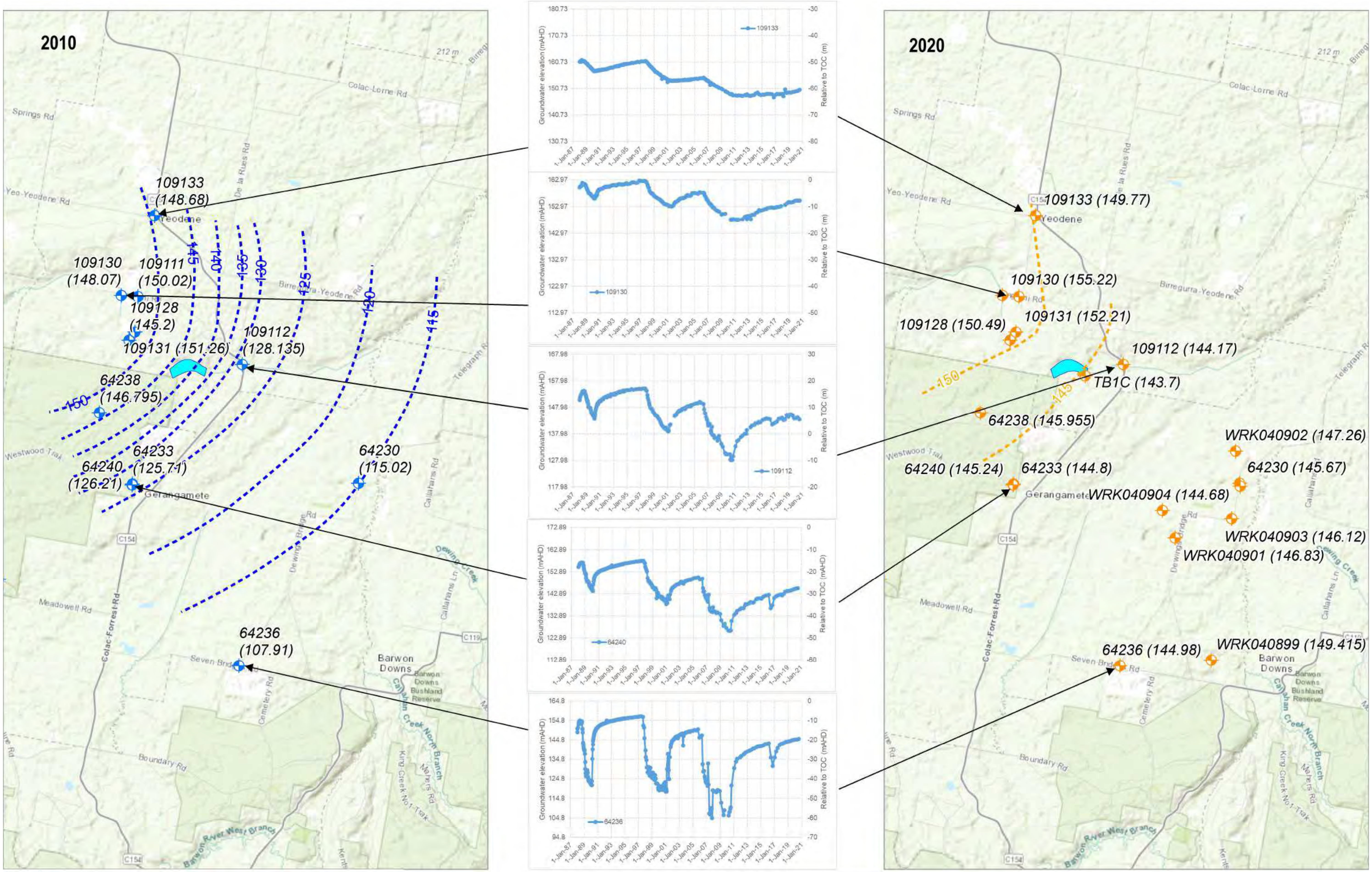
From the point of view of modelling, appropriate representation of piezometric heads in the underlying LTA is important as the nature of aquifer interaction influences the amount of through-flow and leakage into the QA of Big Swamp. Under the current condition, this component is likely to be small and is masked by much larger fluxes from surface water inundation. For this reason, maintaining the flow and inundation along Boundary Creek is the primary focus of the proposed remediation strategy. The interaction between the LTA and QA would be expected to vary over time depending on the future operation of the Barwon Downs borefield and climate that influences recharge into the LTA.

Key findings:

- The QA and LTA aquifer inter-connection along Boundary Creek and Big Swamp influences the amount of aquifer through-flow and baseflow into the QA of Big Swamp, which has an effect on the water balance and water table elevation in the swamp.
- Groundwater levels in the LTA have not yet fully recovered from the influence of pumping and drier climate. In the upstream end of Big Swamp, the QA is likely to be currently “losing” to the LTA following flood inundation events. The water table potentially declines to a level similar to the groundwater levels in the LTA during dry periods.
- From the point of view of modelling, the direction and magnitude of fluxes exchanged between the QA and LTA are important. These are expected to vary over time depending on the future operation of the borefield and climate.

Figure 2-11 Hydrograph of nested monitoring site TB1





Legend

- Groundwater bore (2010 RWL in mAHD)
- Groundwater bore (2020 RWL in mAHD)
- Groundwater contour in mAHD (2020)
- Groundwater contour in mAHD (2010)
- Location of Big Swamp

Paper Size ISO A3

0 1 2 3

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Barwon Water
Big Swamp Modelling for Detailed Design

LTA Groundwater Contours 2010 and 2020

Project No. 12536659
Revision No. B
Date 12/10/2020

FIGURE 2-12

N:\AU\Melbourne\Projects\31\12536659\GIS\Maps\Deliverables\31_12536659_04_DeepBoreContours_A3L_RevB.mxd
Print date: 08 Apr 2021 - 17:51

Data source: WMIS, bore locations and elevations, 2020, BW, groundwater levels, 2020; Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community. Created by: bsmyth (tworth)

2.4 Schematic conceptual model of key processes

Key hydrological and hydrogeological processes driving the behaviour of the Big Swamp aquifer system are summarised in simple schematic block diagrams.

Figure 2-13 shows the conceptualisation of the upstream end of Big Swamp, including the condition prior to the extraction of groundwater from the Barwon Downs borefield and recent drier climate, when the water table within the outcropping LTA was in hydraulic continuity with the QA.

Figure 2-14 shows the conceptualisation of the downstream end of Big Swamp under the existing condition, where the LTA is confined below the MTD.

Figure 2-13 Schematic hydrogeological conceptualisation – Big Swamp upstream

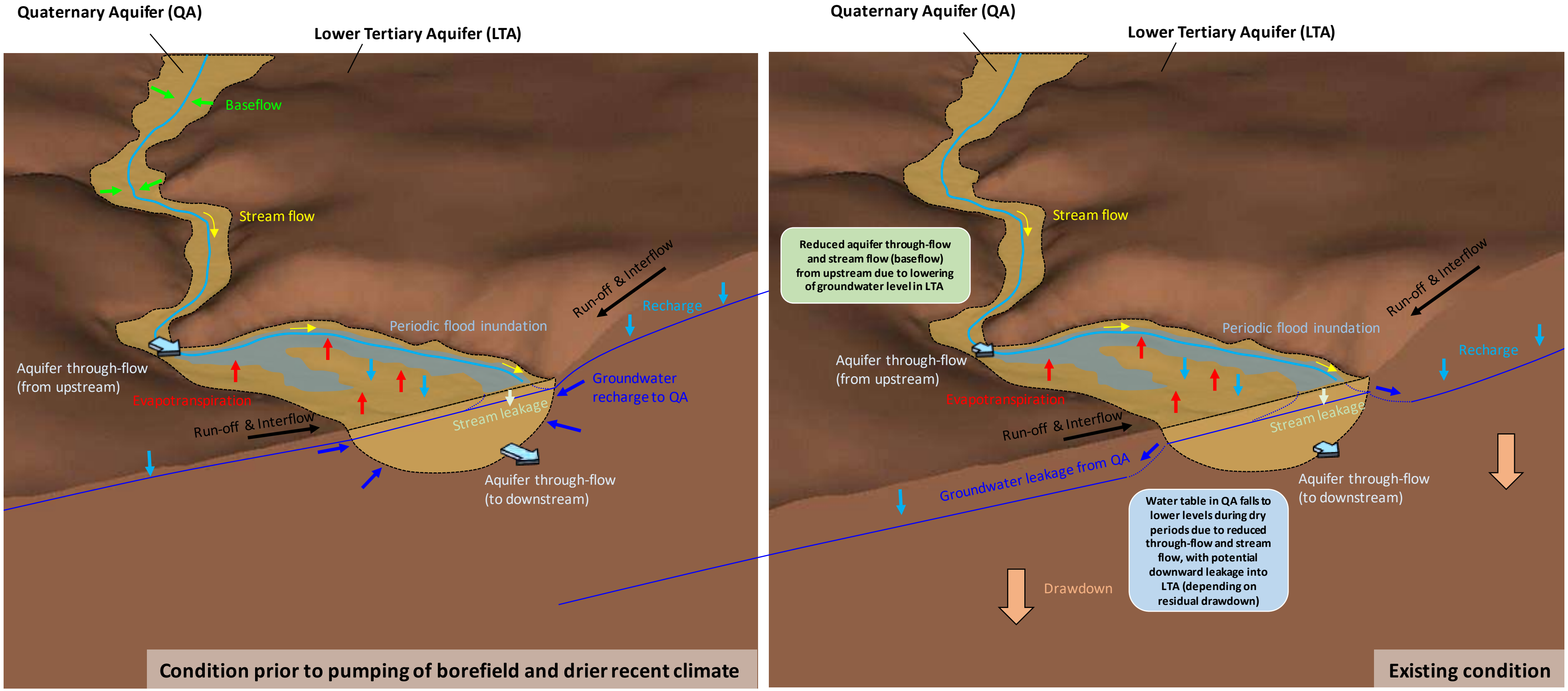
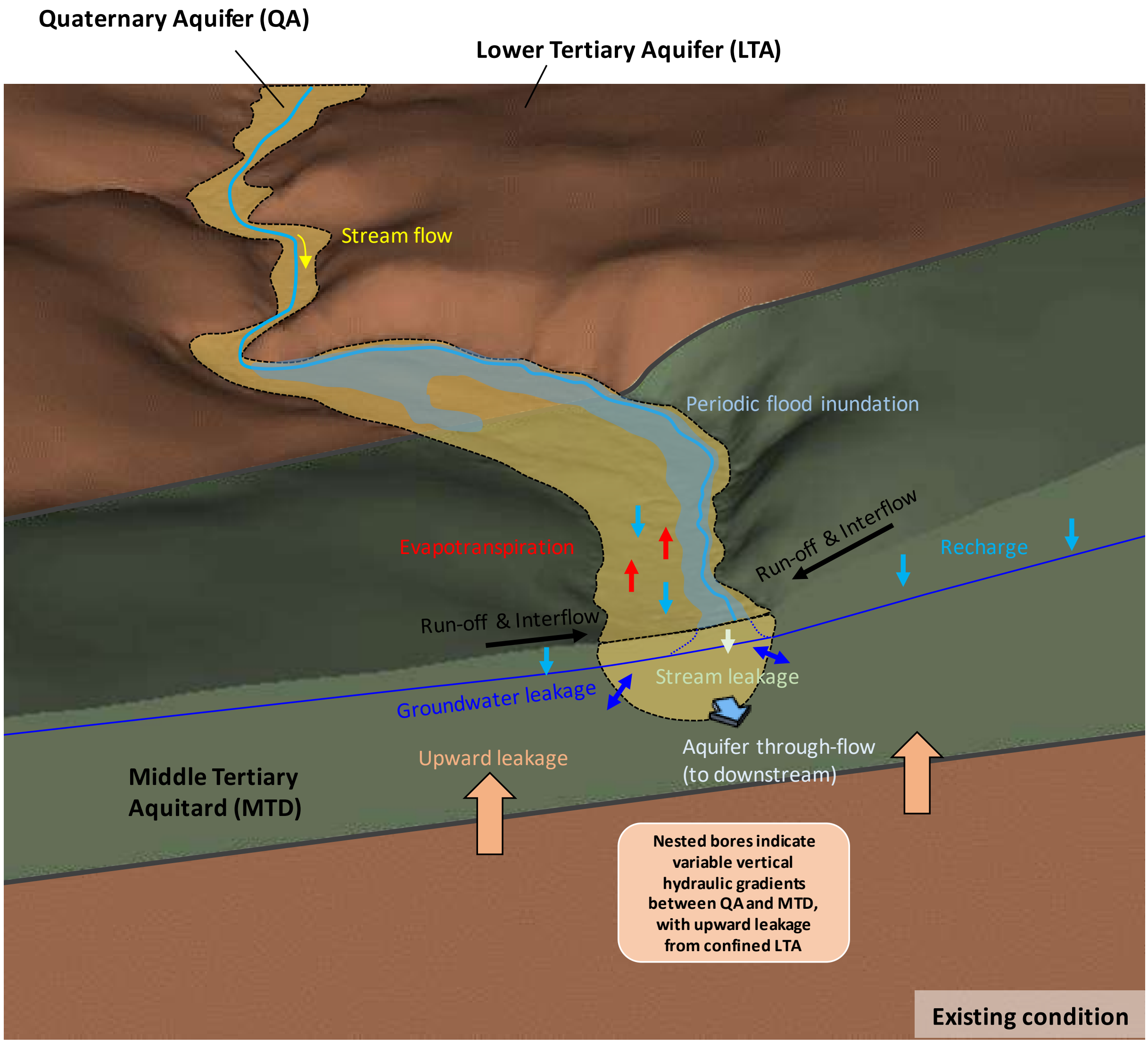


Figure 2-14 Schematic hydrogeological conceptualisation – Big Swamp downstream



3. Model design and construction

3.1 Modelling approach

3.1.1 Integration of surface water and groundwater processes

Hydrological and hydrogeological models can be coupled in several ways. In tightly coupled fully-integrated models, both the surface and subsurface flow equations are solved simultaneously using fine spatial grids and time steps. In loose coupling, external hydrological and hydrogeological models are run independently and outputs from each model are used to inform their respective inputs. The outputs exchanged depend on the types of models used e.g. infiltration calculated using 1D Richard's equation, deep drainage from rainfall-runoff models and infiltration estimated from ponding depths such as those calculated from flood models.

Although the capability of tightly coupled fully-integrated models is appealing, they are often plagued by numerical instability and excessive model run times. The benefit of their use is questionable given that simpler loosely coupled approaches can achieve similar outcomes, for example by using a stream flow routing boundary condition (coupled to groundwater at successive time steps) to accurately represent interaction between Boundary Creek and groundwater. A tightly coupled model would be problematic for this project, given the requirement for run-intensive procedures such as rigorous automated calibration, predictive uncertainty analysis and multiple scenario runs to inform the detailed design.

A complex, cumbersome approach based on tightly-coupled models is also counter to good modern modelling practice, in which the primary goal is to develop models that can simulate the processes of relevance to a sufficiently reliable degree whilst not expending efforts on details that have little material effects on model outcomes. In conjunction with this, the model should be numerically stable and efficient to enable uncertainty to be constrained through a rigorous history-matching process and to facilitate an understanding of uncertainty that underpins the decision-making process for which the model was commissioned to inform. While the loose coupling method is simpler, the benefits gained from improved numerical stability and more transparent exchange of outputs would assist in meeting the modelling objectives within the timeframe of the project.

In this project, the primary mechanism of maintaining the water table in Big Swamp would be via surface water inundation. The information exchanged between the hydrological and hydrogeological models would include the depth, extent and duration of inundation and associated infiltration rates that result in the observed water table response. These are discussed further in Section 3.1.3.

3.1.2 Modelling platforms

For hydrological modelling, TUFLOW has been chosen based on its extensive application to flood modelling studies in a wide range of environments and to maintain continuity with the previous hydrological modelling undertaken by Jacobs (2019a). A rainfall-runoff model is also used to provide inputs to the TUFLOW model.

For hydrogeological modelling, the appropriate modelling platform has been chosen based on careful considerations of the intended model use and updated hydrogeological conceptualisation presented in Section 0.

Broadly speaking, there are two commercially available groundwater modelling platforms that are widely used in Australia. These are the finite element code FEFLOW, developed and maintained by DHI, and finite difference code MODFLOW (and its variants), developed and maintained by the United States Geological Survey (USGS). Both codes have been extensively used and benchmarked, and have similar capabilities. In this sense, the choice of suitable modelling platform often comes down to the skill and experience of the modelling team, although there are subtle differences between the two codes that can influence their suitability.

For this project, an unstructured grid version of MODFLOW called USG-Transport version 1.5 (Panday, 2020) has been chosen as the most appropriate modelling platform. USG-Transport is based on the MODFLOW-USG code (Panday et al, 2013) developed by the USGS and includes several enhancements (such as adaptive time stepping) which are frequently updated by the code’s lead developer. The preference for using a MODFLOW based code over FEFLOW is as follows:

- It is generally recognised amongst experienced modellers that extracting reliable and consistent local water balances can sometimes be challenging with FEFLOW due to the finite element formulation and post-processing methods. This is not a limitation with USG-Transport that uses the control volume finite difference formulation with prismatic cells, in which the flow balance is conserved locally on a cell-by-cell basis. The ability of the model to simulate reliable local water balance of the Big Swamp alluvial aquifer is of critical importance to this project.
- MODFLOW (and USG-Transport) is open source and all input and output files, as well as the source code, are visible to the user. This level of transparency and flexibility can be advantageous in some instances, for example when interfacing the model with third-party software such as PEST and its associated utilities for automated calibration and uncertainty analysis.
- MODFLOW has exiting packages such as Recharge, Evapotranspiration, River and Stream packages, which are particularly suited to simulating the effects of near surface hydrogeological processes that are critical to this project.
- MODFLOW based code has been successfully applied by GHD for Barwon Water’s Anglesea Borefield Project, to model groundwater level, creek flows, a lake and water balance changes in the swampland and associated acid generation risks.

Although the previous modelling was undertaken in FEFLOW, transitioning into a MODFLOW-based code is not an impediment to the modelling process as the knowledge gained from the previous modelling remains applicable. Additionally, the updated conceptualisation has identified several model design aspects that require modifications to meet the modelling objectives and project timeframe. These modifications are necessary irrespective of the modelling platform chosen for the project and are discussed in more detail below.

3.1.3 Specific model design considerations

Specific model design considerations include the following:

- The rapid onset of rise in groundwater level following high stream flow events and generally thin unsaturated zone indicate that accuracies gained from incorporating the unsaturated flow processes and corresponding fine vertical resolution would be immaterial and do not outweigh the computational burden, increased model run time and additional parameters incurred. Reducing the model to only saturated flow has a follow-on benefit to run-intensive calibration and uncertainty analysis required for this project.

- Multiple model layers are not necessary to simulate the net response of the QA in Big Swamp, recognising that the monitoring bores are not designed to capture subtle variations that may exist vertically within the top several meters of the aquifer. This is not important to meet the main objective of the modelling, which is to quantify the water balance of the QA and whether or not the proposed remediation strategy can maintain the water table within the top metre. According to Jacobs (2019a), the justification for dividing the QA into multiple model layers within the FEFLOW model was to provide the fine vertical resolution required to model the unsaturated zone. However, the data suggest that the unsaturated zone is generally 1 to 2 m in thickness, placing the majority of these model layers below the water table. This means the model layers, as currently included in the FEFLOW model, do not actually serve their intended purpose.
- The MODFLOW packages available with USG-Transport simulate the hydrogeological processes and surface water-groundwater interactions in a manner that allows the relative contribution of each water balance component to be examined closely. The Stream Flow Routing (SFR) package can be used, with time-varying stage, to accurately simulate the interaction of Boundary Creek with groundwater based on the calibration to flow gauges, including stream loss along the length of Big Swamp observed during the dry period. This differs from a simple head boundary condition used in the FEFLOW model by Jacobs (2019a), which could provide limitless volumes of water to the groundwater model (even in periods when the creek may not have any water flowing down it) and does not account for loss of water down the creek (which is thought to occur in the upper reaches of the swamp in this project). In contrast, flow routing boundaries only simulate a head of water in the creek when there is water flowing and account for loss of water to the water table as the creek flows through the catchment.
- The infiltration associated with periodic surface water inundation can be simulated using the River (RIV) package, based on the water depth, extent and duration derived from the TUFLOW model outputs[1]. With the SFR and RIV packages the resistance to flow due to the creek bed material is implicitly accounted for by the bed conductance term. This means a 1 m thick top layer incorporated into the FEFLOW model to represent the creek bed sediments is no longer required.
- The time-varying recharge and evapotranspiration can be simulated using the recharge (RCH) and evapotranspiration (EVT) packages, to examine their contributions to the water balance of Big Swamp and effects on water table fluctuations that are key to acid generation processes. These sink and source terms can be derived from a simple water balance model such as LUMPREM (Doherty, 2020) and adjusted during calibration.
- The method of simulating the interaction between the QA and LTA requires careful consideration. Jacobs (2019a) attempted to simulate the distribution of piezometric heads within the LTA by adopting a large model domain and applying heads from the Barwon Downs regional model along the model boundary. The challenge with this approach is that the ability of the model to accurately account for the nature of inter-aquifer connection depends on its ability to accurately simulate the piezometric heads. This is not straightforward when the model domain only represents a portion of the regional flow field, where the distribution of piezometric heads depends on the geology and recharge and discharge dynamics over a much larger spatial area. This is demonstrated by the piezometric head simulated by the FEFLOW model at the nested site TB1, where the modelled head in the LTA is around 141 mAHD compared to the observed head of around

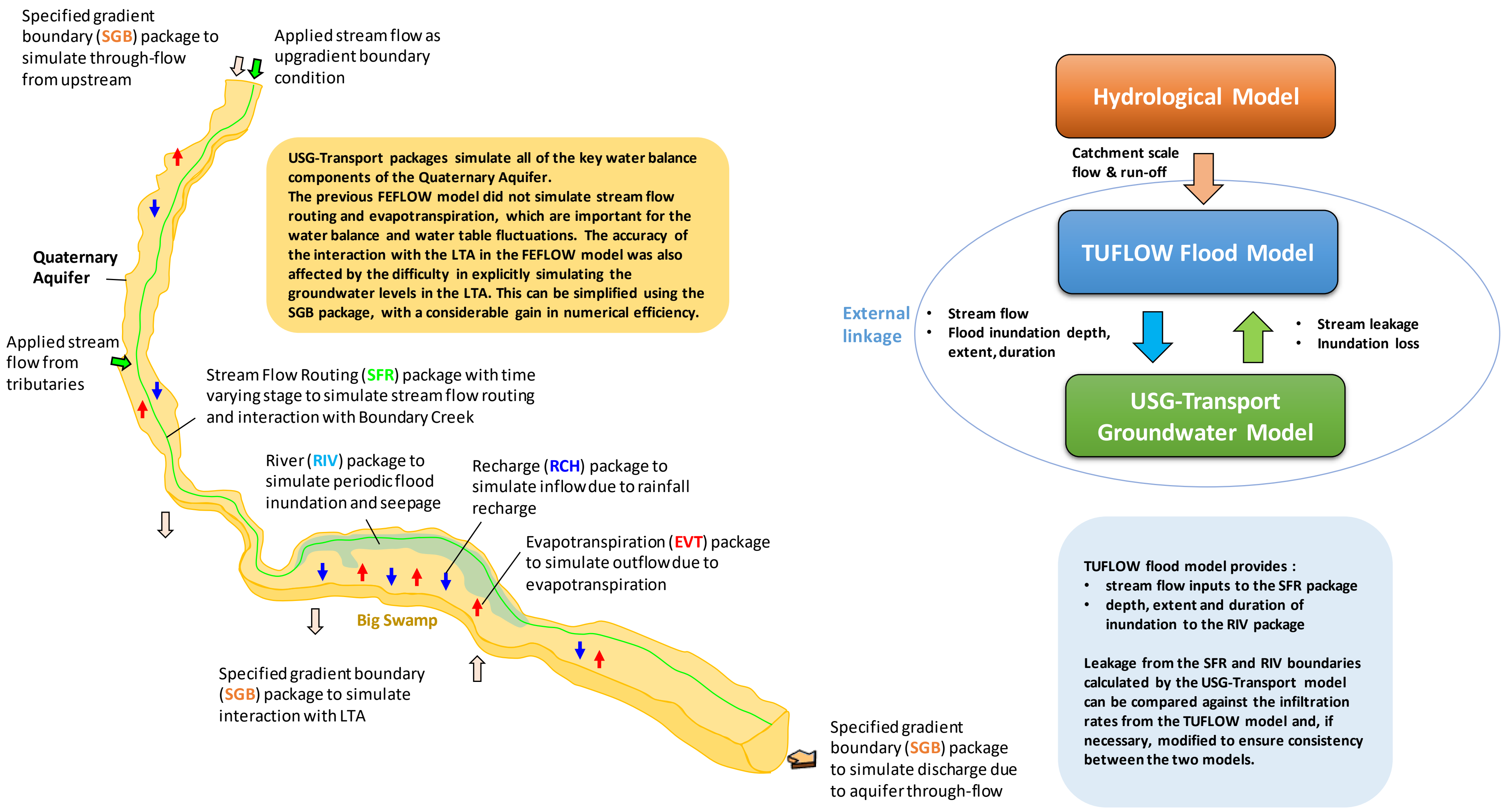
[1] Another reason for using this simple approach to overbank inundation is that it is not common over large areas or over long periods of time in this catchment. Hence, a more complex modelling approach is not warranted and takes the focus away from more critical issues such as uncertainty in water table depth variability in time and space, flow losses from the creek channel to the water table, and the potential acid generation processes.

144 mAHD and the model simulates a downward vertical hydraulic gradient (instead of the upward gradient implied by the data). In contrast, the FEFLOW model overestimates the piezometric heads in the upgradient LTA bores by around 3 m.

- An alternative approach to simulating the inter-aquifer connection is to use the Specified Gradient Boundary (SGB) available with USG-Transport. With the SGB, hydraulic gradients are specified as input and fluxes are calculated by the model in accordance with the gradients and resistance to flow represented by the hydraulic conductivity of model cells. In this study, the SGB can be prescribed along the base of the QA using the observed (and interpreted) difference in the LTA and QA heads. This ensures that the flux into and out of the QA is simulated in the correct direction based on the specified hydraulic gradient and resistance to flow represented by the vertical hydraulic conductivity of the QA. The hydraulic gradient can be varied during calibration to account for uncertainty in the distribution of LTA heads, with constrains placed such that the fluxes are always maintained in the correct directions. While this approach is simpler, it is more efficient than expending efforts to accurately simulate the heads in the LTA which may not be attainable at this scale (or at least to the accuracy required to maintain the correct directions of exchange). It is also possible to use head dependent flux boundary conditions such as the General Head Boundary (GHB), however, these boundaries require both the heads and conductance term to be specified as input and require more post-processing efforts to constrain fluxes or to ensure correct direction of fluxes. They would also require at least one more model layer beneath the QA and could artificially force heads through the base of the swamp.
- The SGB can also be applied along the upgradient and downgradient model boundary to simulate aquifer through-flow into and out of the model.

Figure 3-1 is a schematic representation of the groundwater (USG-Transport) model design. Also included in the figure is the linkage between the TUFLOW and USG-Transport models. The SGB can be extended to account for future conditions when the groundwater levels in the LTA recover to higher elevations, potentially resulting in a gaining condition over a larger area of the QA than currently expected.

Figure 3-1 Schematic representation of groundwater model design



3.2 Hydrological (GR4J) model design and construction

3.2.1 Overview

The purpose of developing the hydrological model is to estimate inflows from rainfall-runoff, which are used as inputs for the TUFLOW and USG-Transport models.

Big Swamp is situated on Boundary Creek, which has a large upstream catchment including McDonald's Dam. Downstream of McDonald's Dam, multiple tributaries join the creek near or within the swamp. Whilst gauged streamflow is available at various locations on Boundary Creek, the local catchment and tributary flows between the last upstream gauge (233229) and the downstream end of the swamp needed to be estimated. A rainfall runoff model has been developed for this area to estimate the flow volumes running into the creek using the software package e-water Source and the conceptual rainfall-runoff model GR4J. This model has been calibrated to the available flow data from the gauges along Boundary creek to generate appropriate flow volumes.

3.2.2 Model attributes

GR4J is a catchment water balance model that relates runoff to rainfall and evapotranspiration data on a daily timestep. It contains two storages and has 6 parameters, as outlined in Table 1.

Table 1 GR4J parameters and ranges

Parameter	Description	Default	Range
x_1	Capacity of the production soil (SMA) store	350 mm	1-1500
x_2	Water exchange coefficient	0 mm	-10.0-5.0
x_3	Capacity of the routing store	40 mm	1-500
x_4	Time parameter for unit hydrographs	0.5 days	0.5-4.0
k	Filter parameter given by the recession constant (as in observed catchment runoff depth model)	n.a.	0-1
C	Shape parameter (as in observed catchment runoff depth model)	n.a.	0-1

Source utilises the GR4J model to generate runoff from several sub-areas and can link and route these flows to get output hydrographs at various points within the model. Source also allows modelling of storages and offtakes which have been used in this model to represent McDonald's Dam.

Further details of GR4J as it is implemented in eWater Source can be found at: https://wiki.ewater.org.au/display/SD41/Rainfall+Runoff+Models+SRG.

3.2.3 Catchment delineations

The Boundary Creek catchment upstream of the Yeodene gauge (233228) has been divided into 15 sub-catchments based on topography (10 m contours) to represent where runoff would enter the creek. The area upstream of McDonald's dam is separated into several sub-catchments to allow direct comparison of flows at gauges to aid in calibration. The area within the TUFLOW model boundary is also separated out from the tributary catchments. Figure 3-2 shows the delineated sub-catchments.

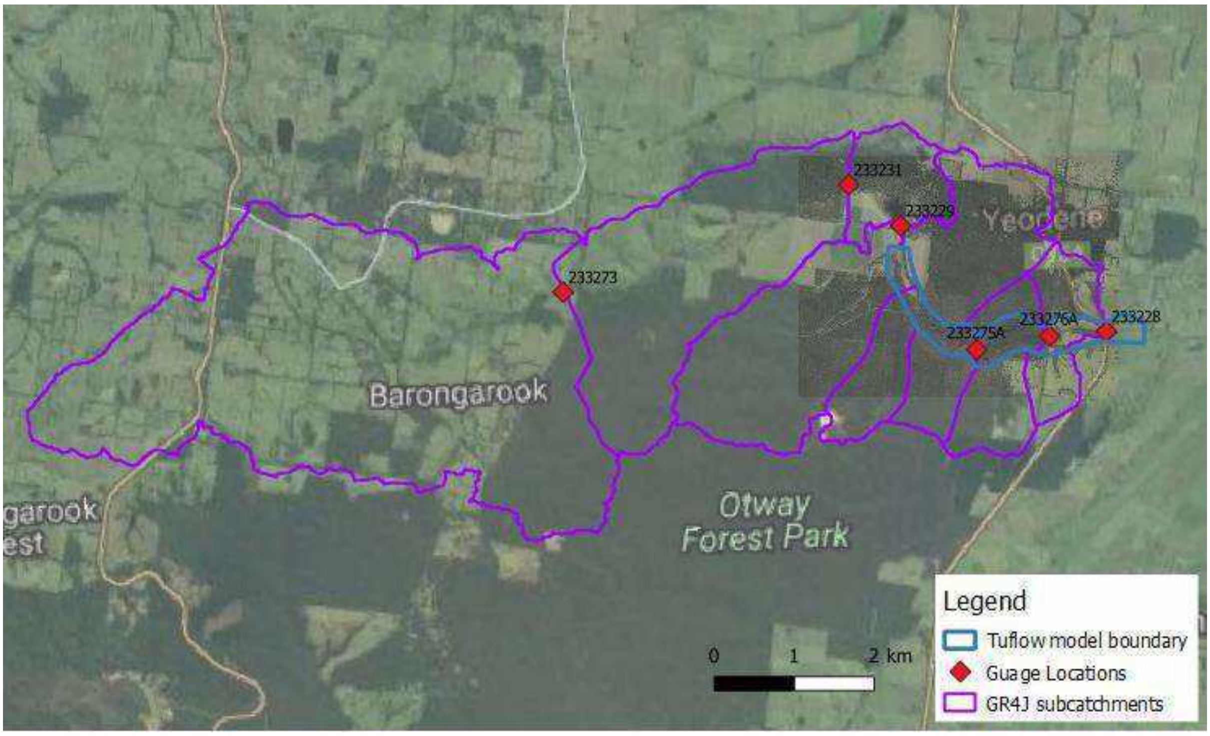


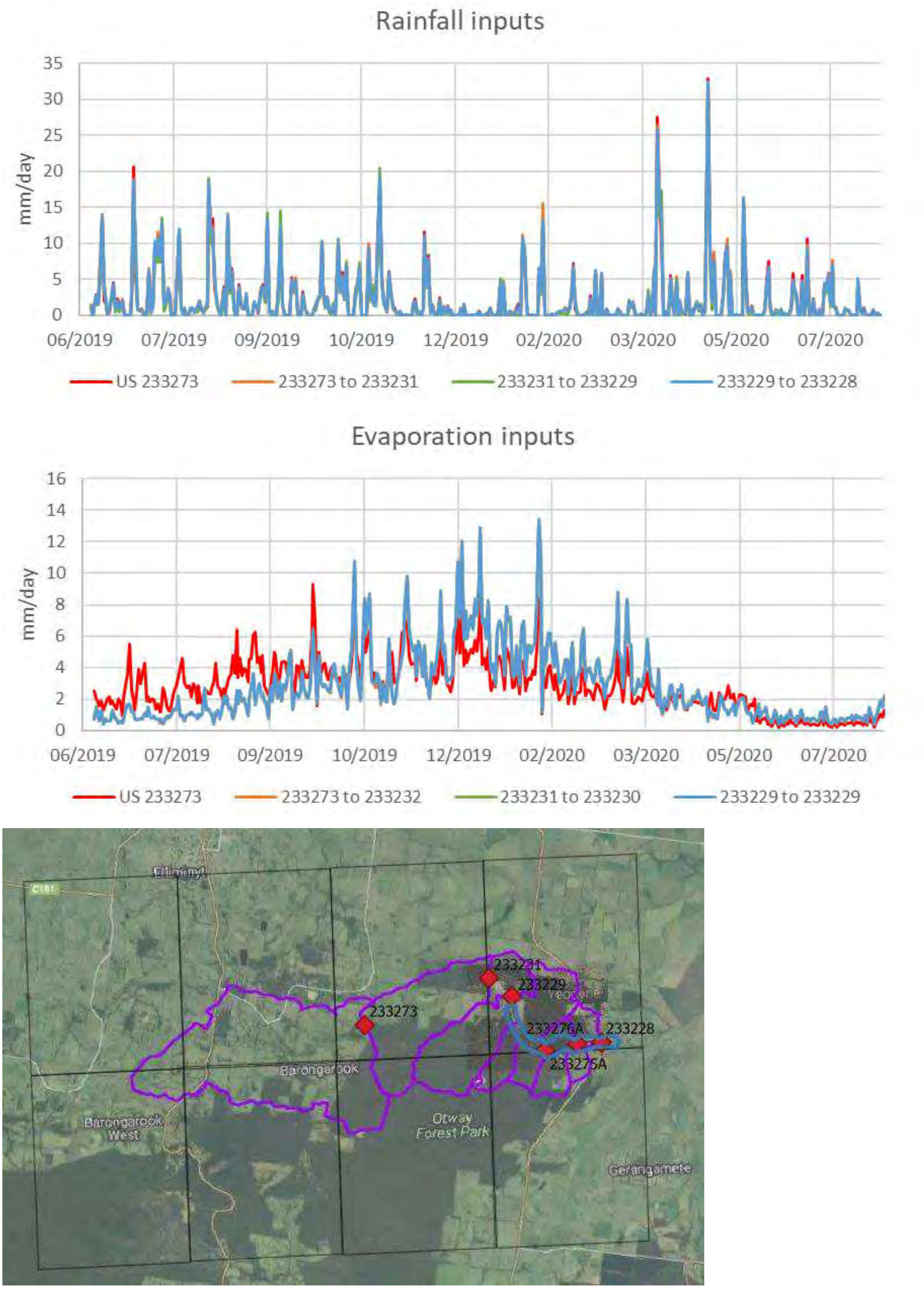
Figure 3-2 Sub-catchment boundaries

3.2.4 Climate data inputs

Due to a lack of complete climatic data for this catchment, daily rainfall and evapotranspiration data have been downloaded from the SILO database (https://www.longpaddock.qld.gov.au/silo/). This is a large data source which provides complete timeseries data for climatic variables using observed data and data infilling techniques. The gridded datasets for daily rainfall and daily Morton's potential evapotranspiration have been downloaded, which provide data interpolated to cover the entirety of Australia in a grid.

The area of interest to this study is covered by eight of these SILO grid cells, so all eight datasets are used, and an area weighted average of these has been calculated for the sub catchments. The weighted averages are based on how much of each of the catchment is inside each cell and separate rainfall and evapotranspiration timeseries are calculated for each of the following groups of catchments: Upstream of gauge 233273, between gauges 233273 and 233231, between gauges 233231 and 233229, and all catchments downstream of 233229. These timeseries are shown below in Figure 3-3.

Figure 3-3 Rainfall and evaporation input data to Source



3.2.5 Streamflow data inputs

There are several gauges with streamflow data available along Boundary creek, with locations shown in Figure 3-2

The site-specific gauges, managed by Barwon water, provide water surface level and flow rate data (limited to flows below to 12 ML/day) covering the period 7th June 2019 to 4th August 2020 at a 15-minute timestep. These provide information immediately upstream (Gauge 233275A) and downstream (Gauge 233276A) of Big Swamp.

Data from the other stream gauges have been downloaded from WMIS online at daily and 15-minute timesteps. These gauges varied in record length, but all had data covering most of the calibration period stated above. The gauges relevant to this study, listed in order from upstream to downstream, are: 233273, 233231(just upstream of McDonald's Dam), 233229 (just downstream of McDonald's Dam and 233228 (downstream of the swamp and at the end of the model).

To demonstrate the relative data quality and completeness of the four station gauges, Table 2 shows the percentage of data that is missing when data of poor quality (considered poor when quality code is above 150) is removed.

Table 2 Data missing for codes 150 and over during calibration period

233228	233229	233231	233273
17%	19%	16%	2%

A concern identified in the gauge data is that the flows at gauge 233229, downstream of McDonald's Dam are in many cases higher that the flows into the dam at gauge 233231, shown in Figure 2 4. This is unexpected as there is very little catchment area between the two gauges that could be causing this flow increase and dams generally also act to slow down the flows and flatten hydrographs slightly. It is likely there is some error in one of the gauges, however it is difficult to identify which one is more reliable. This adds some uncertainty into the modelling. A key improvement for future work on this location would be to complete an analysis of the data reliability of all the available gauges to better identify the most appropriate inflows.

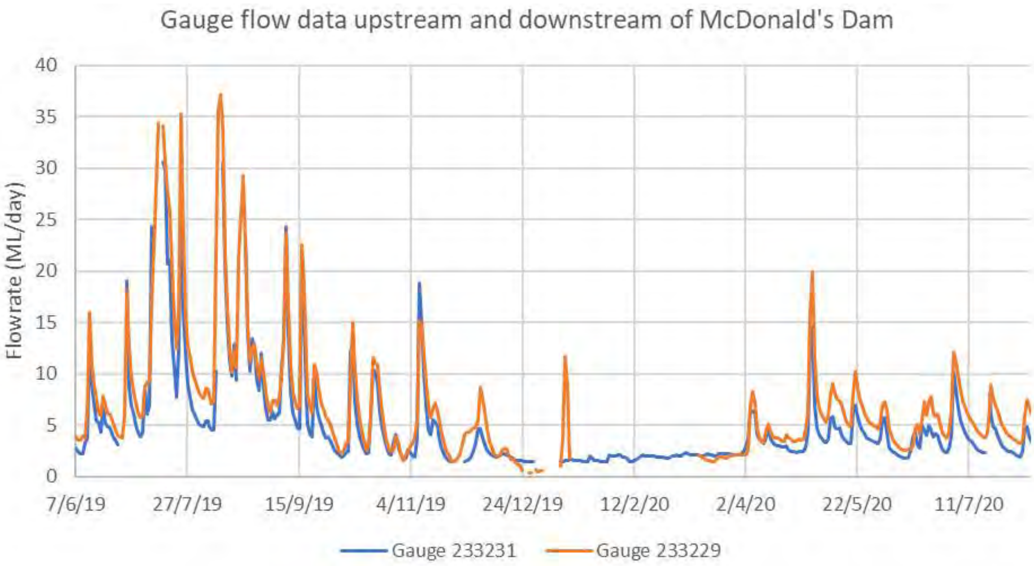


Figure 3-4 Comparison of flowrates at gauges 233231 and 233229

3.2.6 Model construction

Catchment linkages and routing

The topography shows clear gullies for almost all of the sub-areas that feed into the Boundary Creek along the TUFLOW model domain. This means it is possible to estimate approximately where along the channel each tributary flow is added. Source is then set-up to reflect this conceptualisation of added flows, with sub-catchment linkages shown in Figure 3-5.

For this model, straight through routing is adopted along all linkages, meaning the model only provides the runoff hydrographs and simply adds them together for downstream flow. Routing within Source has not been necessary as this is completed in TUFLOW.

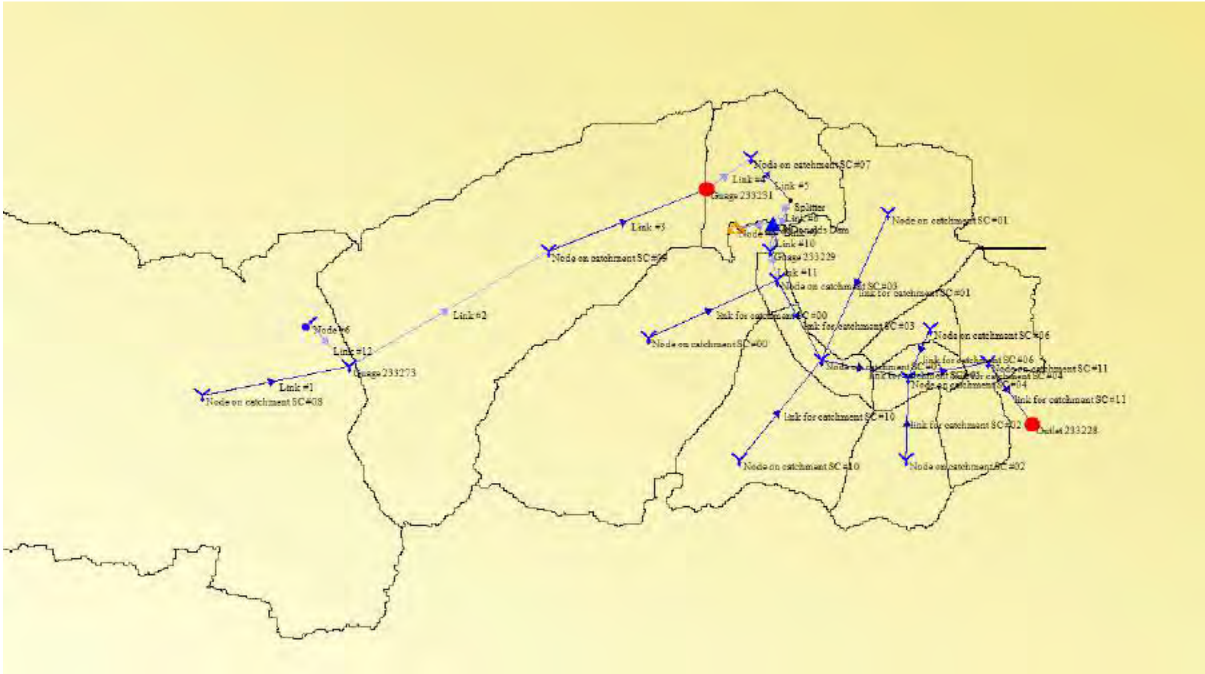


Figure 3-5 Catchment linkages

McDonald's Dam representation

McDonalds Dam has been explicitly modelled in Source using a storage node. There is some uncertainty around the exact operation of the dam that occurred during the calibration period. However, based on correspondence with Barwon Water, the dam operation is understood to be constrained by the following guidelines:

- Flows leave the dam via an outlet valve that has a capacity of 5 ML/day
- This valve is manually operated currently and is adjusted when flow changes are required.
- The dam fill period is 1 July to 31 October
- Outside the fill period, all flows must be passed by the dam.
- Dam extraction is licensed for 3 ML/day and 66 ML total per year.
- The spillway is an overflow weir.

This information still leaves some uncertainty as to when the dam filling and offtakes occurred. Therefore, the following assumptions have been made:

- The dam passes all incoming flows up to 5 ML/day throughout the year. When the flowrate exceeds 5 ML/day it will contribute to filling the dam.
- The dam offtake allowance of 66 ML/year is assumed to be extracted at a constant rate evenly distributing this offtake over the non-fill period. This results in a daily offtake of 0.273 ML for 31 October to 1 July.
- The dam has a capacity of 160 ML, when this is exceeded flows will be passed downstream via the spillway which is set at 167.17 mAHD.

This assumed behaviour has been modelled in Source using a flow splitter to divert incoming flow below 5 ML/d straight through the dam, a storage node to represent the dam, and a minimum flow requirement node to offtake 0.273 ML/d during the non-filling period.

The storage has been set so that the spillway would be overtopped at 160 ML. The dam spillway rating curve, as shown in Figure 3-6, has been generated using HEC-RAS.

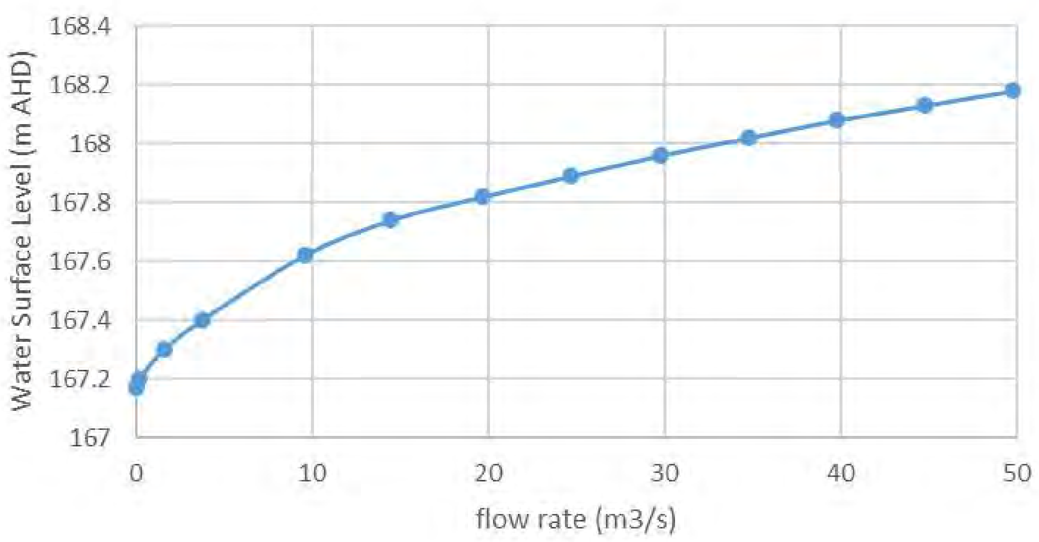


Figure 3-6 Dam spillway rating curve estimated for McDonalds Dam and entered into Source

Land use types

The catchment areas are considered to be made up of two land types: forest and farmland. The area of each land type in each sub-catchment is estimated by using satellite imagery to trace the areas of forest land and calculate the area. Only large blocks of forested land are considered forest and single trees or thin rows of trees have been included as farmland. The resulting land type areas for each sub-catchment are shown in Table 3. These areas are entered into the GR4J rainfall runoff model. Using two different land types allows the model to have two different parameter sets, to model the behaviour of the farmland and forest. The model then generates runoff proportionally to the areas. This is considered important when utilising the upstream gauge information in calibration, as differing land types are accounted for.

Table 3 Sub-catchment proportion of forest and farmland

Sub-catchment number	Total area (km^2)	Forest area (km^2)	Farmland area (km^2)	% forest	% farm
0	4.463	4.015	0.448	90	0.10
1	2.601	2.067	0.534	79	0.21
2	1.022	0.753	0.269	74	0.26
3	0.154	0.154	0	100	0.00
4	0.371	0.371	0	100	0.00
5	0.355	0.355	0	100	0.00
6	0.34	0.34	0	100	0.00
7	1.433	0.762	0.671	53	0.47
8	18.192	3.202	14.99	18	0.82
9	7.173	4.245	2.928	59	0.41
10	1.926	1.926	0	100	0.00
11	1.362	0.381	0.981	28	0.72

Supplementary flow

A supplementary flow of 2 ML/d has been added to the model upstream of gauge 233273. This has been applied as a constant inflow throughout the simulation period using an inflow node in Source.

3.3 Flood (TUFLOW) model design and construction

3.3.1 Overview

The primary purpose of developing the hydraulic model is to determine the areas and duration of inundation over Big Swamp and throughout the calibration (monitoring) period. For this project, TUFLOW version 2020-10-AA-iSP-W64 is used. TUFLOW is a hydrodynamic model used for simulating one-dimensional (1D) and two-dimensional (2D) flows. The model is based on the solution to the free-surface flow equations. The TUFLOW model consists of a 2D domain (TUFLOW) representing the topographic terrain surface, a 1D network (ESTRY) representing the pipe systems and a set of boundary conditions comprising the calculated GR4J and gauge input data hydrograph inflows and the downstream water levels.

The TUFLOW model has been derived from an existing model developed by Jacobs in 2019, with several enhancements to improve the representation of the study area. The base model has been developed to simulate existing conditions and calibrated to the available flow data from the gauges along Boundary Creek. The calibrate model has been used as the basis for testing several hydraulic barrier configurations to inform the design of the remedial system and provide inputs to the USG-Transport model.

3.3.2 TUFLOW model configuration

The TUFLOW model developed for the project is relatively simple, consisting mainly of boundary conditions and a digital terrain model. The major components of the model can be seen in Figure 3-7. Most of the flow comes into the model at the upstream boundary, which uses the gauge data from 233229 as an inflow hydrograph. The inputs from GR4J are added along the model at appropriate locations and the end of the model has a downstream HQ boundary. The main 1D components are two 1D weirs, set to model the v-notch weirs located at gauges 233275A and 233276A.

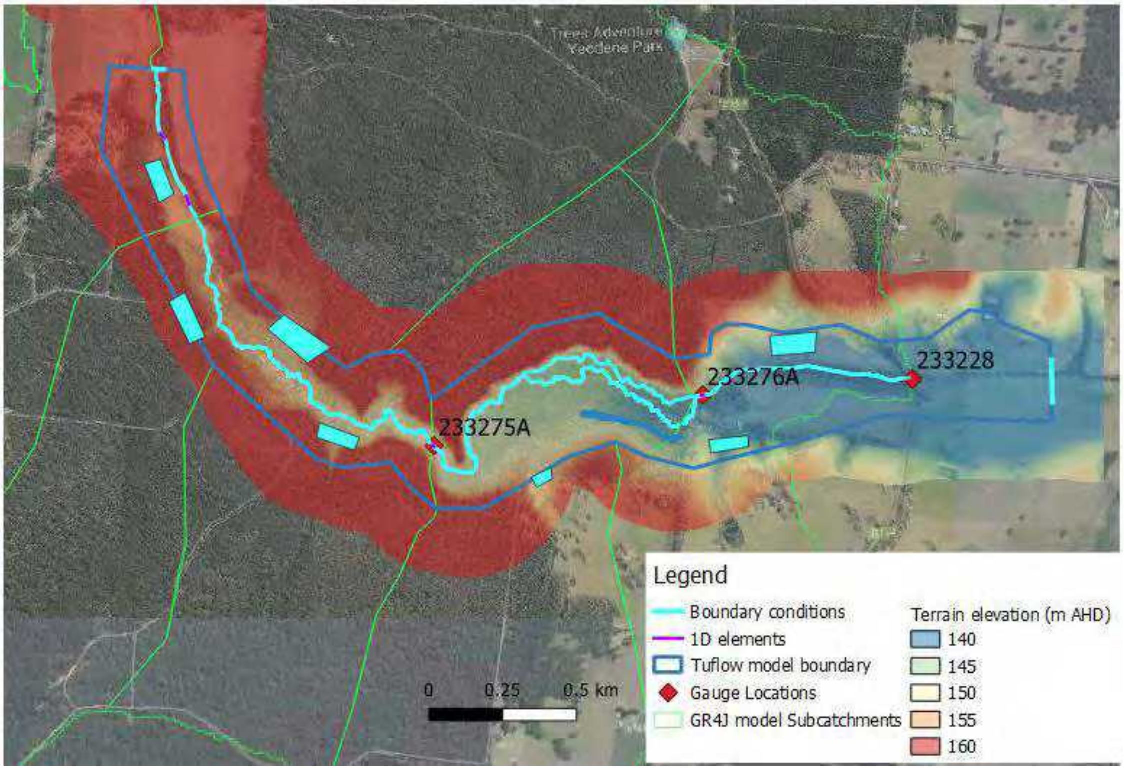


Figure 3-7 Tuflow model setup main components

3.3.3 2D domain

The 2D domain represents the ground surface, and hence the overland flow paths within the model. The digital terrain/elevation model (DEM) has been generated from LIDAR data, which has been processed to create a TIN surface from all the points identified in the metadata as being ground. Using this DEM, grid cells are formed, covering the model domain at a 4 m by 4 m resolution. Each grid cell is made up of nine internal points, with the elevation for each point derived from the DEM. The 2D domain created through this process has been used to model all overland flow paths.

There is currently a high degree of uncertainty in this terrain data, due to the presence of very dense vegetation. It appears that in many cases the top of vegetation, or in some locations the surface of the water, has been read by the LIDAR and included as a ground point. To demonstrate the inaccuracies in the terrain data in some locations, Figure 3-8 shows a sample of the terrain along the main channel. The spikes in the ground surface are clearly visible. This has been problematic along the channel, as bumps in the ground prevented surface water from continuing down the channel and caused the water to spill out and travel downstream via the floodplain. The ground surface along the channel has been improved using terrain shaping to connect the low points along the line and erase high points that are clearly not representative of ground surface. This has been achieved using a thin gully line strung between elevation points in TUFLOW. The outcome of this improvement is also shown in Figure 3-8, where the shaped DEM is smoother than the original. However, it is also clear that the bumps have not been entirely erased by this process.

A thick gully line connecting the low points has also been used to shape the area within the fire trench to ensure that surface water is properly diverted down under the existing conditions. This modification has been incorporated after the initial iteration of USG-Transport model calibration, as the break out (spilling) of surface water from the fire trench was thought to have overestimated the inundation and hence the modelled groundwater levels at bore BSBH08. It has been assumed that the fire trench acts as a channel, only to re-join Boundary Creek at the end of Big Swamp. It should be noted that whether or not surface water could break out from the fire trench is not clear from the terrain data and satellite imagery, therefore there remains some conceptual uncertainty in the actual hydraulic behaviour of the fire trench.

Whilst the terrain has been improved along the gully lines (including the main channel and fire trench), the entire 2D area of Big Swamp has not been treated to remove the highpoints. By using TUFLOW's new sub-grid sampling (SGS) feature, it is expected that the errors associated with this noisy elevation data will be reduced. Sub-grid sampling allows the TUFLOW model to run on a 4 m grid, whilst still using points spaced at 1 m intervals to determine if water can pass through a cell. Sub-grid sampling permits surface water to flow through parts of cells that would be wet, which could mean that most of the time surface water would still be able to flow around these localised terrain spikes.

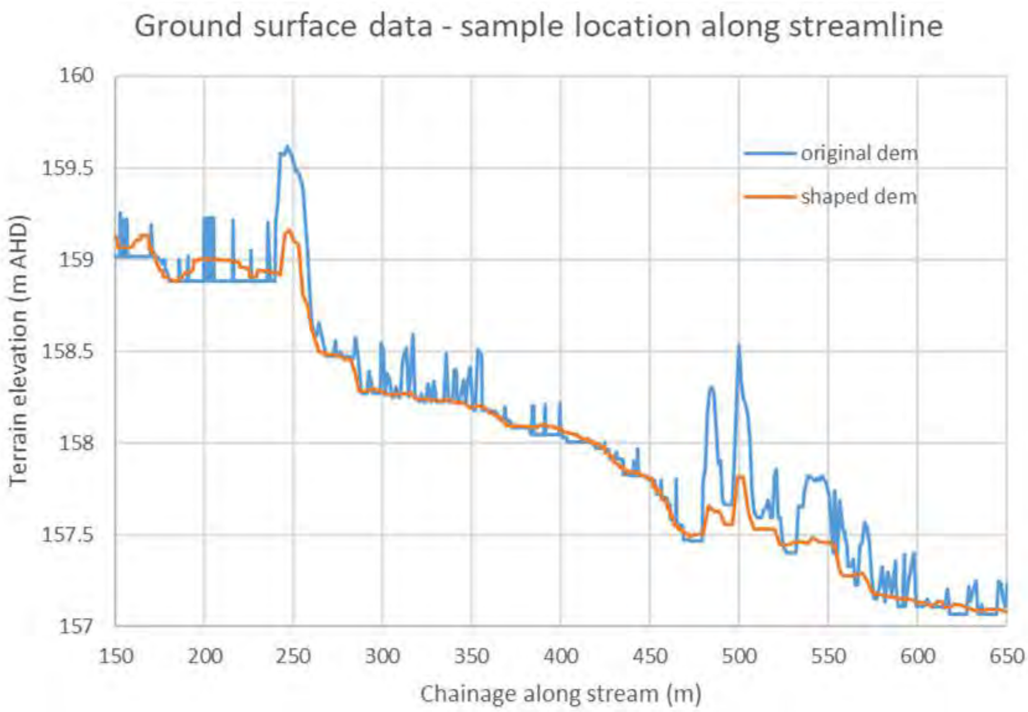


Figure 3-8 Sample of digital elevation model along main channel

3.3.4 1D elements

1D elements have been used in this model to represent the v-notch weirs that exist at gauges 233275A and 233276A. These weirs are represented as m-channels, with a stage-discharge relationship defined by the rating curve used to convert level data to flow data. The invert levels of the m-channels are set to the surveyed invert levels of the two gauges, at 149.421 and 140.393 mAHD for gauges 233275A and 233276A respectively. A thin z-shape line drawn across the channel is used to force the flow to travel through the m-channel only up until it reaches the level of the z line, where it can then flow freely over the top of it. The z-line levels have been set to the level of the top of the v-notch weir plates which are assumed to be 0.4 m above the invert levels, at 149.821 and 140.793 mAHD for gauges 233275A and 233276A respectively.

There are several 1D culverts included in the upstream parts of the model. These pipes were incorporated into the original model developed by Jacobs and have been retained for this project. The information used to configure these culverts have not been verified by GHD.

3.3.5 Model boundary conditions

Inflow boundary conditions

The inflows to the model consist of the main streamflow and the tributary sub-catchment flows.

The upstream flow in the main channel is taken from recorded data at gauge 233229. The gauge data has been filtered to remove flows with poor quality codes above 150. Much of the poor-quality data is due to extrapolation of level data beyond the extent of the rating curve. To address this issue, an additional high flow rating curve has been generated by a TUFLOW run with a steadily increasing flow rate. This rating curve is then used to infill missing data where the level indicated high flows.

At lower flows, the poor-quality data from gauge 233229 needed to be used. There is also one period of time between 23 December 2019 and 12 March 2020 where data from the upstream gauge 233231 needed to be used to infill, as gauge 233229 shows some anomalous behaviour during this time, with a spike in flows that appears erroneous given the absence of such a spike in every other gauge. This occurs over the same time as the rating curve for the gauge is changed, and therefore assumed to be an issue associated with this change. The original recorded gauge data for 233229 and the infilled timeseries, as well as the quality codes and a comparison to gauge 233231, is shown in Figure 2 3. The higher quality codes indicate poorer quality data, so these periods are where infilling has been applied.

The runoff generated by the sub-catchments outside the TUFLOW model boundary are applied as 2d “sa” polygons, located in the gullies where surface water would naturally flow in. The runoff generated by the sub catchments inside the TUFLOW model boundary (directly along the channel) is applied along the streamline using a series of streamline “sa” polygons.

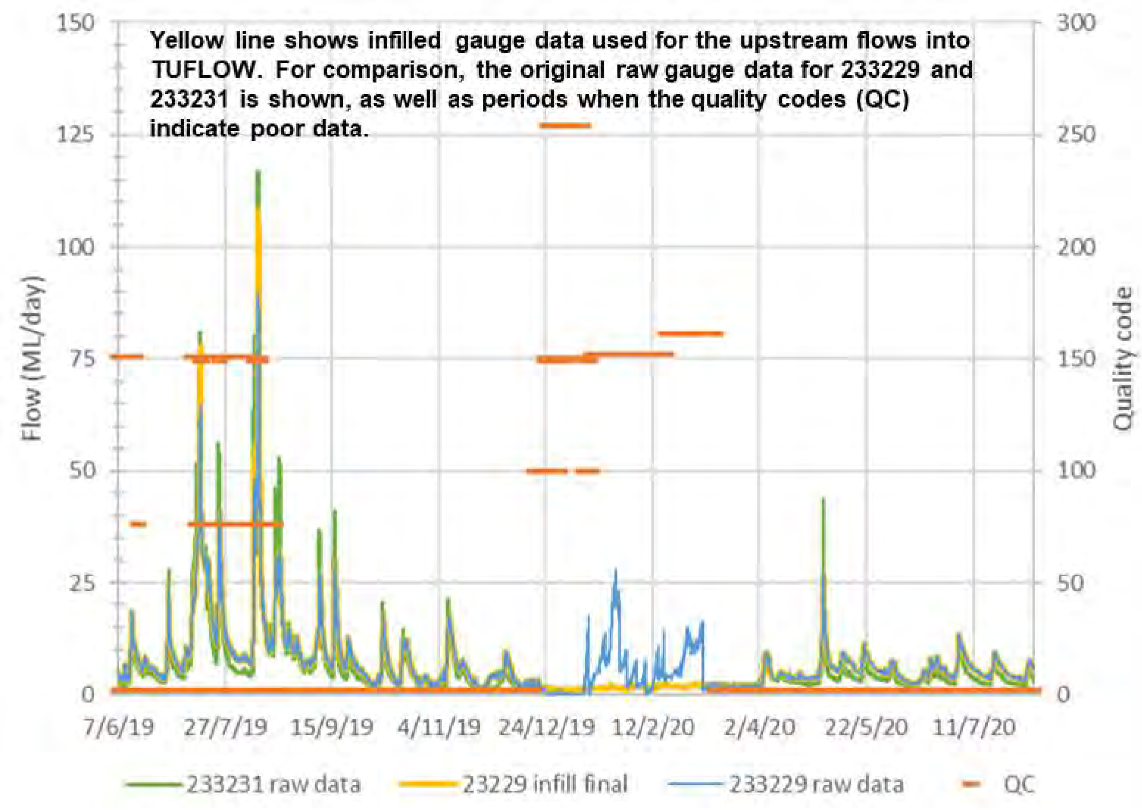


Figure 3-9 Infilled gauge data used for the upstream flows into Tuflow

Downstream boundary condition

The downstream boundary is located at the downstream code boundary of the model and consists of a HQ type boundary line.

Evaporation losses

Evaporation losses have been represented in the model as a constant loss that is lumped in with the infiltration loss.

The initial approach involved applying evaporation as a negative rainfall using an sa_rf polygon in TUFLOW. However, this feature only has the ability to remove a fixed volume of water from wet cells covered by the polygon. This means in dry periods, when very few cells are wet, the effective depths of water evaporated were around seven times higher than in the periods when more cells were wet. Alternatively, the soils function and the initial loss-continuing loss model can be used in TUFLOW to remove evaporation as a fixed depth from wet cells. However, this does not allow this loss to vary in time, as the evaporation forcing varies with the seasons. The limitations associated with these two options means a decision needs to be made between simplifying either the spatial or the temporal variations of evaporation.

After some testing of different options available, a decision has been made in this project to represent evaporation via the soil loss term by adding the average evaporation (about 4 mm/d) to the soil infiltration term. This ensures that evaporation is increasing as surface water spreads out and ponds over a greater area, which is considered to be important when simulating the effectiveness of hydraulic barrier configurations. Figure 3-10 shows the variation in evaporative demand over the period of historical observations, including a ten-day moving average to better show the seasonal average conditions. Evaporation varies from 1 to 8 mm/d between winter and summer. By using a time-constant average value, there are upwards of 4 mm of error in the applied daily evaporation. This is a limitation of the model, as TUFLOW does not currently have the capability for a better representation of these longer term conditions as it is primarily designed for short term event-based modelling. Nonetheless, this is considered a relatively minor issue given the much higher soil infiltration losses estimated from the USG-Transport model and large uncertainties associated with these losses.

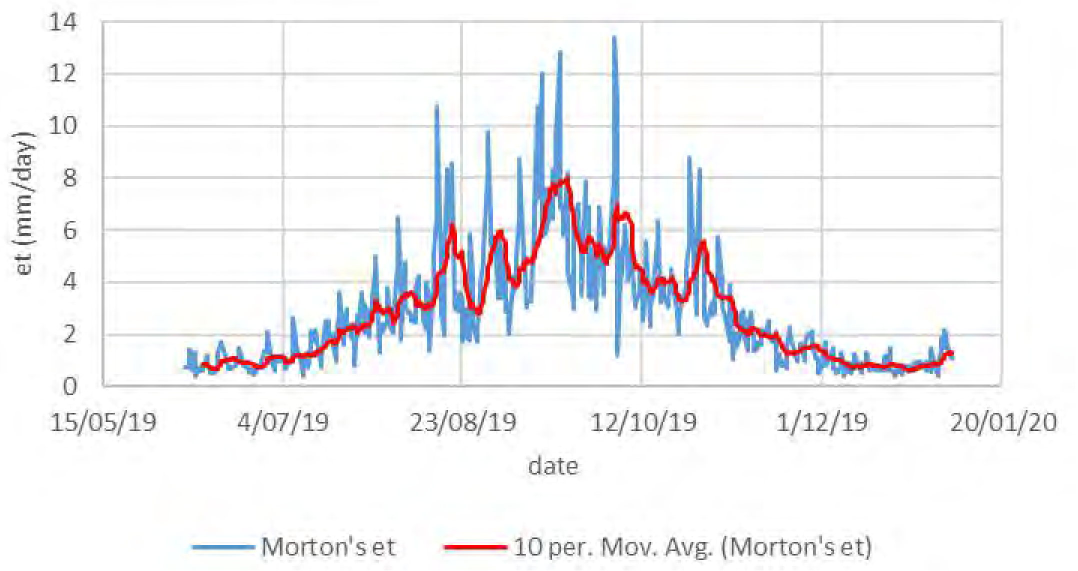


Figure 3-10 Evaporation forcing during monitoring period

Infiltration losses

Soil infiltration losses are accounted for using the soils function in TUFLOW, and the initial loss – continuing loss model. By setting the initial loss to zero and setting the continuing loss to a value in mm/d for each timestep, TUFLOW removes a fixed depth of water equal to the applied infiltration rate only from the wet cells. This capability has been verified using sub-grid sampling in several test model runs, to ensure that specified depths of water are correctly lost from the partially wet parts of the cell.

Due to the uncertainties and variability in the soil infiltration rates simulated by the USG-Transport model, several soil infiltration rates have been tested in the TUFLOW model. These used 35 mm/d infiltration along the main channel, with infiltration in other ponded areas set to 10, 25 and 40 mm/d. These soil loss values also include an average value of around 4mm/d of evaporation, which means the effective soil infiltration rates are 6, 21 and 36 mm/d. The calibrated model currently uses 25 mm/d soil infiltration loss, which is discussed further in Section 4.1.

Note that the use of Green-Ampt soil losses was initially the preferred option for estimating soil infiltration in TUFLOW. However, TUFLOW does not include any way for the soil moisture to be reduced. This means once the soil is saturated during the first wet period, it would remain saturated for the rest of the simulation, leading to incorrect representation of the drying and wetting cycles.

3.3.6 Material roughness

The Manning's n values used to specify the roughness of the ground surfaces are shown in Figure 3-11. These values have been selected based on typical values for each land use type and are unchanged from the previous modelling undertaken by Jacobs. The land use types are broadly consistent with the evapotranspiration zones applied to the USG-Transport model, which is discussed in Section 3.4.2.

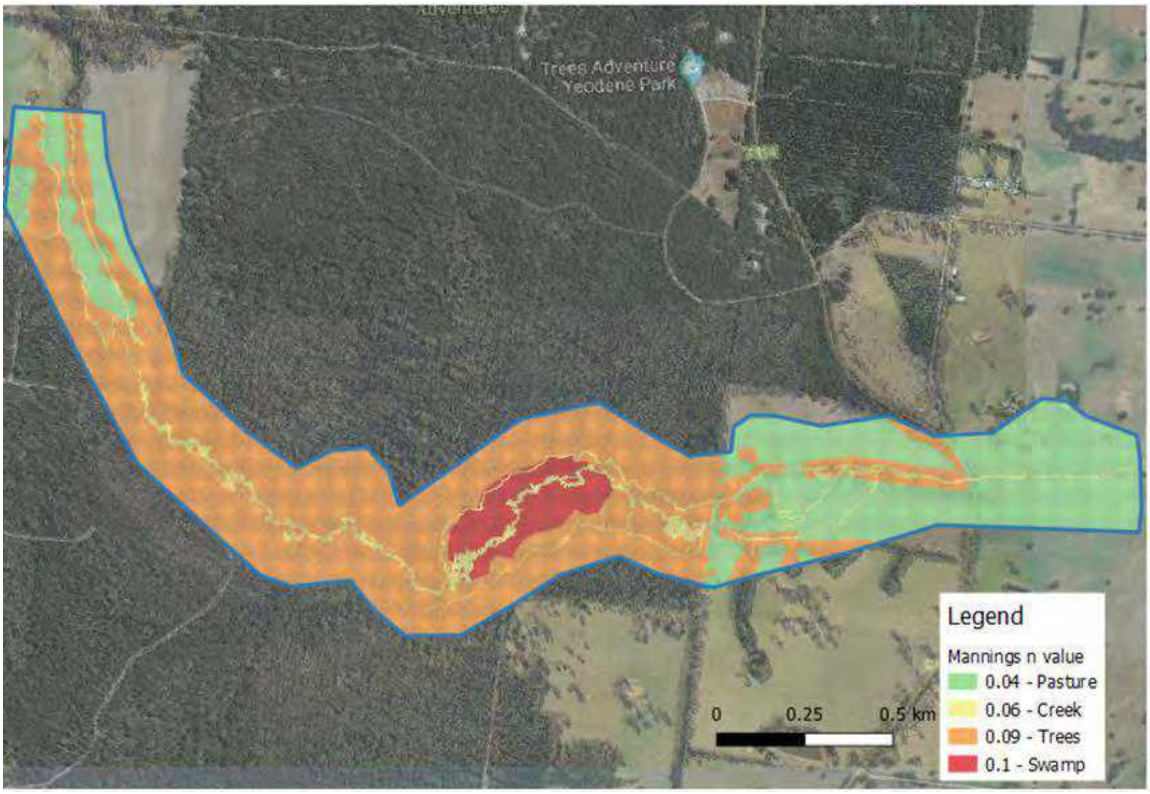


Figure 3-11 **Manning's n values**

3.4 Groundwater (USG-Transport) model design and construction

3.4.1 Model domain and structure

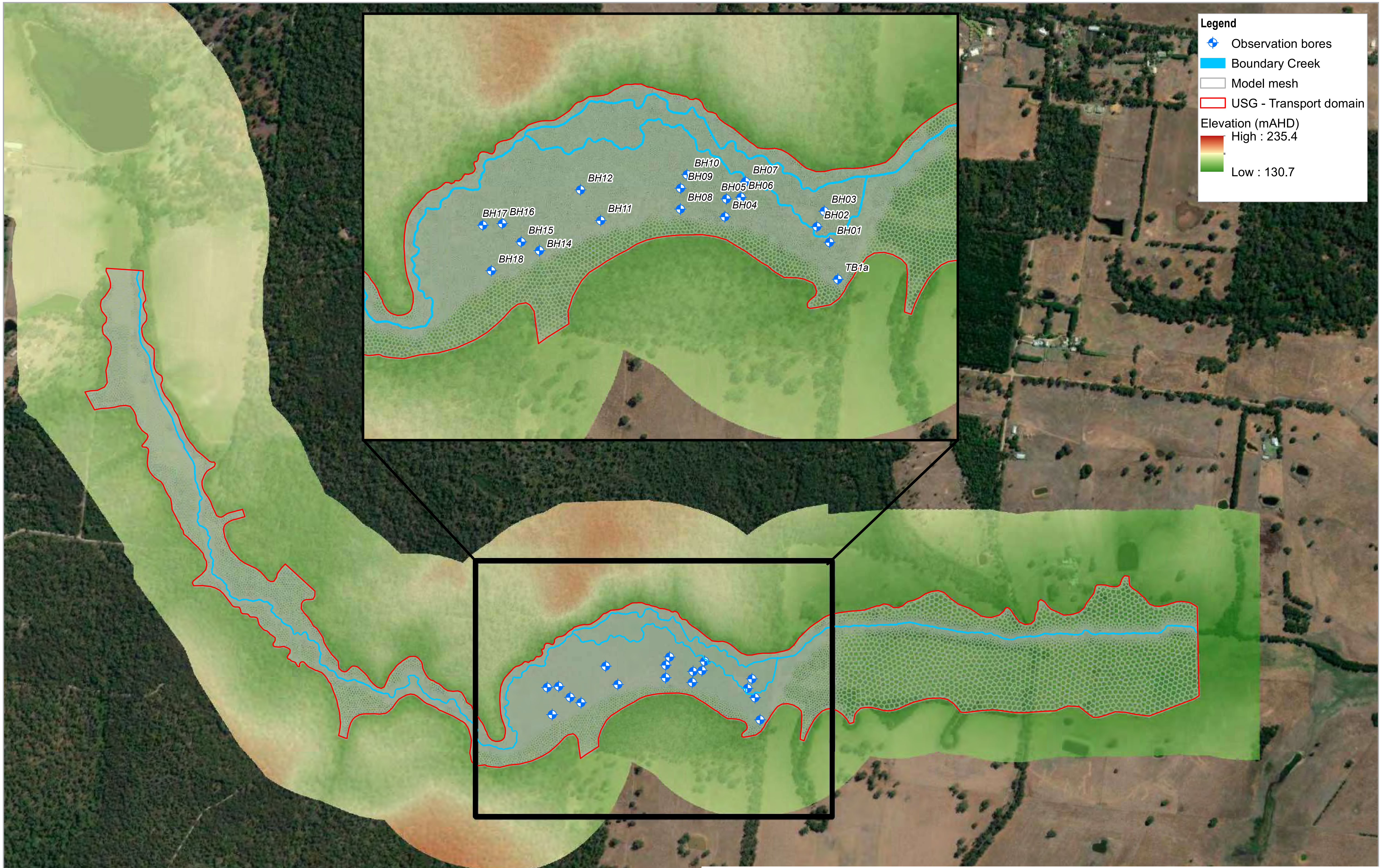
The USG-Transport model domain is based on the revised extent of the QA, taking into consideration the geological map, borehole logs and topography. This is broadly consistent with the QA extent of the FEFLOW model, with modifications to better reflect the presence of alluvial sediments along minor channels/tributaries (such as those encountered at the nested site TB1 and bores TB2b and TB2c drilled further upstream). The domain is defined along the entire length of the TUFLOW model to maintain consistent spatial extents and to facilitate the exchange of information between the two models (including the surface flow/run-off terms applied along their boundaries). The domain covers Reach 2 of Boundary Creek, and approximately a third of Reach 3 downstream of Big Swamp.

The USG-Transport model uses an unstructured mesh, with Voronoi (tessellated) cells that are considered numerically ideal for meeting the requirements of the controlled volume finite difference formulation (a line connecting the centres of two adjacent cells intersects the shared face at or close to a right angle). The mesh is refined in critical areas where the accuracy is considered important. These include much of the wetland area, where the bores are located and overland (inundation) flow is expected, with cell lengths reducing to around 3 m. The bores are used as constrained points to align the Voronoi cell centres to the location of each bore. The mesh is also refined along Boundary Creek, with constrained points spaced at roughly 2 m apart, producing a series of cells connected along the creek alignment with a length of around 2 m and width of around 3 m (broadly consistent with the typical channel width). This is based on the alignment of Boundary Creek delineated from the most accurate DEM and includes the primary channel and secondary channel that diverges within Big Swamp.

The model top is based on the processed DEM used in TUFLOW, which is derived from lidar and has been spot checked against the surveyed bore and gauge elevations. The thickness of the QA is assumed to be around 8 m in the most upstream end of the model, increasing linearly along Boundary Creek and reaching a thickness of around 12 m at the location of nested site TB1 (based on the depth of QA interpreted from the borehole logs). The QA is also assumed to thin towards the edge, where it pinches out against the outcropping bedrock to form a channel-filled geometry.

The QA is split into two model layers, to enable partially penetrating hydraulic barriers to be simulated in the model if required. There are 38,806 cells per layer and 77,612 cells in total.

Figure 3-12 shows the model domain and unstructured mesh, including mesh refinement in the area of Big Swamp and along Boundary Creek. Figure 3-13 shows the 3D view of the model domain, including the model top elevation. The model top elevation is also shown in Figure 3-14, along with the QA thickness.



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Big Swamp Modelling for Detailed Design

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Revision No. B
Date 24/12/2020

Model domain and mesh

FIGURE 3-12

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Print date: 08 Apr 2021 - 17:31

Data source: GHD, TUFLOW domain, 2020; GHD, model mesh and domain, 2020; Jacobs, Bore Locations, 2019; Jacobs, DEM, 2020; Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: bsmyth (tworth)

Figure 3-13 3D view of groundwater model domain

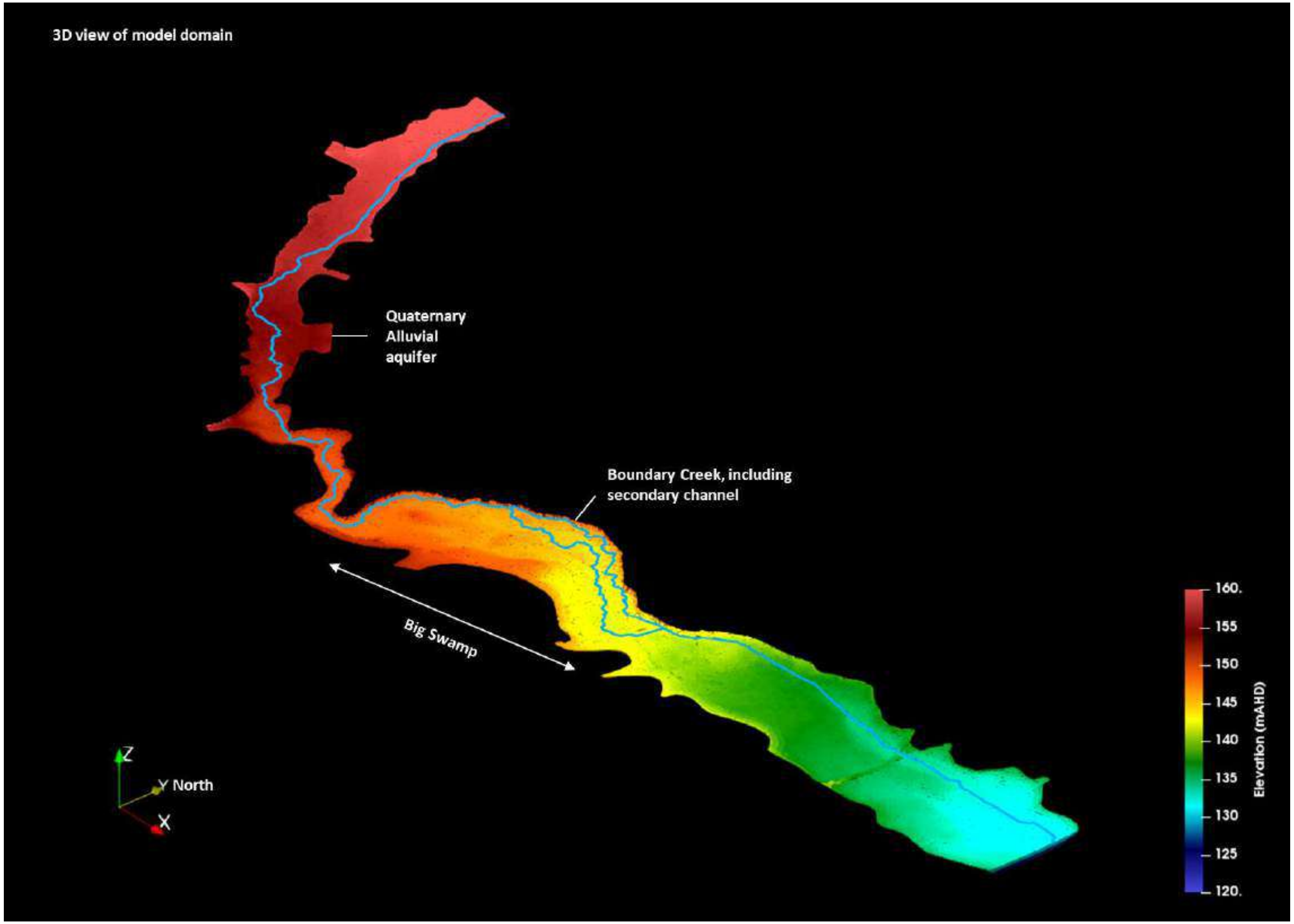
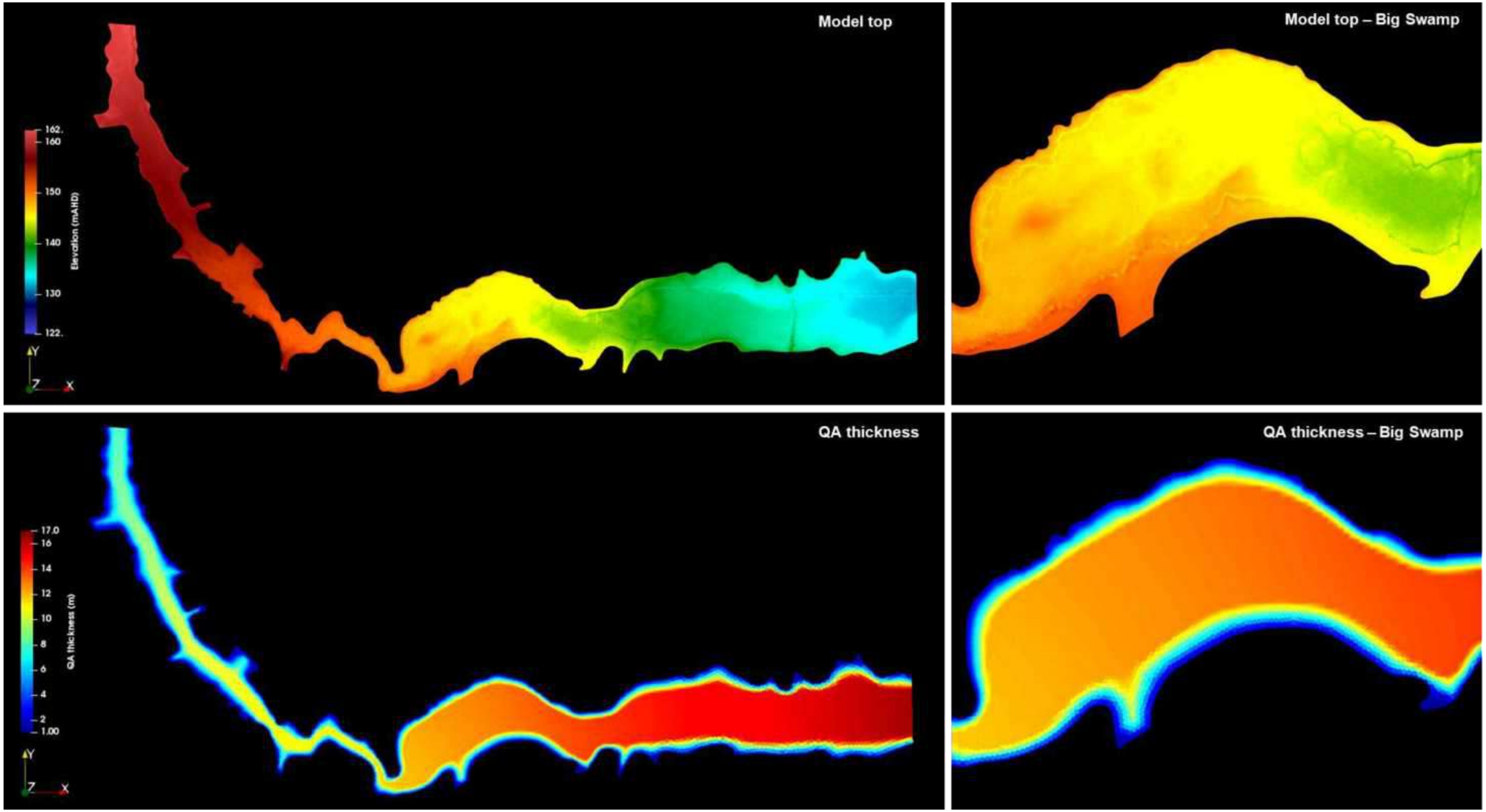


Figure 3-14 Model top and QA thickness



3.4.2 Model boundary conditions

River boundary condition

USG-Transport's River (RIV) package is a head-dependent flux boundary condition, which is used in this study to simulate infiltration due to surface water inundation/overland flow. The surface water depths and extents derived from the TUFLOW flood model are used to parameterise the RIV stage and map the location of RIV cells. As the TUFLOW model is solved using much finer time steps than the length of USG-Transport model stress periods, the water depth and extents from TUFLOW are spatially and temporally averaged over each stress period to derive time-varying RIV boundary condition. This means both the RIV stage and number of RIV cells vary for each model stress period to represent the dynamic nature of surface water inundation process.

The RIV conductance term is rigorously calculated for each RIV cell using the cell area, RIV bed hydraulic conductivity and RIV bed thickness (assumed to be 0.5 m based on the typical thickness of surficial material comprising clayey silt with loose fine sand and rootlets, as recorded in borehole logs).

The RIV cells are absent along Boundary Creek, which is simulated using the Stream boundary condition.

Stream boundary condition

USG-Transport's Stream Flow Routing (SFR2) package is used to simulate Boundary Creek and its interaction with groundwater. With the SFR boundaries, the volume of water available for interaction with the modelled groundwater system is limited to that which has accumulated from upstream within the defined stream channel network (from baseflow, and/or any runoff and artificial discharges, less any diversions). In dry times, there may be no or little water flowing down the stream network, thus avoiding unrealistic leakage of water into the model from these boundaries. This capability is particularly important for this project, as the flow loss observed between gauge 233275A and 2332756A is critical for understanding the stream leakage rates and therefore the effectiveness of supplementary flow regimes in maintaining flow downstream. The model can also be calibrated to both stream flows and stream stage, which aids in narrowing the uncertainty in modelled water balance.

In this study, time-varying stream stage is calculated using Manning's equation with a rectangular wide channel. The channel widths are varied from 1 to 3 m during calibration, based on a typical range of widths estimated from DEM. The Manning's roughness is also varied during calibration from 0.05 to 0.2, with the lower end of the range representing tortuous channels with vegetation (as commonly encountered in swamps).

SFR bed elevations are defined using the processed DEM, with enforced topographic fall down the stream network. The bed elevations at the location of flow gauges 233275A and 2332756A have been corrected against the surveyed gauge zero elevations to ensure accurate computation of stream stage. Stream length within each model cell is calculated rigorously based on the stream geometry derived from DEM. Hydraulic conductivity of the bed material (and hence the stream bed conductance) is adjusted during model calibration. Stream bed thickness is set to 0.5 m, consistent with the RIV boundary condition.

For the calibration period, a total of 14 stream segments are used to assign inflow from downstream of McDonald's Dam and various tributary points along the length of Boundary Creek (see Figure 3-16). These flow terms are derived from the GR4J hydrological model, ensuring consistency with the flow terms applied to the TUFLOW model. The daily flow from the GR4J model have been averaged over the length of model stress periods. Where the secondary channel diverges from the primary channel within Big Swamp, a diversion is created to direct flow into the secondary channel. This is based on the flow split derived from the TUFLOW model, which equates to roughly 20% of flow diverted to the secondary channel.

For the predictive simulation, additional stream segments and diversion have been incorporated to simulate the diversion of flow into the swamp to redistribute flow. This is discussed further in Section 5.3.

Recharge and evapotranspiration

Recharge and evapotranspiration are simulated using USG-Transport's Recharge (RCH) and Evapotranspiration (EVT) packages. The initial estimates of time-varying recharge and evapotranspiration have been derived using a simple water balance model called LUMPREM (Doherty, 2020) which uses daily climate data and unsaturated zone parameters to derive deep drainage, runoff and evapotranspiration. The outputs from LUMPREM are sensitive to the assumed unsaturated zone parameters such as soil moisture store, soil hydraulic conductivity, crop factor and recharge delay which are often not known. Nonetheless, the LUMPREM outputs based on initial parameter estimates can provide a hydrologically sensible starting point for parameterising time-varying recharge and evapotranspiration, which can be subsequently varied during model calibration.

The daily rainfall data from the nearest rainfall gauge 233250 and the daily pan evaporation data from the nearest SILO point are used as climate inputs to the LUMPREM model. The typical plant root zone is assumed to be shallow (1 m), with a soil porosity of 0.3 and vertical soil hydraulic conductivity of 0.02 m/d (an order of magnitude lower than the average from slug tests). A simple time constant crop factor of 0.8 has been assumed.

A total of four zones are used to parameterise the EVT package's extinction depth. This defines the maximum depth below land surface above which the water table must occur before evapotranspiration is removed from the groundwater model. The evapotranspiration rate varies linearly from nil if the water table level occurs at or below the extinction depth, up to the defined maximum rate if it occurs at or above the land surface. The EVT zones for parameterising the extinction depths are based on the echo-hydrological zones developed by Ecological Australia (2019) and broad inspection of aerial imagery, and include:

- Zone 1, defined over woodlands where deep-rooted vegetation/trees are likely to be accessing groundwater (including various Eucalyptus species). Within Big Swamp, this includes Damp Woodlands and Main Channel eco-hydrological zones. The plausible range of extinction depth is assumed to be 1 to 5 m.
- Zone 2, corresponding to the Swamp Plain eco-hydrological zone comprising shallow rooted vegetation (such as Riparian Fern Scrub) the require a near-constant waterlogged condition. The extinction depth is assumed to be shallow, ranging from 0.3 to 1 m.
- Zone 3, corresponding to pasture/grass areas outside of Big Swamp where the extinction depth is expected to be shallow. As per Zone 2, the extinction depth is assumed to be shallow, ranging from 0.2 to 1 m.
- Zone 4, defined along the perimeter of the model where the QA is thin and the extinction depth is constrained to prevent unrealistic EVT i.e. to prevent the extinction depth extending below the bottom of model. The extinction depth for this zone is assumed to range from 0.1 to 1 m.

Recharge and EVT are set to zero over the location of RIV and SFR cells. As the number and location of RIV cells vary dynamically, the location and number of zero RCH and EVT cells also vary from one stress period to the next.

Specified gradient boundary condition

USG-Transport's Specified Gradient Boundary (SGB) package is used to simulate the component of through-flow into and out of the model and vertical flow to and from the underlying LTA. The SGB provides efficient means of allowing fluxes into and out of the model based on hydraulic gradients, cross-sectional area perpendicular to the direction of flow and anisotropy ratio relative to the horizontal hydraulic conductivity in x-direction. The positive SGB terms represent flow into the model and negative SGB terms represent flow out of the model.

For aquifer through-flow into and out of the model, positive and negative SGB terms are assigned along the northern (upgradient) and eastern (down gradient) boundary of the model respectively. The SGB term is calculated for each cell based on the cross-sectional area and horizontal hydraulic gradients estimated from the regional piezometric contours of the LTA, which are varied during calibration within a plausible range.

For the vertical flow component, the SGB terms have been calculated using the following steps:

- Firstly, an interpreted surface of piezometric heads was derived using the recent measurements of groundwater levels in the LTA bores 109130, 109128 and TB1C and the horizontal hydraulic gradients between them. This provides a piezometric surface that accurately matches the measured groundwater levels at the location each bore.
- The vertical hydraulic head difference is then computed on a cell-by-cell basis using the interpreted LTA heads and heads in the QA. Because the latter is also not known everywhere in the model in advance, a reference depth to water has been calculated from the bores within the swamp. This is subtracted from the model top to derive approximate QA head for each model cell. As the shallow groundwater levels are highly dynamic, the reference depth (and hence the heads in the QA) is varied over time based on the range of groundwater depths recorded at the bores over each model stress period (which is varied during calibration). While simplified, this provides highly efficient means of allowing the direction and magnitude of vertical fluxes to vary spatially and temporally such that their effects on the observed groundwater levels and trends can be closely examined. The vertical hydraulic head differences are divided by the half aquifer thickness to calculate hydraulic gradients.
- The vertical hydraulic gradient at each model cell is multiplied by the cell area and an anisotropy ratio (kz/kx), which vary spatially. This means the SGB term computed for each model cell is unique and reflects the spatial differences in vertical hydraulic gradients, cell area and anisotropy ratio. Where/when the heads in the LTA are lower than the QA heads, negative SGB terms are used to compute fluxes out of the QA and vice versa.

The interpreted surface of the LTA heads indicate that the LTA becomes artesian in the downstream part of the swamp. This corresponds to the interpreted extent of the MTD, which is thought to occur approximately in the middle of the swamp based on the regional geological map. Although there is uncertainty in the exact location of this boundary, the development of an artesian condition is consistent with the confining effect of the MTD which limits the hydraulic connection between the LTA and QA, as seen at the nested site TB1. The early testing of the model also indicated excess upward flow into the model when the SGB terms are prescribed in the artesian/MTD area, which is not supported by the available data. For this reason, no SGB terms have been assigned over the interpreted area of the MTD.

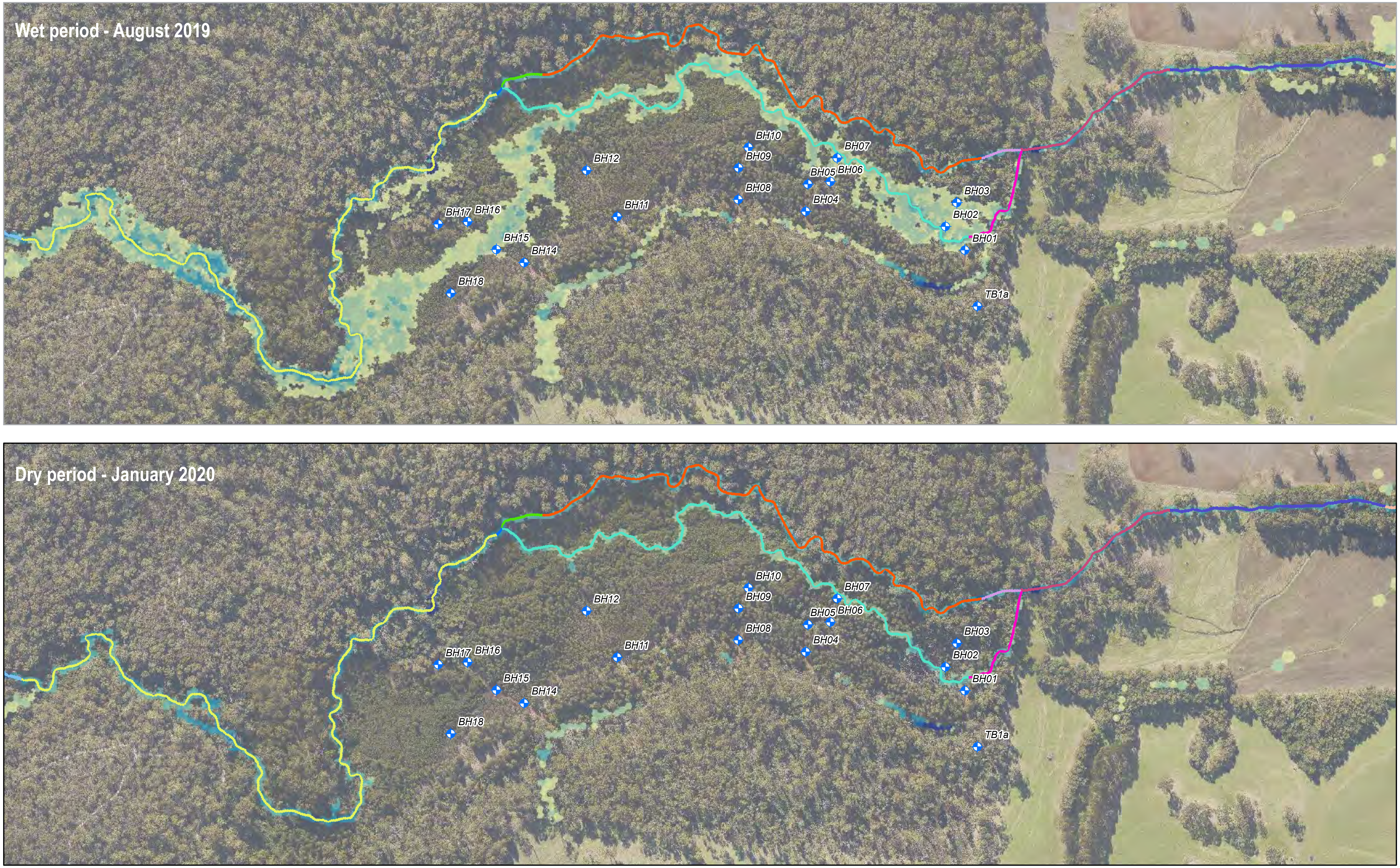
In the current SGB configuration, the LTA heads are assumed to be constant during the period of model simulation (14 months). This is supported by very little variation in the LTA heads observed over this period (see Figure 3-19), which is small compared to the seasonal variations in the QA heads. For future model use, the effect of changes in the LTA heads can be easily incorporated to the SGB terms by varying the LTA heads and recalculating the SGB terms.

Figure 3-18 and Figure 3-19 provide further information on the configuration of the SGB terms.

Drain boundary condition

USG-Transport's Drain (DRN) package is used to simulate the presence of narrow fire trench along the southern boundary of Big Swamp. The DRN elevation is based on the lowest DEM intersected by the DRN cell and the conductance term is calculated accurately using the length of fire trench intersecting each DRN cell and a width of 2 m. The DRN hydraulic conductivity is derived from the RIV bed hydraulic conductivity used to parameterise the surficial material.

During wet periods, the TUFLOW model simulates ponding of surface water in the fire trench. This means the DRN cells switch on and off dynamically depending on whether or not RIV cells are active in a given stress period.



Legend

Observation bores

SFR Segment

- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14

RIV ponding depth (m)

- 0.02 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6

Paper Size ISO A3

0 25 50 75 100

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

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SFR and RIV boundary conditions

Project No. **12536659**
Revision No. **B**
Date **23/12/2020**

FIGURE 3-15

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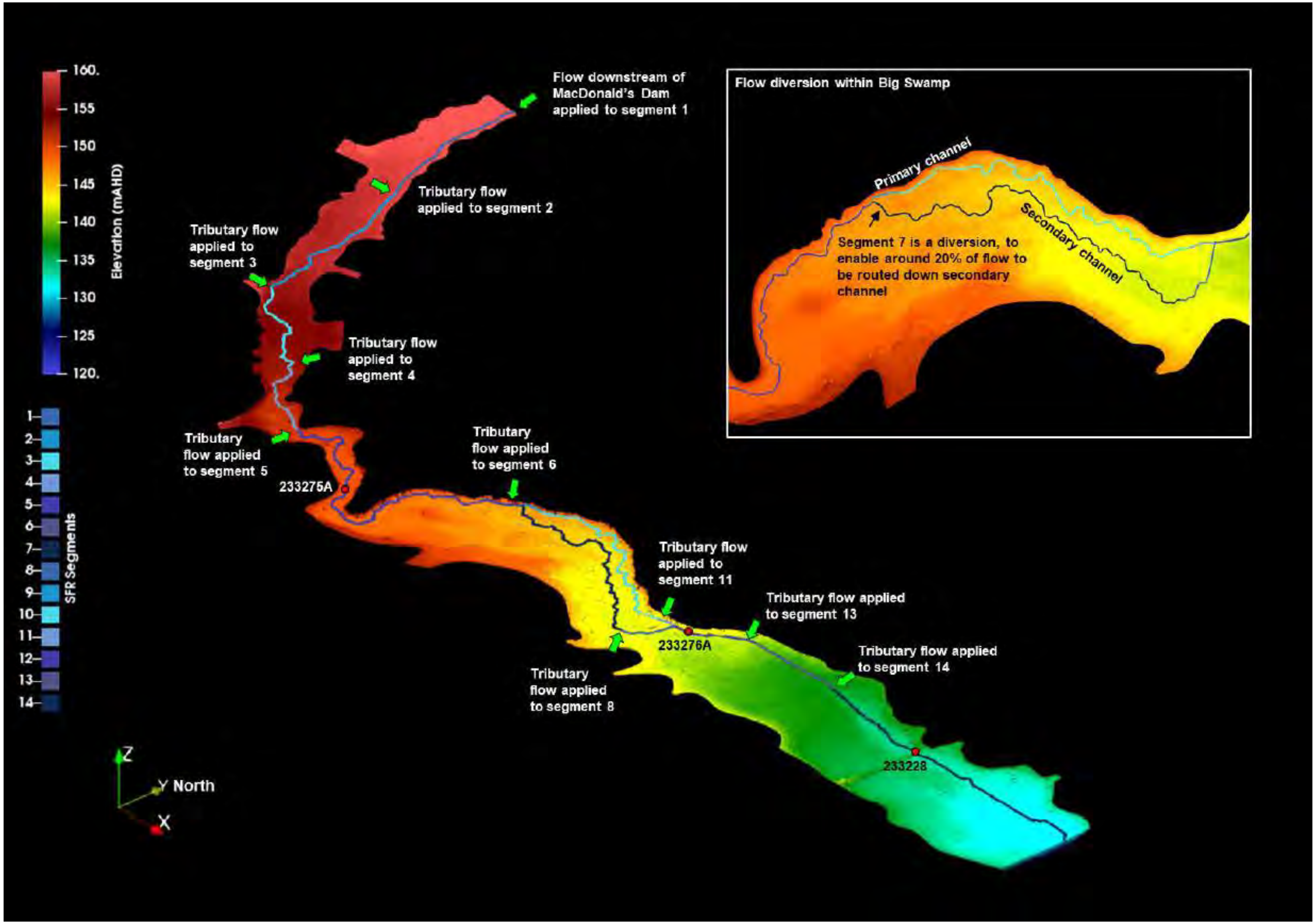
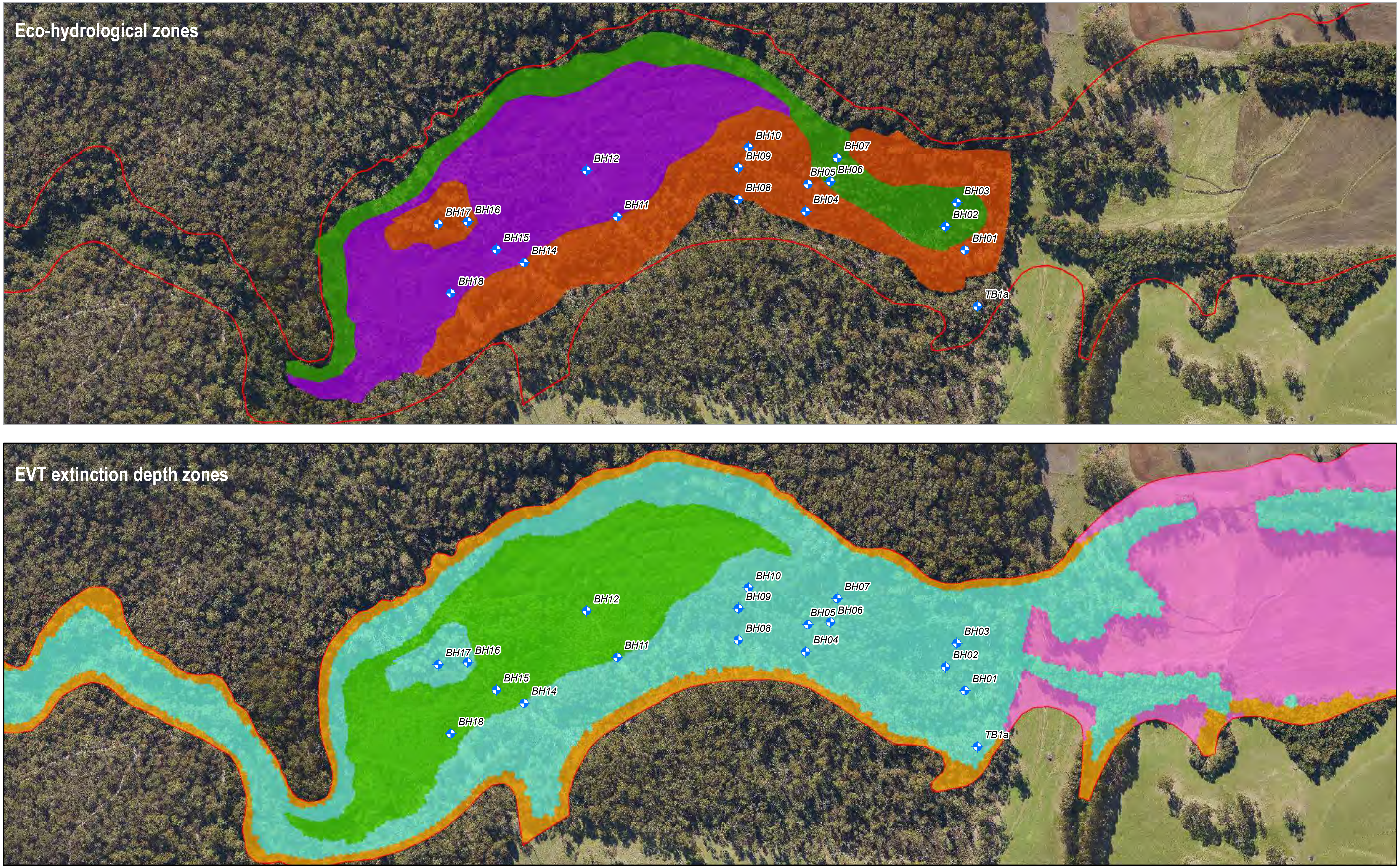
Print date: 08 Apr 2021 - 17:29

Data source: Jacobs, Bore Locations, 2019; GHD, RIV and SFR boundary conditions, 2020; BW, Imagery, 2019; . Created by: bsmyth (tworth)

Figure 3-16 SFR segments and inflows





Legend

Observation bores
USG - Transport domain
Eco-hydrological zones
Damp woodlands
Main channel
Swamp plain
EVT extinction depth zones
1
2
3
4

Paper Size ISO A3

0 25 50 75 100

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Project No. **12536659**
Revision No. **B**
Date **23/12/2020**

EVT extinction depth zones

FIGURE 3-17

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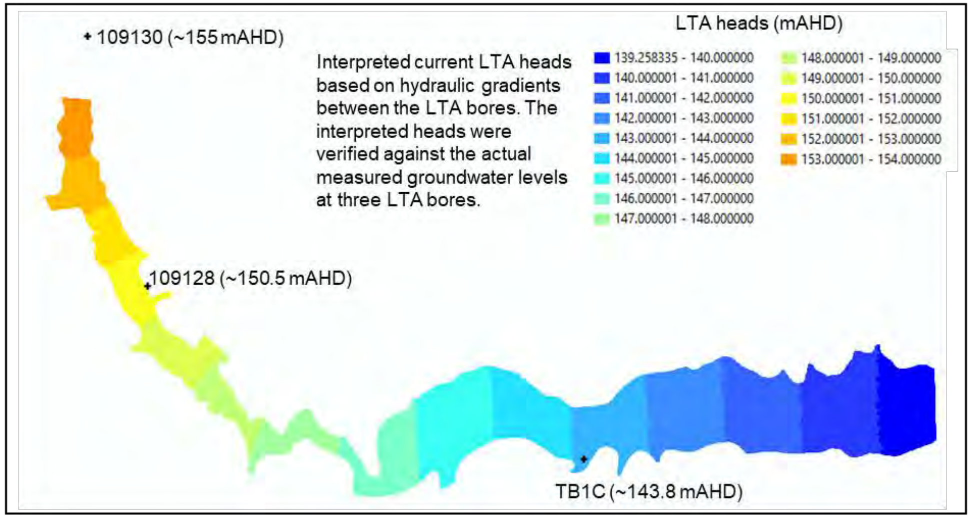
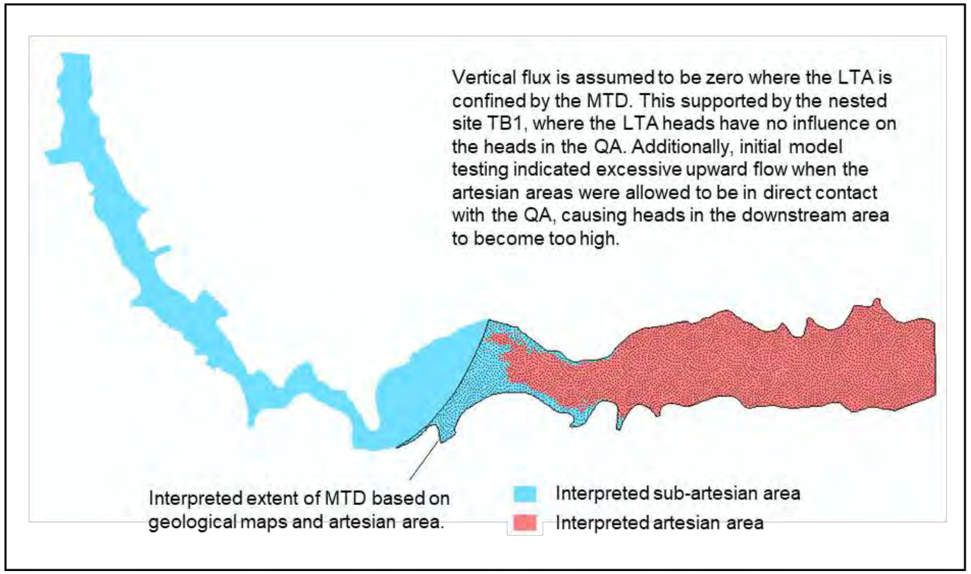
Print date: 08 Apr 2021 - 17:28

Data source: Jacobs, Bore Locations, 2019; GHD, REVT extinction depth zones, 2020; Ecological Australia, eco-hydrological zones, 2019; BW, imagery, 2019; . Created by: bsmyth (tworth)

Figure 3-18 SGB set up – part 1





Specified gradient boundaries (SGB) are parameterised in the following manner:

- Along the up gradient and down gradient boundaries, positive and negative horizontal SGB terms are prescribed to represent the component of through-flow into and out of the model, respectively. The SGB terms are applied to both layer 1 and 2 and are calculated by multiplying the hydraulic gradient by the cross-sectional area of each voronoi cell.
- Elsewhere, vertical SGB terms are prescribed to simulate the component of vertical flow into and out of the QA. The vertical head difference is calculated by subtracting representative water levels in the QA from the interpreted heads in the LTA. Because appropriate water levels are not known everywhere in the QA prior to modelling, these were adjusted during calibration within the expected range of water level (creating a surface of reference depth to water from which reference water level is calculated on a cell-by-cell basis). The vertical gradient is calculated between the base and mid-point of the QA (head difference divided by the half thickness of QA). As the QA water levels are highly dynamic, the minimum and maximum reference water depths have been calculated for each stress period based on the observed water levels from bores in the area where the QA is in contact with the LTA. The vertical SGB terms are then calculated on a cell-by-cell basis using the surface area and kz/kx anisotropy ratio of each voronoic cell.
- Where the MTD is present and limits the vertical hydraulic connection between the QA and LTA, no SGB terms have been prescribed. This is based on the limited hydraulic connection observed at the nested monitoring site TB1.
- The LTA heads are assumed to be steady during the calibration period based on the observed data; however, this simple approach allows the effects of future changes in the LTA heads to be easily incorporated into the model by shifting the LTA heads and recalculating the SGB terms.

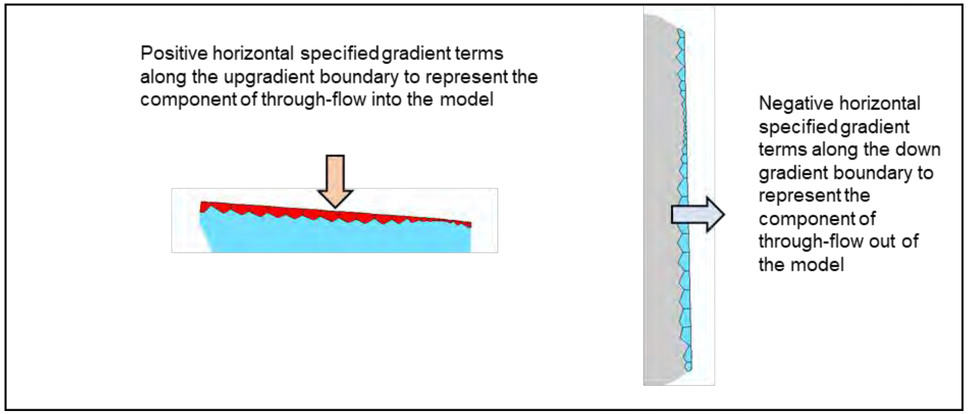
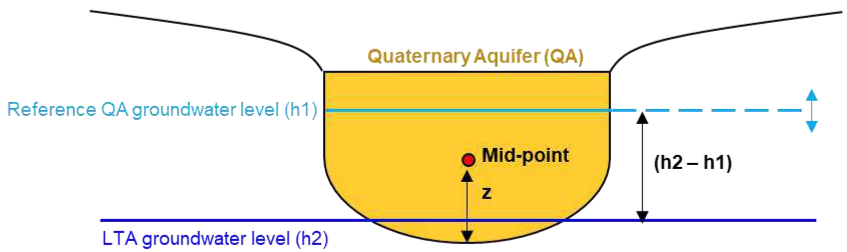


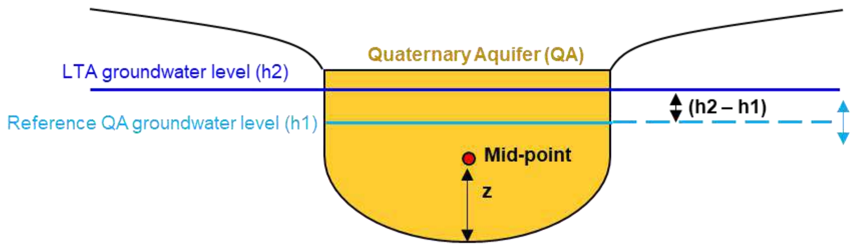
Figure 3-19 SGB set up – part 2

Losing condition



Z gradient = (h2 – h1) / z = negative gradient indicating vertical flow out

Gaining condition

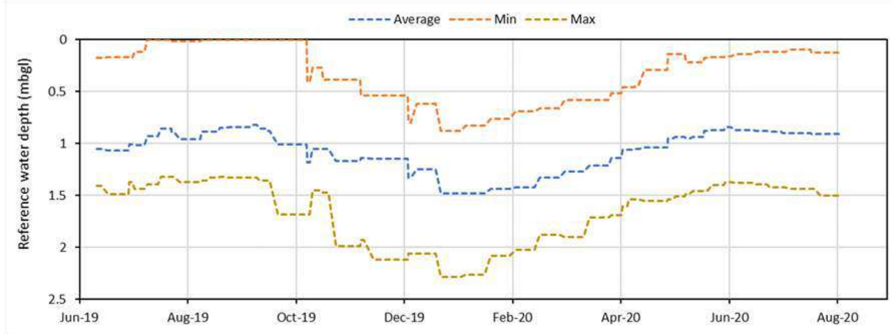


Z gradient = (h2 – h1) / z = positive gradient indicating vertical flow in

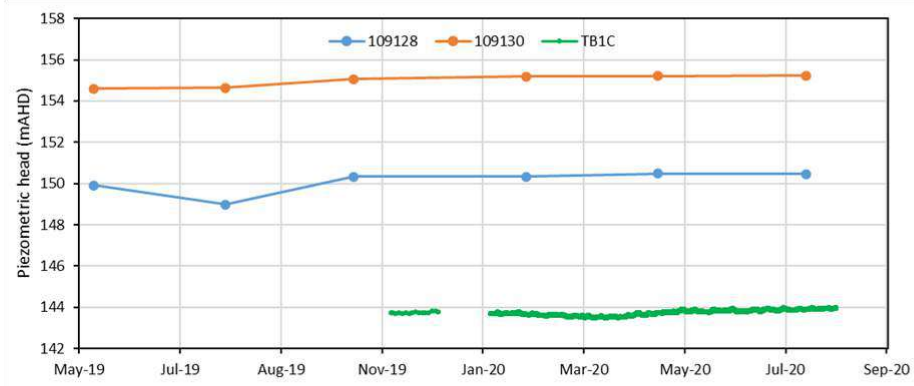
Reference water level has been allowed to shift during calibration within a range defined by the water levels of upstream bores where the QA is in contact with the LTA.

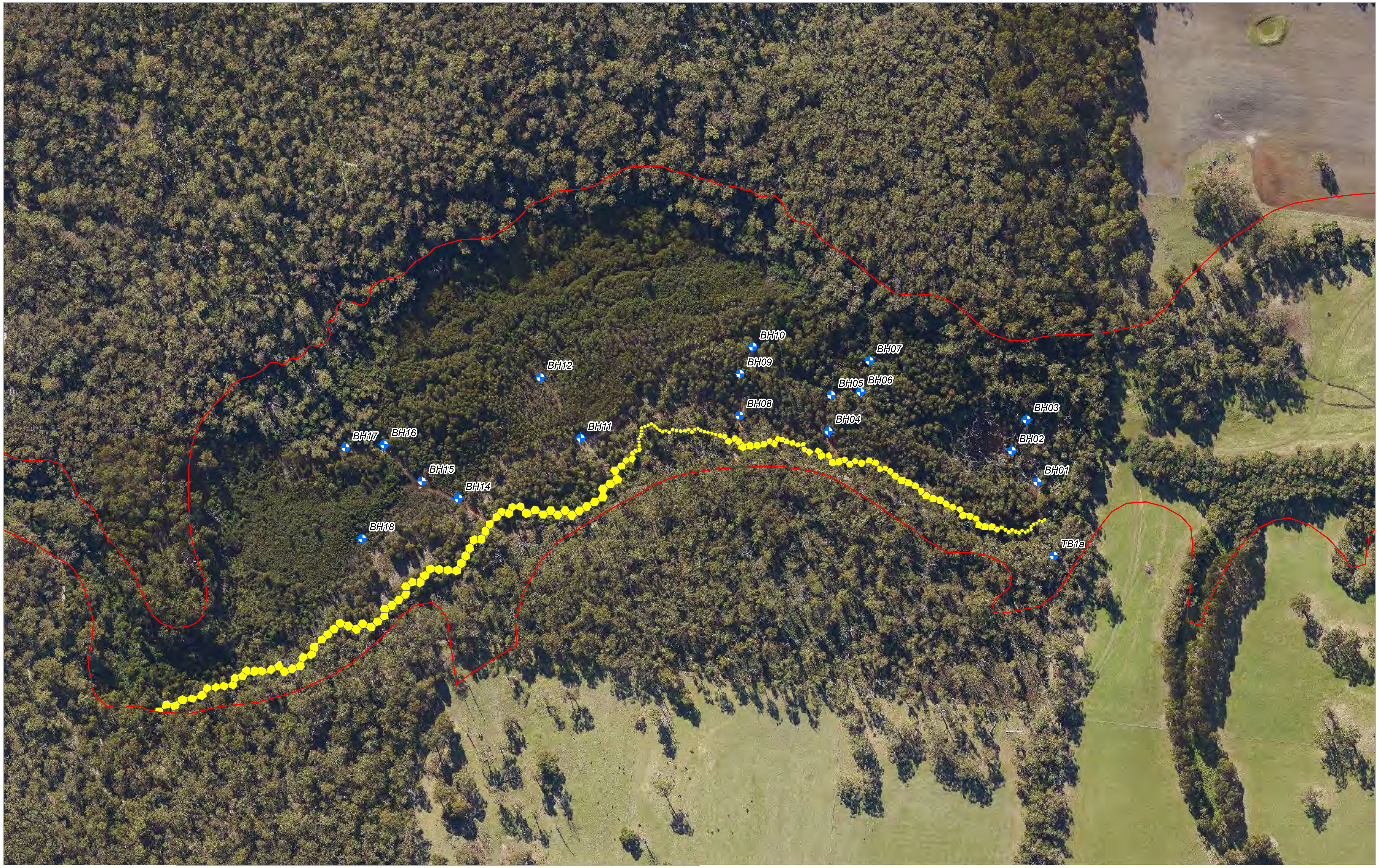
Where the QA is thin (towards its edges), the reference levels can fall below the mid-point or bottom of the QA during calibration. When this occurs, the reference levels are assumed to be equal to the mid-point of the QA to prevent unrealistic gradients.

The chart below shows the average, minimum and maximum water depths calculated over time from the bores. The reference water levels have been allowed to vary within this range to provide some flexibility to adjust the rate and direction of vertical fluxes during calibration.



The chart below shows recent measurements of LTA heads. With the exception of a slight dip in July 2019 at 109128, the LTA heads over the last 12 months have been effectively constant. The SGB terms therefore assumes constant LTA heads for the 14-month monitoring period.





Legend

- Drain boundary condition
- Observation bores
- USG - Transport domain

Paper Size ISO A3

0 25 50 75 100

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Drain boundary conditions

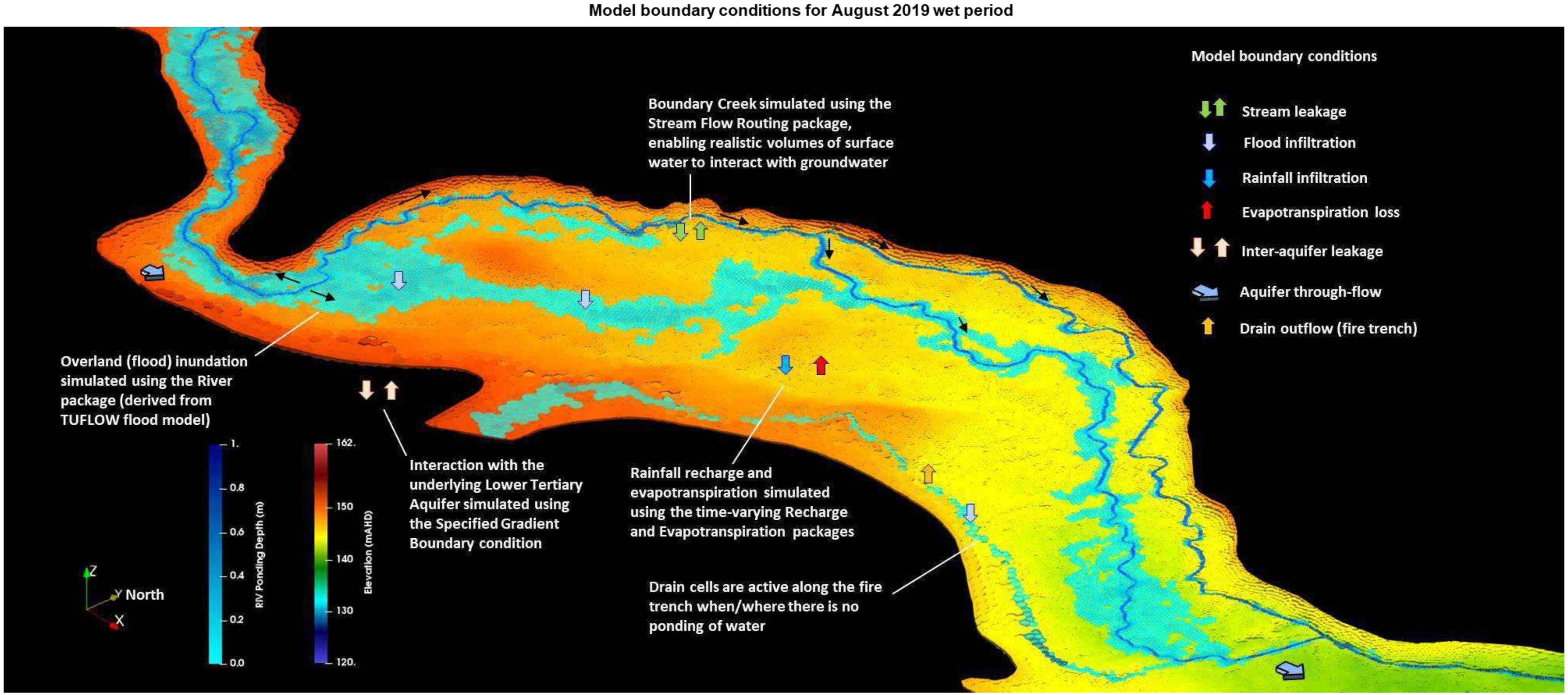
Project No. **12536659**
Revision No. **B**
Date **23/12/2020**

FIGURE 3-20

N:\AU\Melbourne\Projects\31\12536659\GIS\Maps\Deliverables\31_12536659_09_DRNboundary_A3L_RevB.mxd
Print date: 08 Apr 2021 - 17:27

Data source: GHD, model domain, 2020; Jacobs, Bore Locations, 2019; BW, imagery, 2019; . Created by: bsmyth (tworth)

Figure 3-21 Model boundary conditions and processes – existing condition



3.4.3 Model parameterisation

The USG-Transport model is highly parameterised, with a total of 611 adjustable parameters used to introduce local scale variability in material properties required to replicate the observed groundwater levels, trends, steam flow and their spatial differences within Big Swamp.

For horizontal and vertical hydraulic conductivity, RIV bed hydraulic conductivity and specific yield, local scale variability within Big Swamp is simulated using pilot points. For each of these parameters, a total of 110 adjustable pilot points are used, which include pilot points located at each observation bore and the surrounding area on a 50 m by 50 m grid. For the upstream and downstream areas of the model outside of the swamp, parameter values are varied uniformly using gridded pilot points tied to one of the adjustable pilot points. Similarly, tied pilot points are used to the north and south of the swamp to minimise spurious interpolation of parameter values towards model edges. Figure 3-22 shows the location of adjustable and tied pilot points used for horizontal hydraulic conductivity. The same pilot point locations are used for the vertical hydraulic conductivity, RIV bed hydraulic conductivity and specific yield.

For the SFR bed hydraulic conductivity, a total of 80 pilot points are distributed along the alignment of Boundary Creek at roughly 40 m spacing within Big Swamp, increasing up to around 200 m regionally. The SFR bed hydraulic conductivity is linearly interpolated between the pilot points along Boundary Creek. The SFR width and Manning's roughness are also parameterised separately for each of the 14 SFR segments.

The SGB cells used to simulate vertical fluxes are parameterised using a model-wide reference water depth, from which the representative QA heads are calculated. The reference water depth is varied for each model stress period to simulate the temporal variability.

Time-varying recharge and EVT rates are applied uniformly over the entire model domain, albeit with zero rates assigned where SFR and RIV cells are present.

The model parameters are discussed further in Section 4.4 in the context of model calibration.

Legend

Hydraulic conductivity pilot point
- log
- tied
- Observation bores

USG - Transport domain

Model mesh

Paper Size ISO A3

0 25 50 75 100

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Horizontal hydraulic conductivity pilot points

Project No. 12536659
Revision No. B
Date 23/12/2020

FIGURE 3-22

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Print date: 08 Apr 2021 - 17:27

Data source: GHD, model domain, mesh and pilot points, 2020; Jacobs, Bore Locations, 2019; BW, imagery, 2019; . Created by: bsmyth (tworth)

4. Model calibration

4.1 Calibration approach and iterations

Model calibration is a process by which model parameter values are altered within realistic bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012). In this study, the calibration period commences in June 2019 and extends to August 2020, capturing approximately 14 months of data.

As discussed in Section 3.1.1, the integrated modelling requires outputs from the GR4J model to inform the flow inputs to both the TUFLOW and USG-Transport models, and outputs from the TUFLOW model to inform the boundary condition of the USG-Transport model. Because the rate of infiltration assumed in the TUFLOW model cannot be well constrained until running the USG-Transport model, iterations are required to ensure a degree of consistency between the two models. This means the calibration process has been staged as well as iterative.

The method in which infiltration (leakage from flooded areas) is accounted for by the TUFLOW and USG-Transport models is different, and simplifications are therefore necessary when seeking consistency. While TUFLOW provides several options for simulating infiltration, the time-constant net loss term has been most effective in limiting infiltration specifically to flooded areas that vary over time. In reality, the infiltration rates vary over time as well as spatially, with the USG-Transport model indicating greater infiltration when/where the water table is deeper and little to no infiltration once the aquifer becomes fully saturated.

Following several iterations, a time-constant net loss of 25 mm/d was assumed over the flooded areas in TUFLOW and a higher net loss of 35 mm/d was assumed along and within the vicinity of Boundary Creek. The USG-Transport model was then recalibrated using the flood inundation extents and depths computed by this version TUFLOW model. The calibrated USG-Transport model currently simulates a typical infiltration (RIV leakage) rate of around 30 mm/d when normalised against the entire ponded (RIV cell) areas within Big Swamp. This is within the 25 to 35 mm/d range assumed in TUFLOW and is considered reasonable given the approximate nature of infiltration in TUFLOW. Additionally, a portion of infiltration (RIV leakage) computed by the USG-Transport model is lost from the swamp in the downstream area where the water table equilibrates with the flood level and there is net discharge of groundwater accumulated from further upstream. This may provide further justification for assuming a lower net loss in the TUFLOW model than that computed by the USG-Transport model. However, given the level of calibration ultimately achieved in the USG-Transport model, these differences and assumptions are not considered to limit the application of the models to informing the design of the preferred remediation system (the intended model use). Further discussions on parameter assumptions and water balance are provided for each model in the following sections.

4.2 GR4J model calibration

4.2.1 GR4J model calibration approach

The rainfall runoff model has been calibrated with the primary aim of simulating the inflows from the sub-catchments along the length of the TUFLOW model. Due to the swamp gauges (233275A and 233276A) lacking flow data at high and moderate flow rates and having relatively short record lengths, the GR4J model has been calibrated to the flow data of other gauges along Boundary Creek. The flow data from the two swamp gauges have been used for model validation.

There are four relevant gauges with data available to aid in calibration: 233273, 233231(just upstream of McDonald's Dam), 233229 (just downstream of McDonald's Dam) and 233228 (downstream of Big Swamp and at the end of the model). The daily flow data for each of these gauges has been filtered to exclude unacceptably extrapolated or compromised data. For the WMIS quality code system, this means excluding data with codes of 150 and above. An automatic calibration tool in Source has been used, utilising a shuffled complex evolution algorithm and the Nash-Sutcliffe Error (NSE daily) as an objective function to evaluate the degree of fit between the observed and modelled values.

4.2.2 Calibration challenges

Ideally, a split sample approach would be undertaken, in which the model is calibrated to match the gauge data from the first half of the simulation period, and the performance of the model is then validated by comparing the model outputs to the gauge data from the second half of the simulation period. This approach resulted in a very poor fit to the data, with NSE objective function values of around 0.03 being achieved. The use of different objective functions, with greater calibration iterations, and even altering the rainfall runoff model to the Australian Water Balance model did not improve the calibration outcomes to an acceptable level when using the split sample approach.

Further analysis of the gauge data found some anomalies, most notably a shift in gauge 233229 where the flow to level relationship shifts around 22 March 2019 and 28 May 2019. The rainfall data from SILO also did not exactly match the gauge hydrographs, leading to further difficulties in getting the modelled response to match that of the gauges. Given these issues, the calibration of the GR4J model has been limited to the period of historical observations (7 June 2019 to 5 August 2020). This targeted calibration resulted in a much more acceptable degree of fit with NSE values in the range of 0.67 to 0.82, adequately capturing the peaks and troughs in the hydrographs.

While this approach is appropriate for the purpose of informing the calibration of the TUFLOW and USG-Transport models, the absence of consistent relationships between the rainfall data and gauged runoff over a much longer period of several years means the GR4J model is not capable of reliably estimating runoffs for synthetic climate data. This limitation, resulting from either the inadequacy of the rainfall-runoff models to capture the complex behaviours in this area or due to the inconsistencies in the gauge data, should be taken into consideration if the future use of the models is extended to include examining the influence of different climatic conditions.

4.2.3 GR4J calibration results

The GR4J model calibration involved three runs, each targeted at certain sub-catchments to mimic the flow observed at a particular flow gauge. These included:

- Calibration of all sub-catchments to simulate downstream flow to match gauge 233228 data (downstream of Big Swamp and at the end of the model).
- Calibration of the top sub-catchment to simulate flow at gauge 233273 (furthest upstream).
- Calibration of the top two sub-catchments to simulate flow at gauge 233231(just upstream of McDonald's Dam).

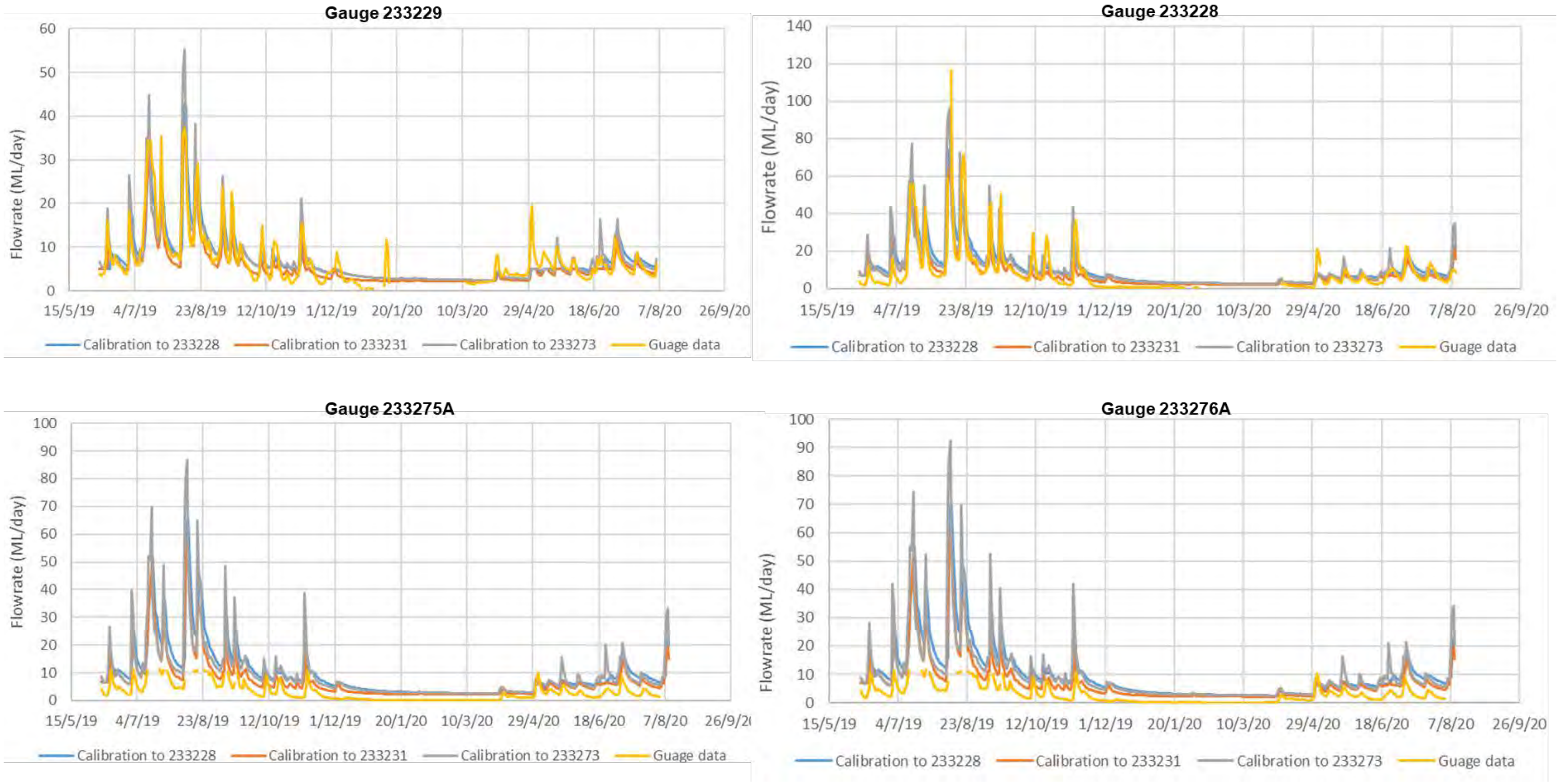
The automatic calibration was completed using the NSE daily objective function. The number of shuffles in the shuffled complex evolution algorithm was increased to ensure calibration outputs converging on a consistent set of parameters, by examining the top 50 calibration sets and whether or not the NSE objective function had converged to a consistent value. This was achieved for most parameters, although slight variations were observed in some parameter values, indicating low model sensitivity to minor changes to sub-set of parameters.

When a rainfall-runoff model is calibrated on a sub-catchment basis, a common approach to deriving the most optimal set of parameters is to calculate the average of the parameter values estimated from each calibration run. In this case, however, the parameter values from the three calibration runs were quite variable and the average of these parameter values resulted in a poor overall fit to the gauge data. Based on the objective function, the best calibration has been achieved at gauge 233228, followed by 2332231 and then 2332273, with NSE values of 0.83, 0.77 and 0.68 respectively. However, calibration to the downstream gauge 233228 is problematic for this project due to the potential for double accounting flow losses in the GR4J and TUFLOW models.

The GR4J model works by using rainfall and evaporation data to determine the runoff volumes and these runoff hydrographs are added together by Source to obtain the flow in the main channel. Once the flow is in the main channel, no routing or losses are applied. In reality, a significant portion of flow along Boundary Creek is lost to infiltration and evaporation as water travels downstream, particularly across Big Swamp. Since the GR4J model cannot account for this loss, calibrating to the downstream gauge would underestimate tributary inflows as they would be reduced to match the downstream hydrograph that already experienced these losses. This means any further infiltration simulated subsequently in the TUFLOW model would be in addition to flow losses that have already been compensated by the reduced tributary inflows. For this reason, the parameter set derived from calibration to the most upstream gauge 233273 has been chosen as the best calibrated parameters, which is least affected by the bulk of infiltration and evaporation losses that occurs further downstream (through the TUFLOW model domain). Additionally, the parameter values from gauge 233273 calibration appear to best mimic the filling and overtopping of McDonald’s Dam that occurs around May 2020, which is poorly replicated in the other two calibration runs.

Figure 4-1 compares the GR4J model outputs from the three calibration runs against the flow data at key gauges used to inform the TUFLOW and USG-Transport models. These include gauge 233229, located downstream of McDonald’s Dam which provides the upstream flow boundary to the TUFLOW and USG-Transport models, gauge 233228 located downstream of Big Swamp and the two swamp gauges 233275A and 233276A. For each hydrograph, the calibration run referred to as “Calibration to 233273” (grey line) represents the outputs from the final set of calibrated parameters. Although there are differences, the hydrographs from the three calibration runs are broadly consistent. On this basis, and for other reasons provided above, the use of calibrated parameters from the upstream sub-catchments to simulate the behaviour of the downstream sub-catchments is considered appropriate for this project.

Figure 4-1 GR4J modelled flow hydrographs at key gauges



4.3 TUFLOW model calibration

4.3.1 Stream flow and stage calibration

The TUFLOW model calibration has been undertaken for the entire period of historical observations, commencing on 7 June 2019 and ending on 6 August 2020. The TUFLOW model has been run using three different soil infiltration rates of 10, 25 and 40 mm/d, as discussed in Section 3.3.5.

The calibration involved comparing the flow rates and water levels simulated by the TUFLOW model against those observed at gauges 233275A, 233276A and 233228. The first iteration of the TUFLOW model resulted in simulated water levels that were significantly lower than those observed at the two swamp gauges (233275A and 233276A). This led to the refinement of the model, including simulating the v-notch weirs as m-channels. Figure 4-2 compares the modelled flow hydrographs against the observed hydrographs at the three gauges. Also included in the Figure are hydrographs focusing on the low flow period, when little to no flow was observed. The hydrographs indicate that the TUFLOW model is capable of replicating the temporal variations (trends) in flow, with the modelled and observed timing of peaks and troughs matching reasonably well. However, there are some discrepancies between the modelled and observed flow rates, with the TUFLOW model generally overestimating flows at gauges 233275A and 233276A, particularly during the dry/low flow period, and periodically underestimating flows at 233228.

The differences between the modelled and observed flows are potentially related to uncertainties in the reliability of the gauge data, resulting in inaccuracies in the inflow terms derived from the GR4J model which are passed onto the TUFLOW model e.g. inflows overestimated by the GR4J model resulting in generally overestimated flows at gauges 233275A and 233276A.

Where the flow is overestimated at gauge 233276A but underestimated at 233228 further downstream, this could be due to either too much infiltration loss or insufficient tributary inflow added between the two gauges. Neither of these two possibilities are considered likely given that the differences are seen with the infiltration rate as low as 10 mm/d and the GR4J inflows consistently overestimate flow at gauges 233275A and 233276A, suggesting that any inflows applied between 233276A and 233228 are likely to be also overestimated. Another possibility is errors in estimating flows at either 233275A and 233276A or 233228; however, a comprehensive investigation into the reliability of the gauge data, including those used to inform the GR4J model, is not part of the current scope.

The calibration of the USG-Transport model described in Section 4.4.4 also indicates that the flow recorded at these gauges, at least during the low flow period, is sensitive to the accuracy of surface water – groundwater interaction simulated along Boundary Creek, which would be difficult to simulate in a hydraulic model like TUFLOW. These limitations may be further affected by other model design considerations, such as the 4 m grid cell size adopted in the TUFLOW model to improve model run times, which may lead to inaccuracies along parts of the Boundary Creek where the channel width is potentially as small as 1 m (refer to Section 6.1.2).

Figure 4-3 shows hydrographs of the modelled and observed stage/water levels. There is generally good agreement between the modelled and observed values, particularly at gauge 233228 where the modelled levels are within 10-30 mm of the observed levels for most of the calibration period, with the only major deviation occurring during the dry period when the level was observed to drop by 0.6 m and the creek became dry (which did not occur in the model potentially due to higher than actual inflows). At gauges 233275A and 233276A, the TUFLOW model generally underestimates the level at high flows and overestimates the level at low flows although the discrepancies are generally within 100 mm of recorded levels (with up to about 150 mm discrepancies during the highest peak and the driest point of the calibration period).

While there are some discrepancies between the modelled and observed values, these are generally within the expected range of accuracy. Importantly, the calibrated TUFLOW model is able to simulate the seasonal dynamics (wetting and drying cycles) of the swamp, at spatial and temporal resolutions appropriate for informing the boundary conditions of the USG-Transport model.

4.3.2 Interface with USG-Transport model

The primary outputs of the calibrated TUFLOW model required for the USG-Transport model are the flooded extents and depths for each of USG-Transport model's stress periods (refer to Section 4.4.1). Because the TUFLOW model uses a fixed grid, whilst the USG-Transport model uses a flexible mesh, a large number of PO points have been used to extract water levels from the TUFLOW model at the centroid of every single USG-Transport model cell. As TUFLOW only records its output on a cell-by-cell basis, this leads to more than one USG-Transport model cell extracting results from the same TUFLOW cell in some places. An example of the relationship between the two model meshes is shown in Figure 4-4.

The USG-Transport model requires an average water depth for each cell whereas calculating an average depth from TUFLOW is not straightforward due to level differences that occur internally within each cell. Figure 4-5 presents a single TUFLOW cell when sub-grid sampling is applied. TUFLOW reports the water surface level when any point within the cell is wet, meaning that when the cell is only partially wet, the water surface level can be below the average elevation of the cell. The ground level used to calculate the water depth could use any one of the minimum, average or maximum elevation in the cell. For this project, the minimum cell elevation is used as the ground surface for calculating the water depth. Therefore, the water depth reported by TUFLOW is the maximum water depth simulated anywhere within the cell. The rationale for selecting the maximum elevation is to avoid registering partially wet cells as dry, which could happen when water depths occur in the lower part of the cells. In this sense, the ponded depths extracted from the TUFLOW model are likely to be an overestimate, although a threshold is applied subsequently in the USG-Transport model to filter out any wet cells where the ponding depth is less than 0.02 m (see Section 3.4.2).

To match the length of stress periods used by the USG-Transport model, the ponded depths from for all timesteps of the TUFLOW model that occur within the same stress periods are averaged. This results in an average water depth for each USG-Transport model cell for each one of its 50 stress periods.

4.3.3 Calibration of infiltration rates

As discussed in Section 4.1, the TUFLOW model uses a simple time-constant soil infiltration loss whereas the infiltration (leakage) rates calculated by the USG-Transport model are more complex, varying both spatially and temporally. To minimise the need for a very large number of iterations, a time-constant infiltration rates of 35 and 25 mm/d are applied along Boundary Creek and flooded areas of the calibrated TUFLOW model, respectively. The spatially and temporally averaged infiltration rate from the USG-transport model is around 30 mm/d, which is within the range of soil infiltration losses applied to the TUFLOW model. While it would be possible to expend more time and effort to closely match the infiltration losses of the two models, this is unlikely to materially improve the outcomes of the modelling given that an appropriate level of calibration has already been achieve with the USG-Transport model (see Section 4.4.4) and the ponded depths simulated by the TUFLOW model are relatively insensitive to the infiltration rates over the range of 10 to 40 mm/d, as discussed further in Section 6.1.

Figure 4-2 TUFLOW modelled and observed flow hydrographs

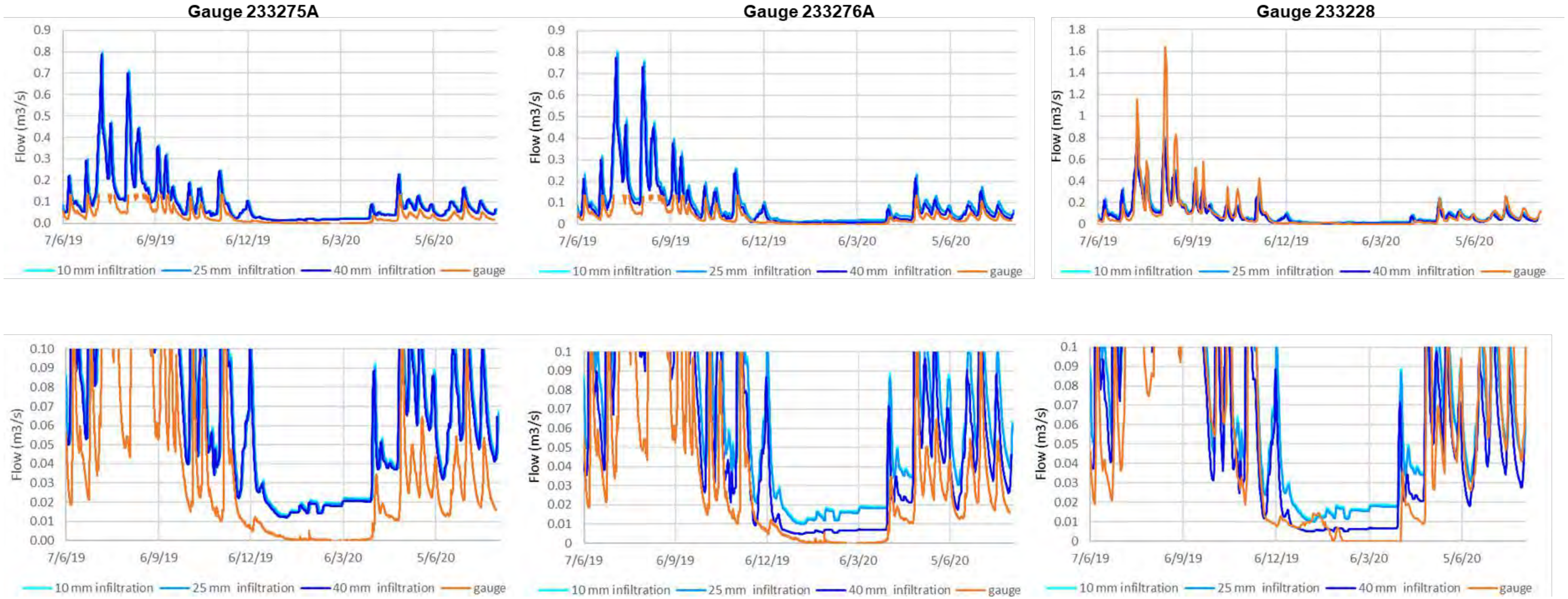
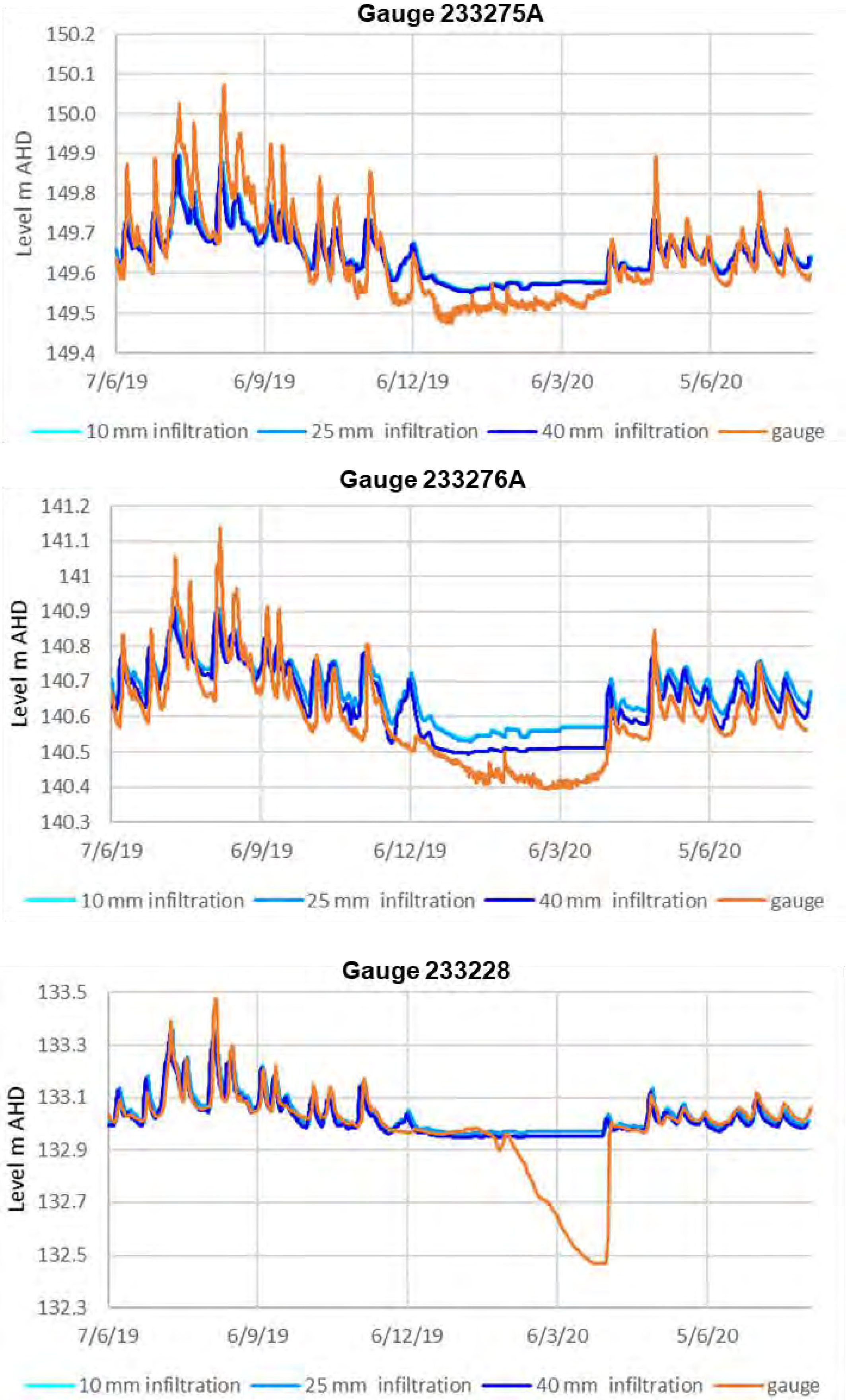


Figure 4-3 TUFLOW modelled and observed stage hydrographs



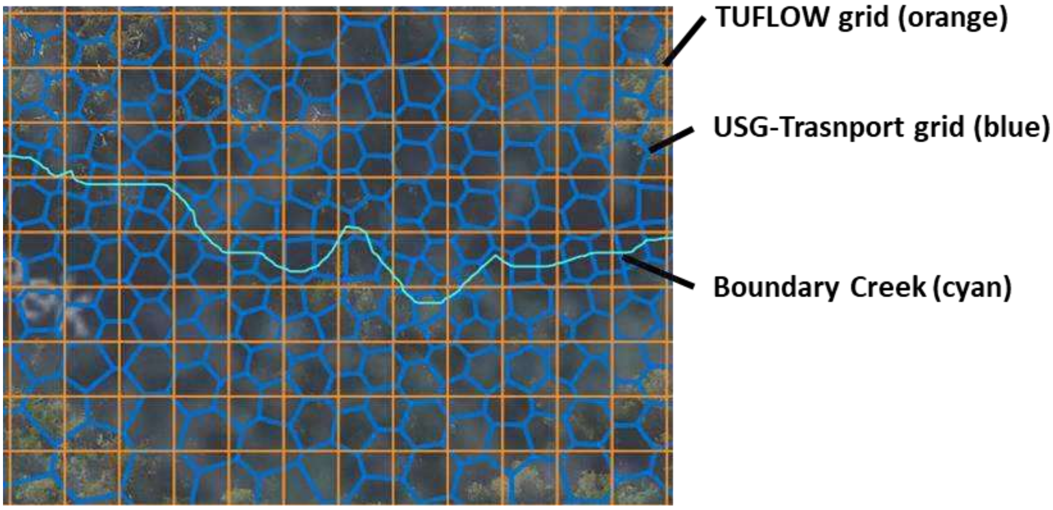


Figure 4-4 Relationship between TUFLOW grid and USG-Transport mesh

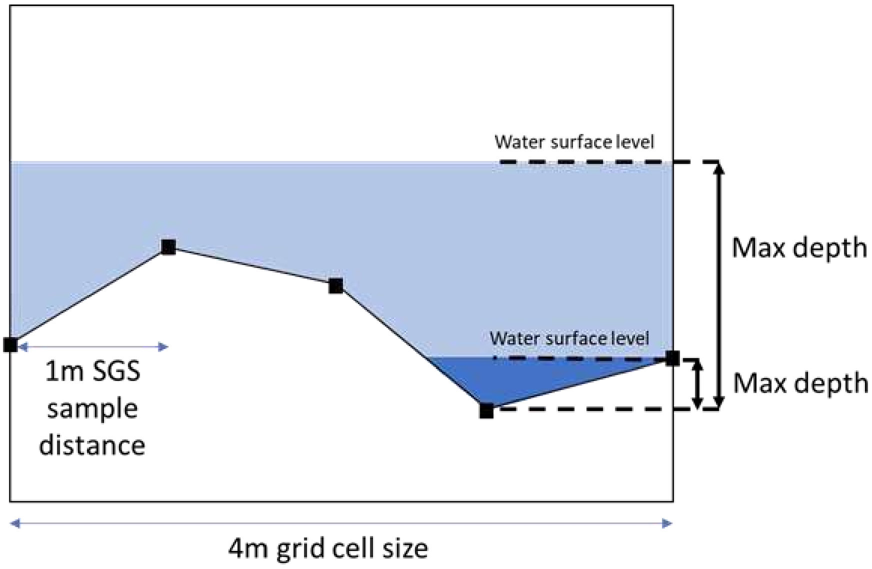


Figure 4-5 TUFLOW cell with sub-grid sampling

4.4 USG-Transport model calibration

4.4.1 Stress periods

The transient calibration uses a total of 50 stress periods to simulate 21 distinctive flow events and intervening drier periods. The stress period length varies from around 1.2 to 24.8 days, including eight 14-day stress periods over the dry period from December 2019 to April 2020 when there was negligible flow and inundation.

A steady-state simulation provides initial heads to the transient simulation. The steady-state model utilises average inundation extents and depths derived from a week-long conditioning run undertaken in TUFLOW, to provide a sensible starting point for the transient model. Similarly, average recharge and evapotranspiration have been derived from LUMPREM using climate data from several months preceding the start of transient calibration, which have been scaled during calibration to place the initial heads at sensible elevations.

4.4.2 Calibration targets

The calibration targets for the USG-Transport model include:

- Piezometric heads measured in a total of 18 monitoring bores constructed within Big Swamp. For the purpose of calibration, hourly measurements have been converted to average daily targets resulting in up to 419 targets per bore and a total of 7,339 head targets.
- Piezometric head differences, representing the change in piezometric head from the initial reading (temporal trend) calculated from the 7,339 head targets. There are 7,321 head difference targets in total.
- Horizontal head differences between a pair of monitoring bores, representing the spatial differences in observed heads and how they vary over time. Head difference targets have been derived from a total of 15 pairs of bores, as summarised in Table 4. There are 6,451 horizontal head difference targets.
- Stream stage at gauge 233275A and 233276A, converted to mAHD targets using the recently surveyed gauge zero elevation and averaged over the length of each stress period. There are 100 stream stage targets in total.
- Stream flow at gauge 233275A and 233276A, converted to m3/d to be consistent with the USG-Transport model flux unit. The flow targets are averaged over the length of stress periods, excluding periods when the flow is above the gauge capacity. Logarithmic flow targets are used due to the wide range of flow rates and to ensure that low flow targets from dry periods remain visible during calibration. There are 80 stream flow targets.
- Stream flow differences between gauge 233275A and 233276A for the dry period, when the flow differences represent the loss of surface water to the groundwater system, which is of critical importance to understanding how effective supplementary flow could be in maintaining flow downstream. There are four flow difference targets for four stress periods within the dry period, when low flows were recorded.

Table 4 Horizontal head difference targets

Bore 1	Bore 2	Direction	NO. Targets
BSBH18	BSBH17	North to south	364
BSBH18	BSBH14	East to west	364
BSBH14	BSBH16	North to south	419
BSBH16	BSBH12	East to west	419
BSBH14	BSBH11	East to west	419
BSBH12	BSBH11	North to south	419
BSBH12	BSBH10	East to west	419
BSBH11	BSBH08	East to west	419
BSBH08	BSBH10	North to south	419
BSBH10	BSBH07	East to west	419
BSBH08	BSBH04	East to west	419
BSBH04	BSBH07	North to south	419
BSBH07	BSBH03	East to west	419
BSBH04	BSBH01	East to west	419
BSBH03	BSBH01	North to south	419
TB1A	BSBH01	North to south	271

4.4.3 Calibration procedure

Calibration workflow

Calibration has been undertaken rigorously using PEST-based automated procedures in a highly parallelised computing environment. This involved several iterations, with the outputs from each calibration iteration providing the basis for modifying the observation weights and groups to guide the calibration effort, as well as exploring different calibration techniques. The key stages of calibration included:

- Initial calibration using PEST++ (PEST++ Development Team, 2020) and its Iterative Ensemble Smoother (IES) technique, which provided insights into areas of the model where calibration was challenging and adjustments to observation weights and groups required to make certain targets more visible.
- Targeted calibration using PEST_HP (Doherty, 2017) with Singular Value Decomposition (SVD) and 224 superparameters to improve calibration in critical areas. This procedure was repeated using the final flood inundation depths and extents computed by TUFLOW after updating the infiltration (net loss) term to better match the leakage rates computed by the USG-Transport model.
- Final calibration using PEST_HP with all 611 adjustable parameters to fine tune the model, particularly in areas where further improvement could not be attained using the SVD-assisted calibration.

The highly iterative calibration procedure required in excess of several tens of thousands of model runs. This run-intensive procedure was made possible by prioritising numerical stability and run time efficiency in the model design while retaining complexity where details are considered important (such as spatial parameter variability and surface water – groundwater interactions).

The automated calibration utilised a number of PEST utilities to facilitate pre- and post-processing of model data, including:

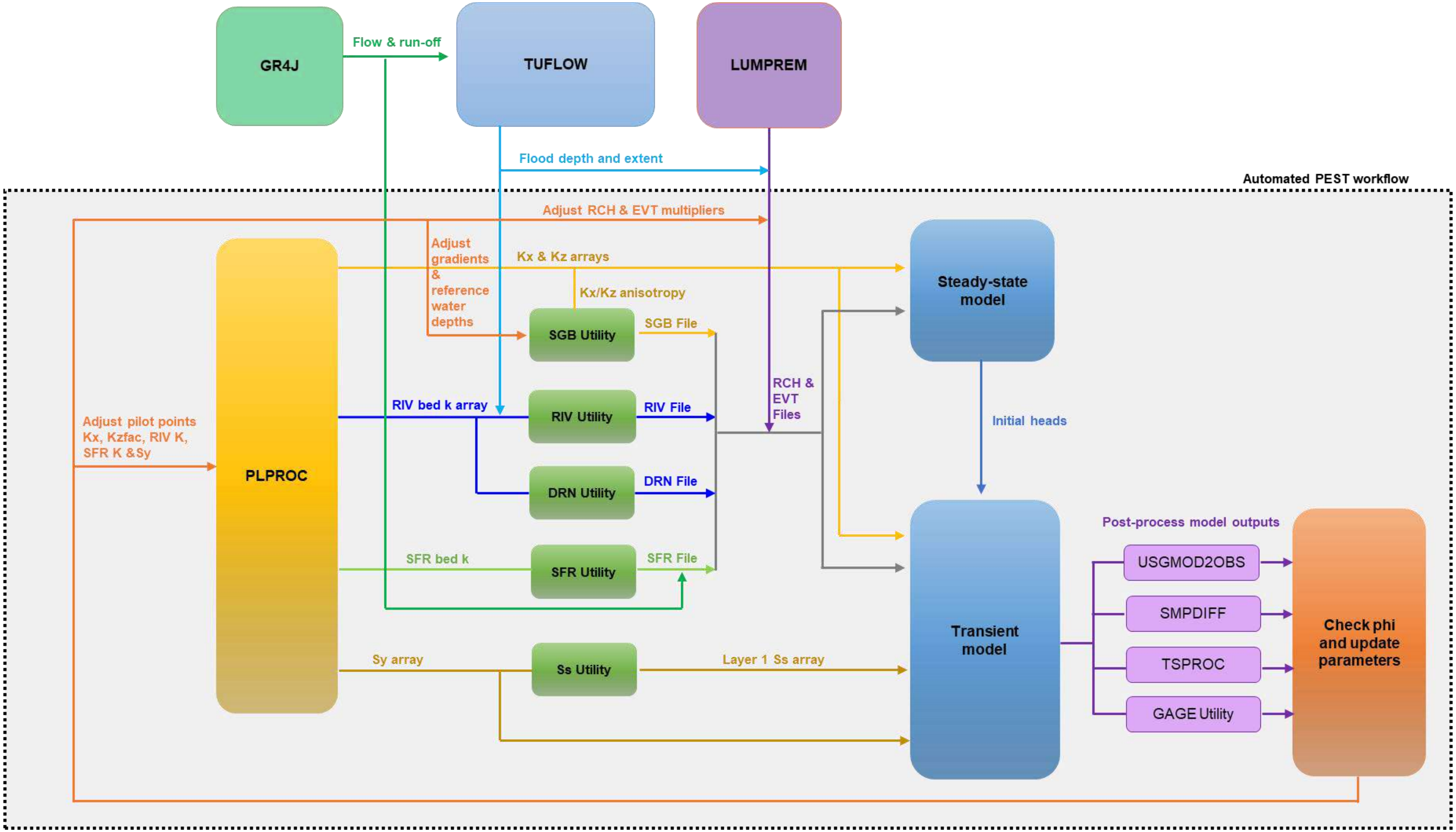
- PLPROC that undertakes spatial interpolation of parameters from pilot points to the model mesh, in this case to generate spatially varying arrays of horizontal and vertical hydraulic conductivity, RIV and SFR bed hydraulic conductivity and specific yield.
- TSPROC that undertakes calculations, filtering and interpolations on multiple time series data. This was used to calculate observed and computed horizontal hydraulic head differences between monitoring bores.
- USGMOD2OBS that extracts computed hydraulic heads at the time and location of observations and SMPDIFF that converts the computed hydraulic heads into temporal hydraulic head differences (trends) at the location of observations.

In addition to the PEST utilities, project-specific utilities have been prepared in Fortran and Python to write model input files based on parameters adjusted by PEST and to post-process model outputs. These include utilities that:

- write the RIV files based on the flood depths from TUFLOW and updated conductance terms calculated from the gridded RIV bed hydraulic conductivity array processed by PLPROC and area and bed thickness of each RIV cell.
- write the SFR file based on linearly interpolated SFR bed hydraulic conductivity generated by PLPROC.
- write the DRN file with updated conductance terms calculated from the gridded RIV bed hydraulic conductivity array processed by PLPROC.
- write the SGB terms based on the updated reference water depth for each stress period and the anisotropy ratio for each model cell calculated from the horizontal and vertical hydraulic conductivity arrays generated by PLPROC.
- write the specific storage array for layer 1, using layer 1 thickness and specific yield array generated by PLPROC.
- read the SFR outputs generated by the GAGE package and convert the model flows into logarithmic flows as well as calculating flow differences between gauge 233275A and 233276A.

A single batch file was prepared to run PEST and associated utilities in sequential order and to process model outputs. Figure 4-6 provides a graphical representation of the automated calibration workflow.

Figure 4-6 PEST automated calibration workflow



Observation groups

During calibration, it became necessary to group the head, head difference and flow targets into several different observation groups so that the calibration effort can be targeted at areas where the model calibration was initially deficient or where the model performance was considered particularly important (such as the dry period stream flow). This was achieved iteratively, resulting in the following observation groups:

- Group 1 head and head difference observation groups (Head1 and Hdiff1), which include the 2019 wet period observations for all bores and the whole 14-month observations for downstream bores BSBH01 to BSBH03 (bores that generally remained well calibrated throughout the calibration process and required no special grouping).
- Group 2 head and head difference observation groups (Head2 and Hdiff2), which include the dry period observations from January to end of March 2020 for upstream bores BSBH11 to BSBH18. These observation groups were generated to make the distinctive falling and rising trend observed during the dry period in the upstream bores visible to PEST.
- Group 3 head and head difference observation groups (Head3 and Hdiff3), which include the observations from April 2020 for upstream bores BSBH11 to BSBH18 to focus on the rising trend observed following the dry period.
- Group 4 head and head difference observation groups (Head4 and Hdiff4), which include the whole 14-month observations for bores BH04 to BSBH07 where the calibration performance remained slightly poorer than at other bores.
- Group 1 flow observation group (Flow1), which includes all flow targets except for the critical dry period.
- Group 2 flow observation group (Flow2), which includes flow targets during the critical dry period from January to end of March 2020.

For horizontal head difference, flow difference and stage targets, all observations have been grouped into their respective groups (Xdif, Flodif and Stage groups, respectively).

Calibration parameters

As discussed in Section 3.4.3, a large number of pilot points are used to simulate spatial variability in hydraulic conductivity, RIV and SFR bed hydraulic conductivity and specific yield. The vertical hydraulic conductivity has been calibrated using pilot points of anisotropy ratio between horizontal and vertical hydraulic conductivity (referred to as kz factors herein). The anisotropy ratio is converted to vertical hydraulic conductivity using PLPROC.

For recharge and EVT, simple model-wide factors are used to shift the recharge and EVT rates derived from LUMPREM up or down.

Table 5 provides a summary of model parameters adjusted during calibration. The initial parameter values are based on the prior knowledge and initial testing of the model performance. The automated calibration has been undertaken in the regularisation mode, utilising these initial values (as well as pilot point covariance matrices) as prior information to minimise parameter variability unless deemed necessary by PEST.

Table 5 Summary of calibration parameters

PEST Parameter ID	Parameter type	Initial	Min	Max	Comment
kxp1 to kxp110	Kx	0.2 – 0.8 m/d	0.01 m/d	5 m/d	Range based on slug tests
kzfp1 to kzfp110	Kz factor	0.08 – 0.15	0.0001	1	Maximum at 1 to prevent Kz > Kx
rivkp1 to rivkp110	RIV bed Kz	1 m/d	0.001 m/d	5 m/d	Based on slug tests (as per Kx), with a lower minimum to account flow in vertical direction
sfr_pp_kz0 to sfr_pp_kz80	SFR bed Kz	1 m/d	0.001 m/d	10 m/d	As per above, but with a higher maximum to account for potential local presence of sand along channels
syp1 to syp110	Sy	0.1	0.03	0.3	Range based on literature for clay, silt and sand
ss1	Ss	5×10^{-6} m^{-1}	1×10^{-6} m^{-1}	1×10^{-5} m^{-1}	Range based on literature
rchfac1 to rchfac2	Recharge	0.5	0.05	1	Maximum factor equals LUMPREM recharge
evtfac1 to evtfac2	EVT	1	0.6	1.1	Initial factor equals LUMPREM groundwater EVT
exdp1 to exdp4	Extinction depth	0.3 – 2 m	0.1 m	5 m	Maximum 5 m applies only to zone 1, elsewhere 1 m used
gradx1 to gradx2	gradient	0.005	0.003	0.005	Horizontal gradient for through-flow SGB term
sgb1 to sgb50	water depth	0.82 - 2.15 m	0.001 m	2.26 m	Range varies for each stress period, with minimum effectively equal to 0 m water depth (wet period)

- Kx – horizontal hydraulic conductivity, Kz – vertical hydraulic conductivity, Sy – specific yield, Ss – specific storage, EVT – evapotranspiration.
- Parameters rchfac1 and evtfac1 are used for the steady-state model and rchfac2 and evtfac2 are used for the transient model. The maximum rchfac1 and rchfac2 are constrained at 1, as LUMPREM recharge was considered already towards the upper end of plausible range.
- The range for EVT extinction depths are 1 to 5, 0.3 to 1, 0.2 to 1 and 0.1 to 1 for zones 1,2,3 and 4 respectively.
- The reference water depths for SGB parameters sgb1 to sgb50 varies for each stress period based on the range of average depth to water recorded at upstream bores (where the QA is in contact with the LTA)

4.4.4 Calibration performance

Head calibration

Figure 4-7 shows the scatter plot of the observed and computed heads, which provides a useful indication of the overall quality of model calibration. The Scaled Root Mean Squared (SRMS) error is around 3% and the Root Mean Squared (SRMS) error is around 0.2 m. This means the computed heads are generally accurate to within 0.2 m of the observed heads.

The quality of calibration can be further demonstrated using hydrographs of observed and computed heads for the 18 monitoring bores used in calibration, as shown in Figure 4-8 and Figure 4-9. While larger discrepancies between the observed and computed heads can be seen in some bores such as BSBH06, the degree of fit for critical upstream bores such BSBHBH12, BSBH14 and BSBH15 is considered high and the model is able to adequately replicate the overall seasonal trend, including the falling trend at the start of the dry period and the subsequent rising trend observed in the middle of the dry period in upstream bores. The latter is of particular interest, as it occurs during a period when there is negligible inundation and recharge. The model calibration indicates that this is due to upflow from the SGB cells (LTA) which occurs when the water table falls to a critical level and results in a temporary reversal in vertical hydraulic gradient.

Figure 4-10 shows the contours of computed heads for the wet (August 2019) and dry (Jan 2020) periods. The overall flow direction is to the east, with a steeper hydraulic gradient (contour spacings) in the wet period. The model simulates a local low point near Boundary Creek (to the west of BSBH17 and BSBH18), which is due to locally elevated hydraulic conductivity at this location where the effects of vertical fluxes are more pronounced (in this case, downward leakage). Uncertainty analysis presented in Section 6.2 considers realisations of the model with much lower hydraulic conductivities in this area, where the degree of connection with the underlying LTA is less certain due to the absence of observation data.

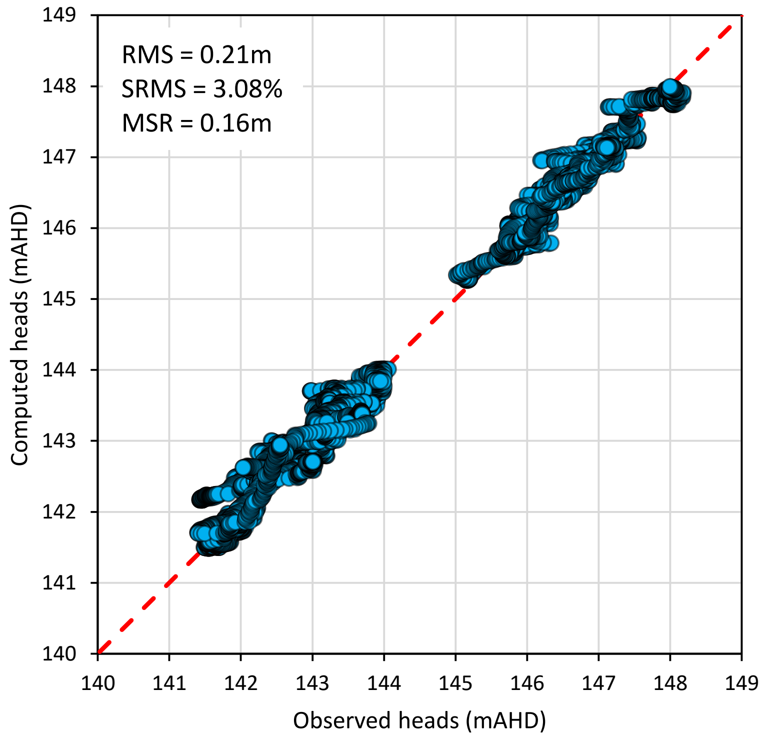


Figure 4-7 Scatter plot of observed and computed heads

Figure 4-8 Calibrated bore hydrographs – BSBH01 to BSBH09

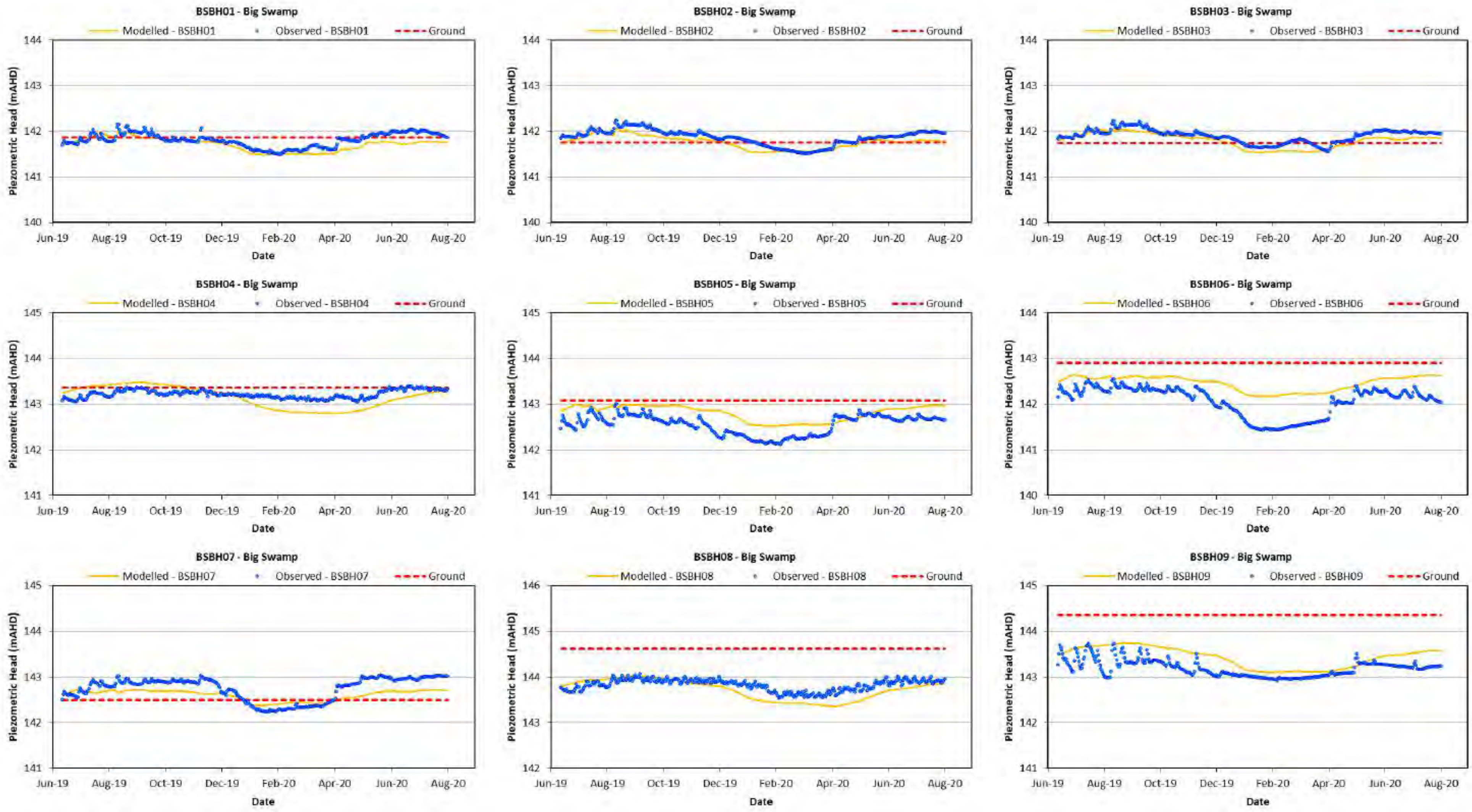
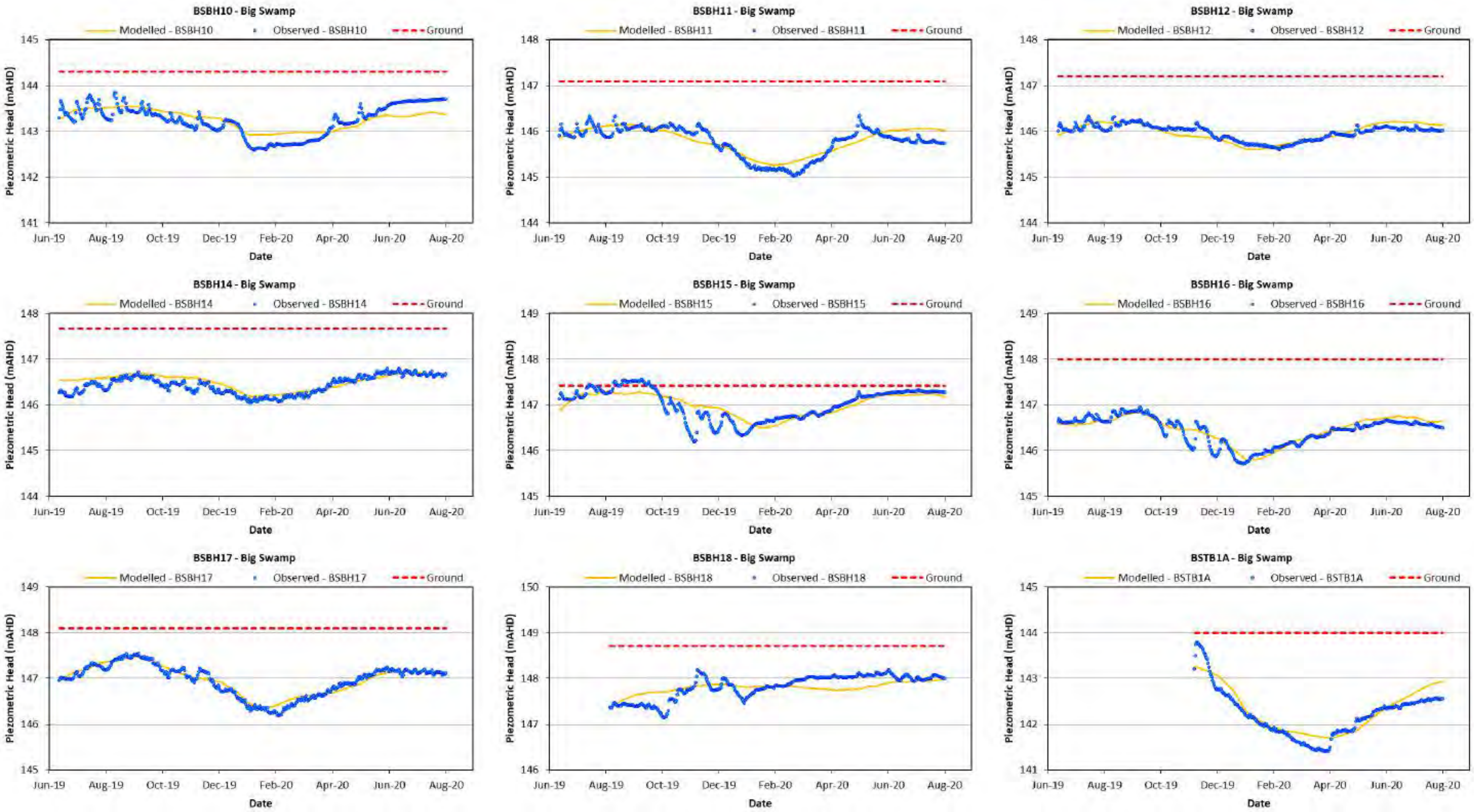
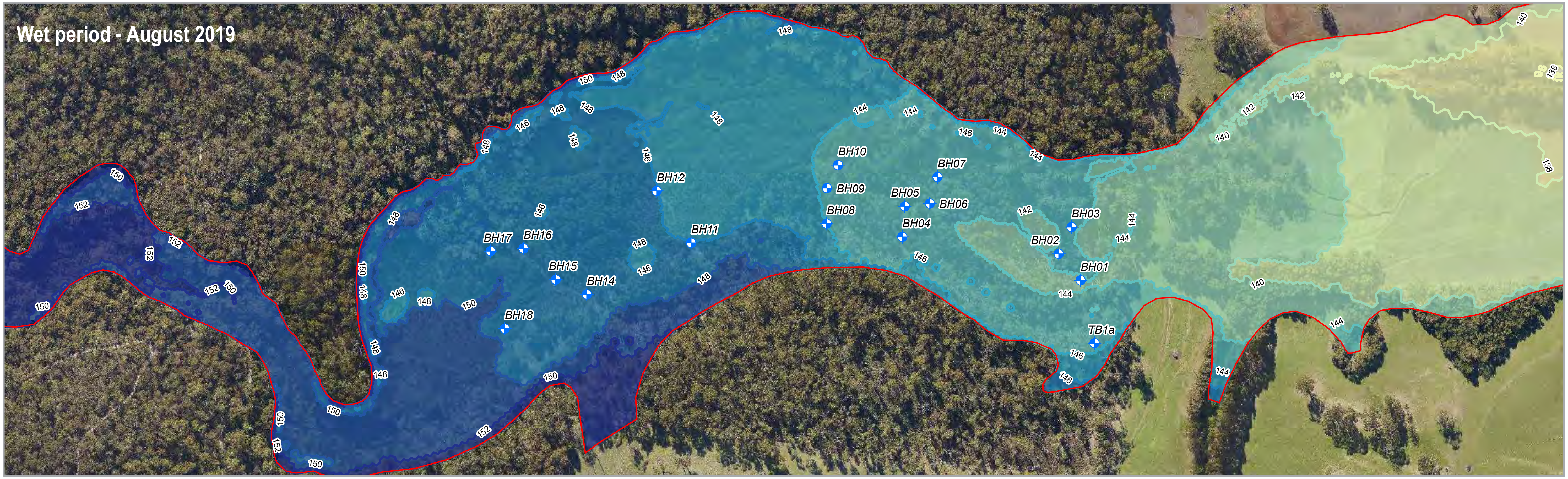
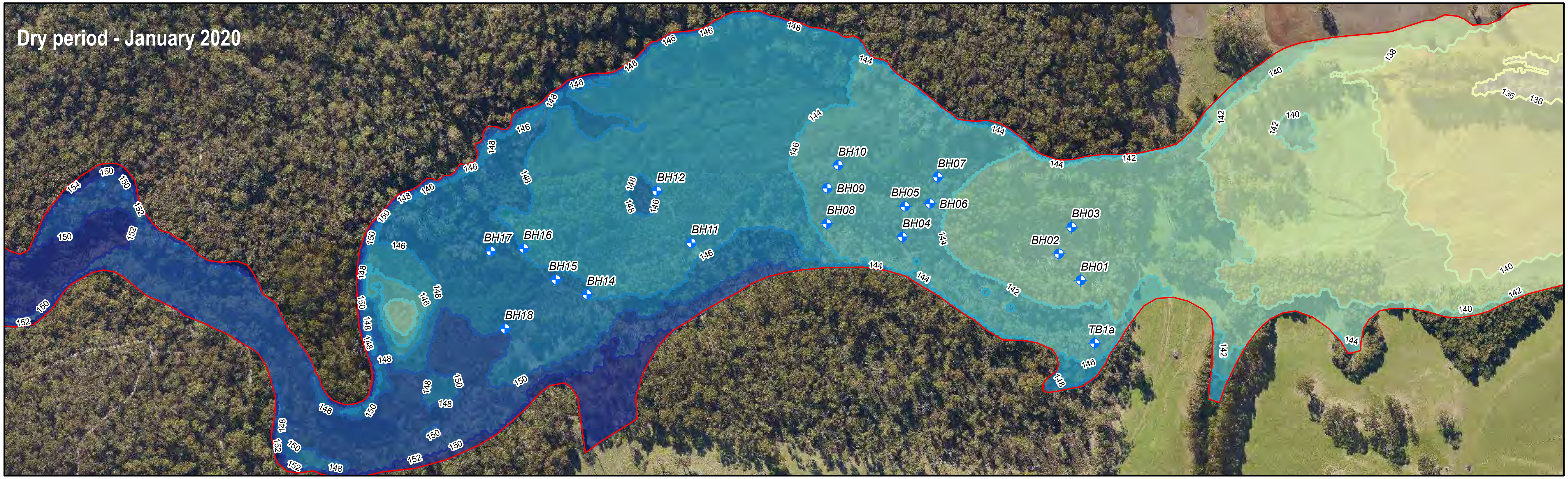


Figure 4-9 Calibrated bore hydrographs – BSBH10 to TB1A







Legend

- Observation bores
- Modelled groundwater contour (mAHD)
  - 134 - 136
  - 136 - 138
  - 138 - 140
  - 140 - 142
  - 142 - 144
  - 144 - 146
  - 146 - 148
  - 148 - 150
  - 150 - 152
  - 152 - 154
- USG - Transport domain

Paper Size ISO A3

0 25 50 75 100

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Project No. **12536659**
Revision No. **B**
Date **24/12/2020**

Modelled groundwater contours

FIGURE 4-10

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Print date: 08 Apr 2021 - 17:26

Data source: Jacobs, Bore Locations, 2019; GHD, modelled groundwater contours, 2020; BW, imagery, 2019; . Created by: bsmyth (tworth)

Stream stage and flow calibration

The model calibration also focused on replicating the observed stream stage and flow, particularly during the dry period when the reduction in stream flow has been observed at downstream gauge 233276A. This is considered of critical importance because understanding the effectiveness of supplementary flow regimes depends on the ability of the model to adequately simulate the flow loss/stream leakage during dry periods when the system is most stressed. Figure 4-11 compares the observed and computed stream stage at the two gauges, which are generally accurate to within 0.1 m of each other.

Figure 4-12 compares the observed and computed stream flow at the two gauges. The critical dry period is highlighted in green. The figure indicates that the observed and computed flows match well during this dry period, including zero flow recorded at gauge 233276A in February and March 2020.

Figure 4-11 Calibrated stream stage

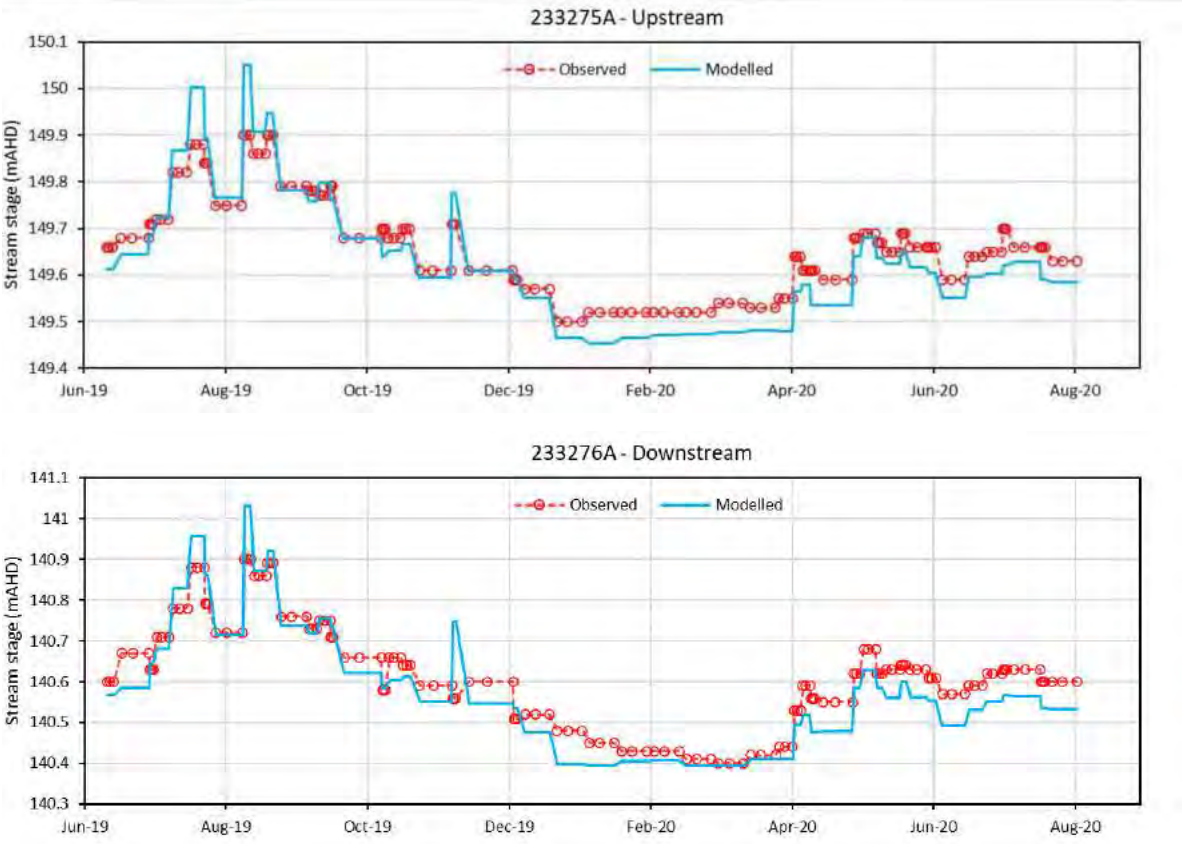
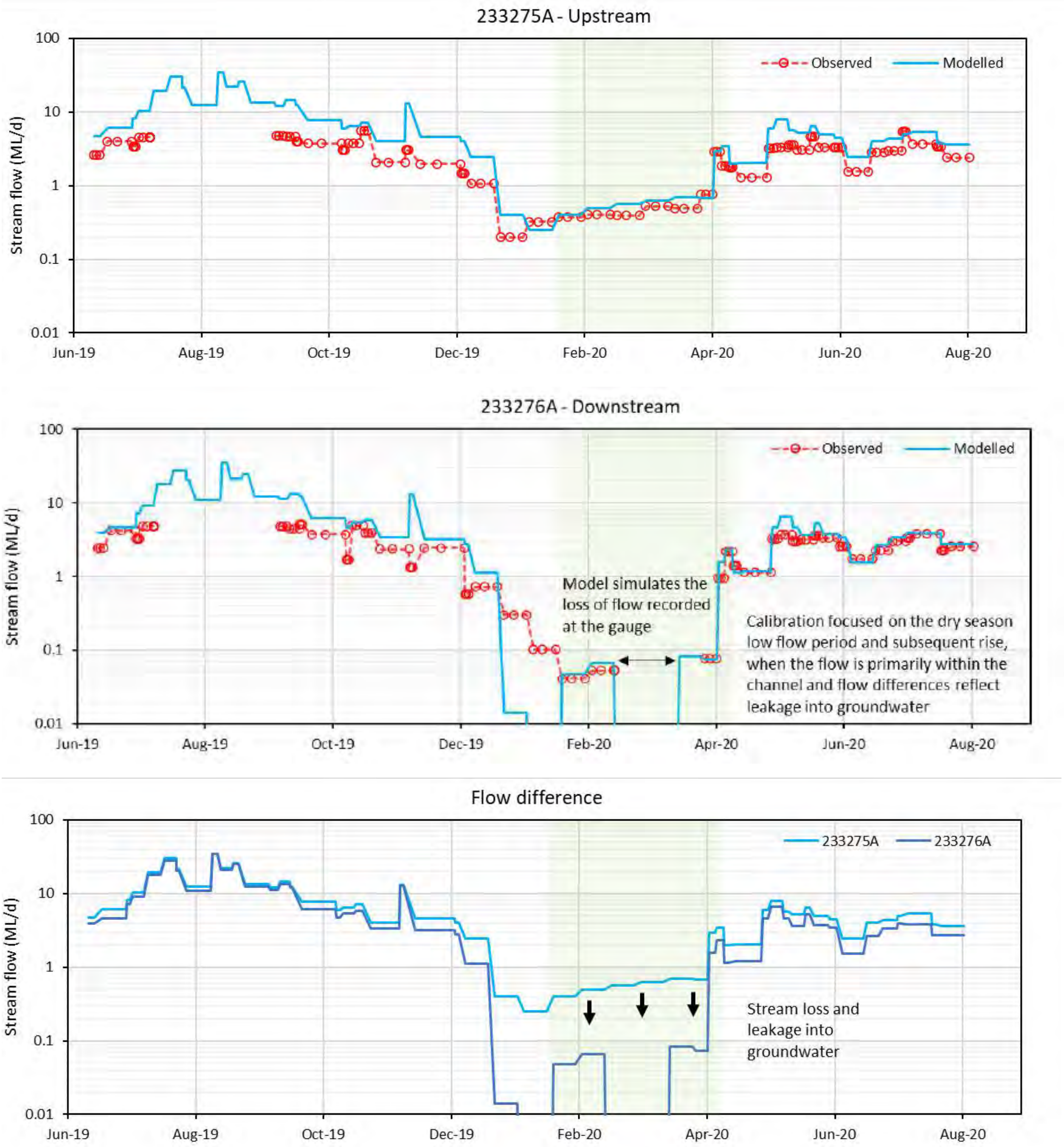


Figure 4-12 Calibrated stream flow hydrographs



4.4.5 Calibration parameters

Calibrated parameter values

The calibrated model parameters are presented graphically in Figure 4-13 to Figure 4-16. The spatial variability derived from the interpolation of pilot points parameters is presented in Figure 4-17 to Figure 4-19

The calibrated horizontal hydraulic conductivity within Big Swamp is around 1.3 m/d on average, although this is skewed by localised areas of elevated hydraulic conductivity. The median hydraulic conductivity of around 0.5 m/d is considered more representative, which is broadly consistent with the range of values derived from slug testing and the calibrated hydraulic conductivity from the previous FEFLOW model. The average and median vertical hydraulic conductivity is 0.2 and 0.01 m/d, respectively.

The calibrated RIV bed hydraulic conductivity within Big Swamp has average and median values of 1.5 and 1 m/d, respectively. The calibrated specific yield has an average value of 0.14 and is similar to the median value of 0.1.

The recharge factor for the transient model (rchfac2), is calibrated at around 0.7, which means the calibrated transient recharge is around 70% of the initial estimate derived using LUMPREM (although higher than the initial value of 0.5 set at the start of calibration). The average calibrated recharge is still considered towards the upper end of a realistic range, equating to around 40% of average rainfall over the calibration period; however, as recharge is only applied to dry areas, it has a relatively small net contribution to the model water balance compared to fluxes from Boundary Creek and flooded areas (see Section 4.4.6).

Figure 4-13 Calibrated parameters and their range – zone-based parameters

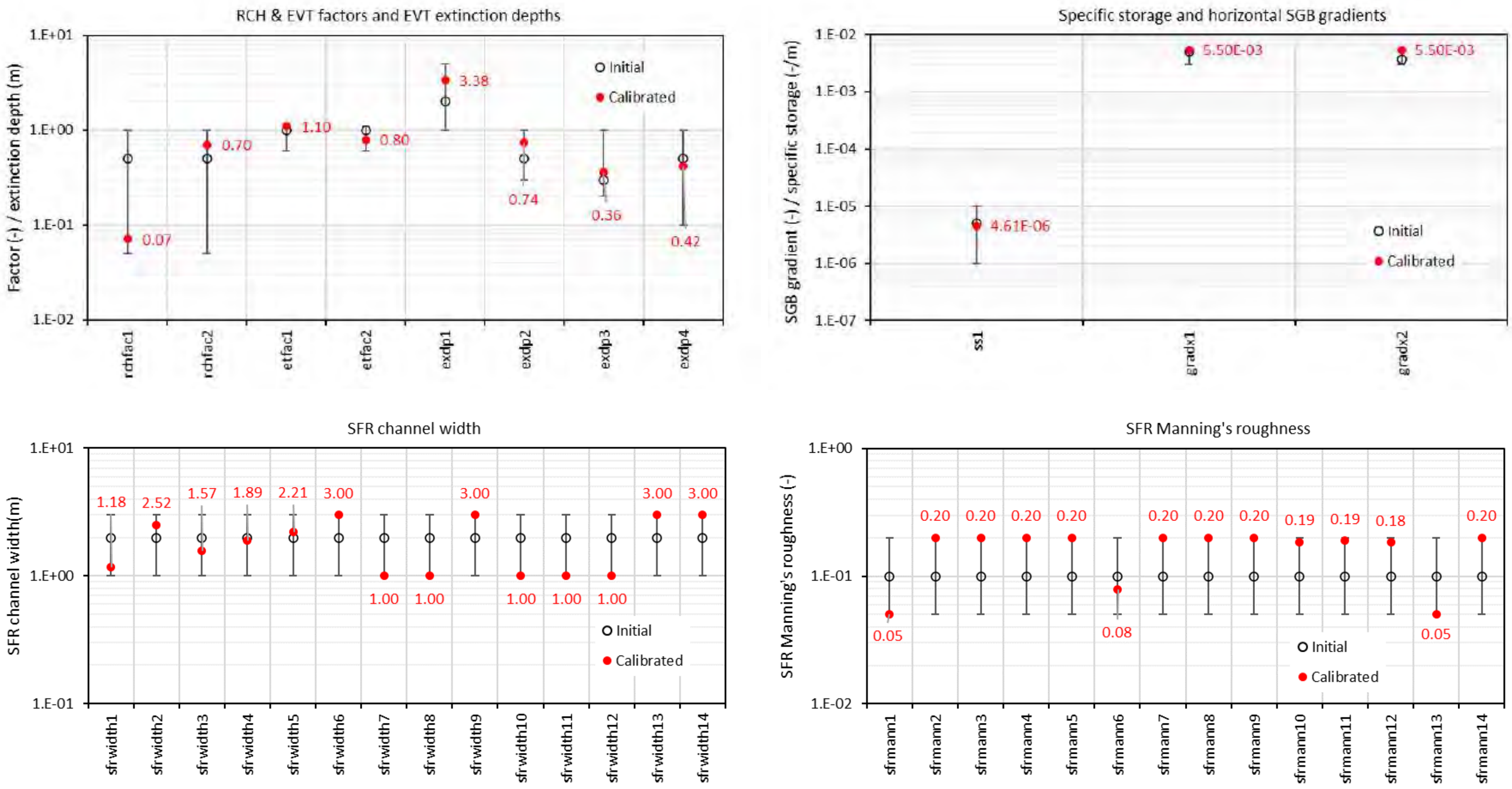
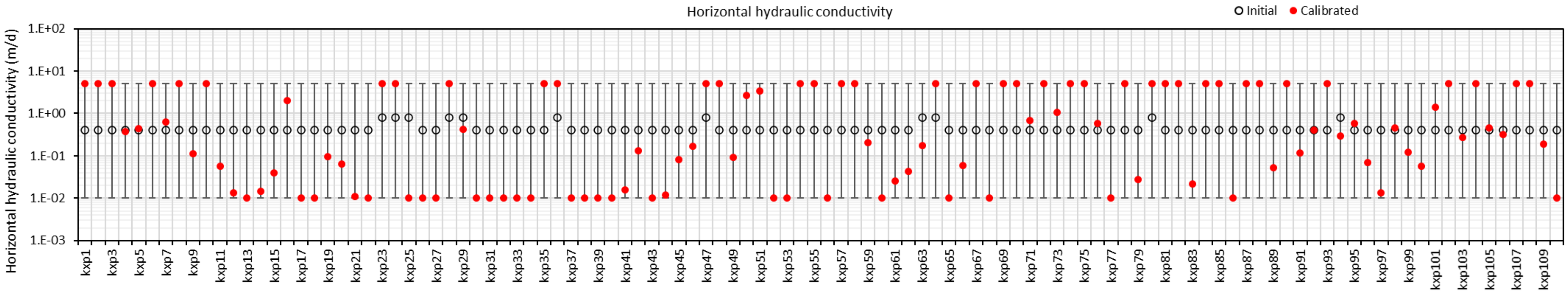


Figure 4-14 Calibrated parameters and their range – horizontal and vertical hydraulic conductivity pilot points



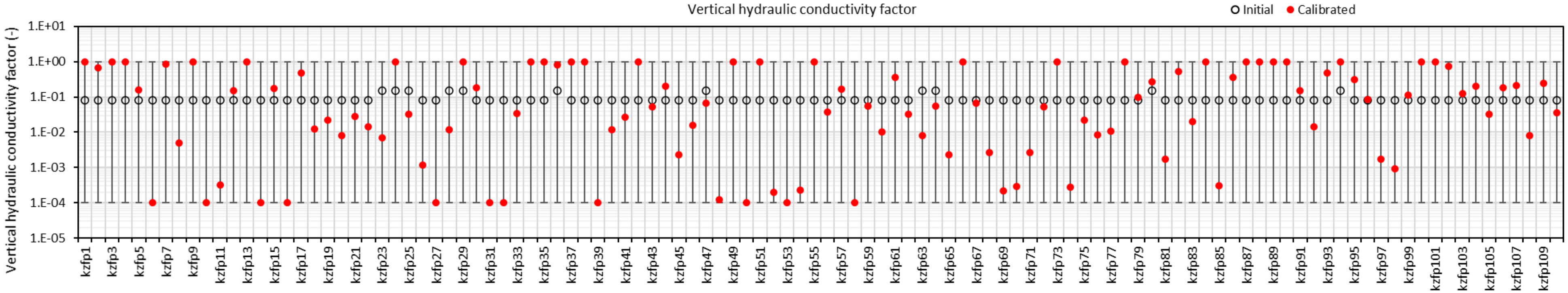
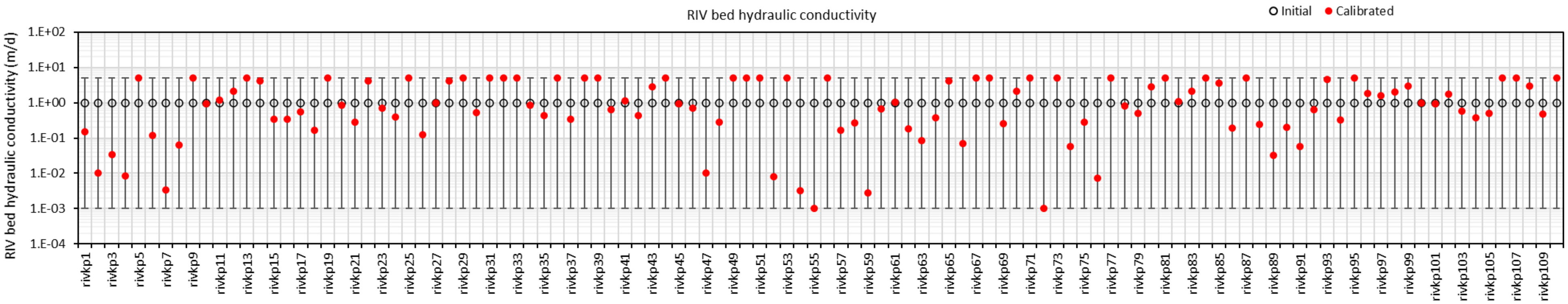


Figure 4-15 Calibrated parameters and their range – RIV and SFR bed hydraulic conductivity pilot points



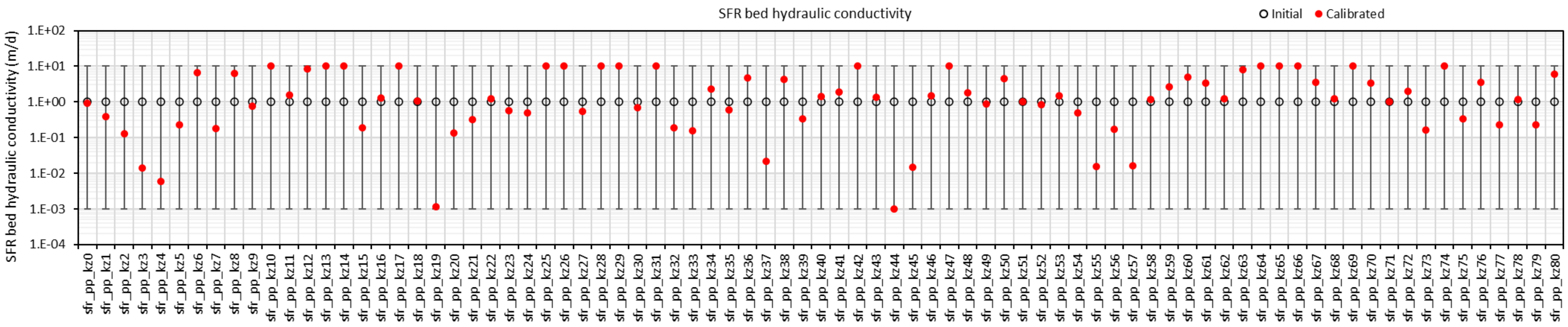
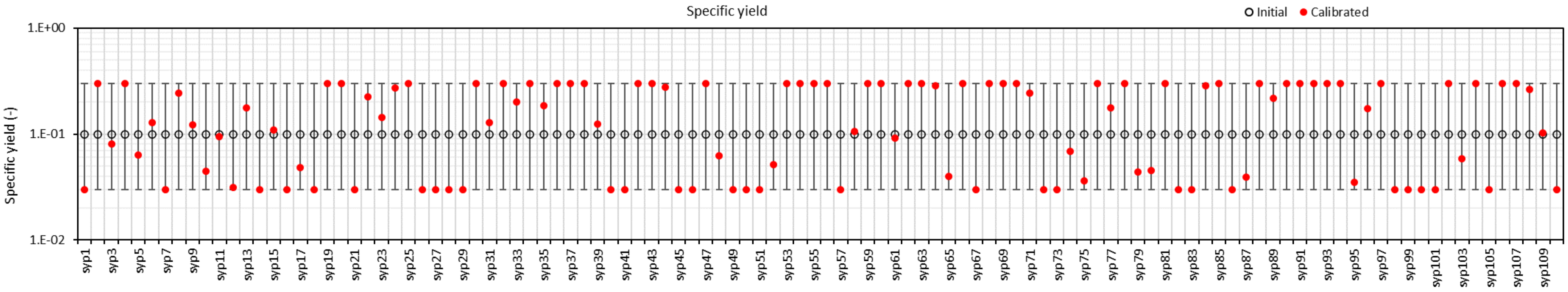


Figure 4-16 Calibrated parameters and their range – specific yield pilot points and SGB reference water depths



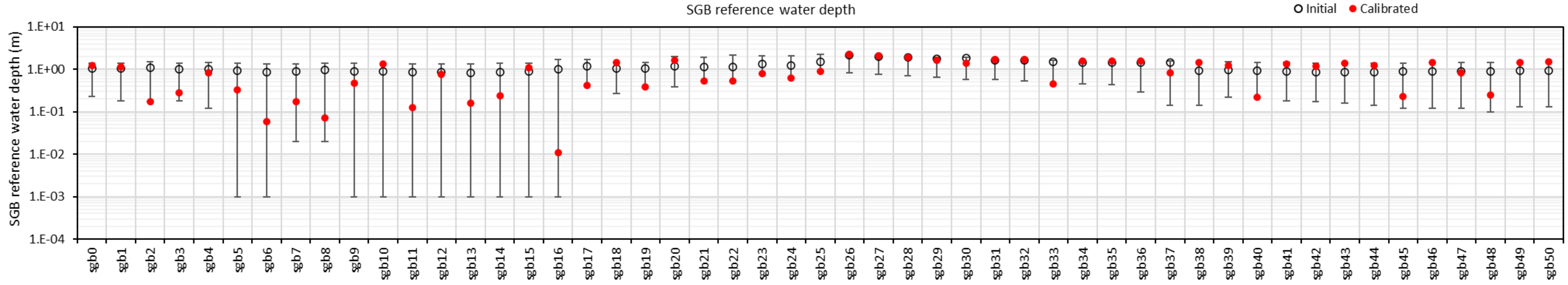


Figure 4-17 Horizontal and vertical hydraulic conductivity distribution

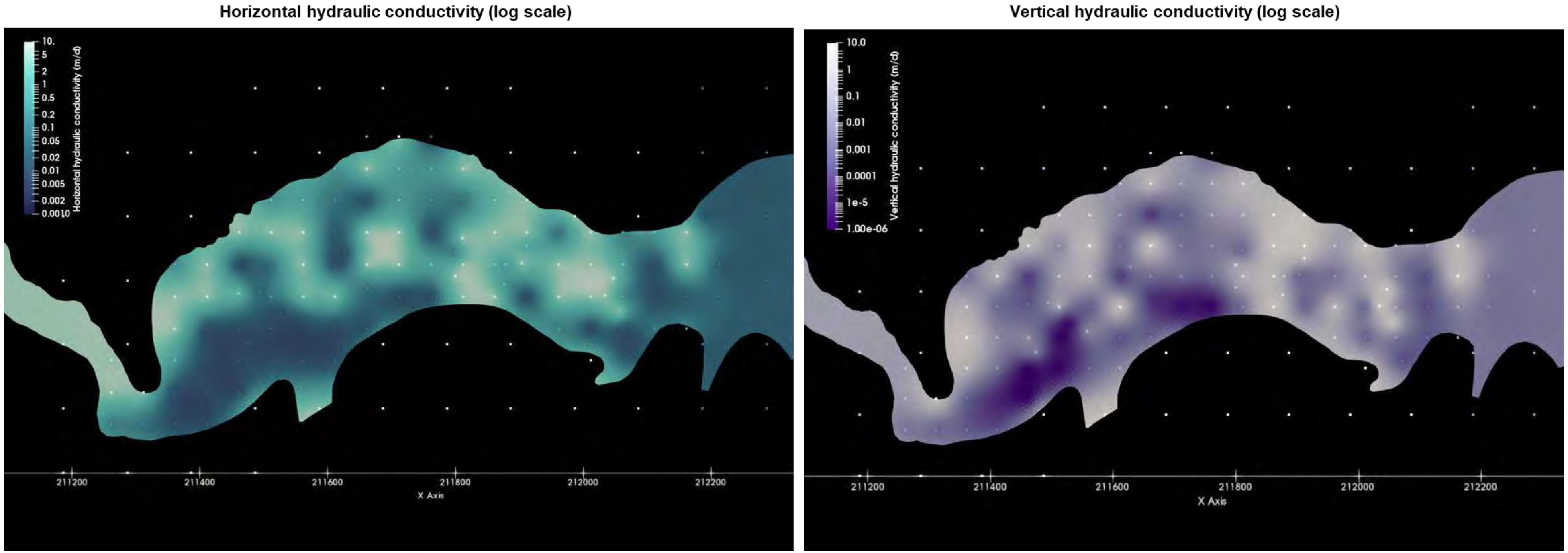


Figure 4-18 RIV and SFR bed hydraulic conductivity distribution

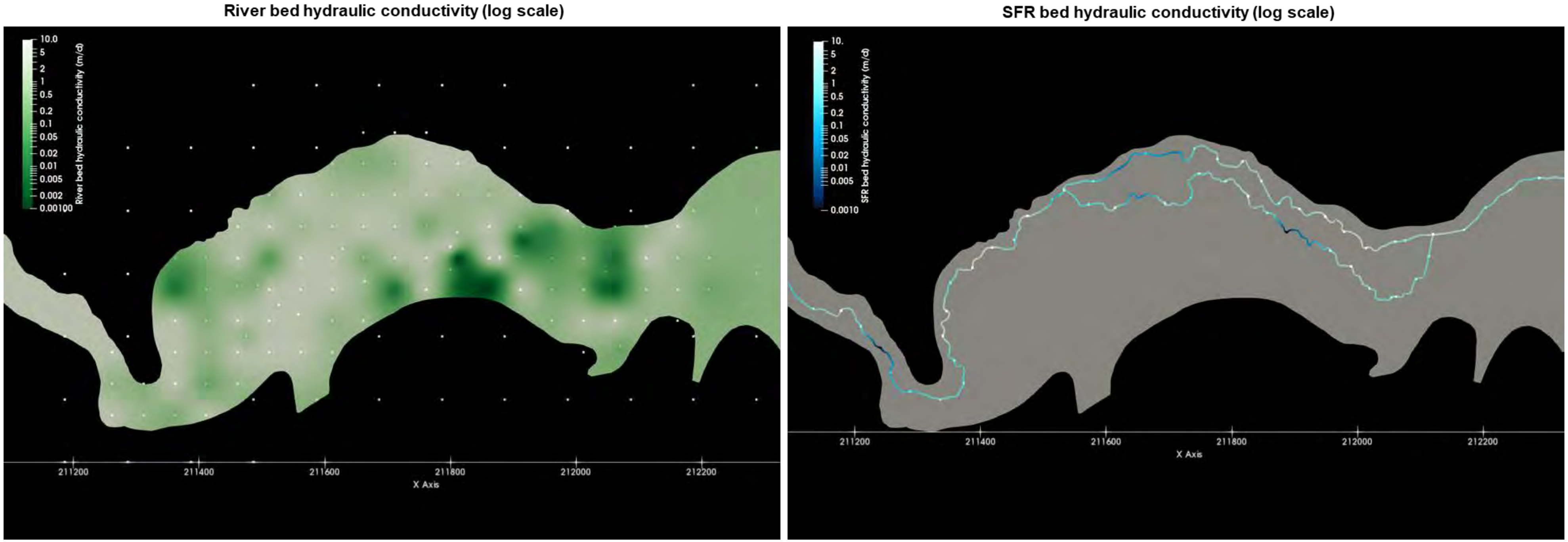
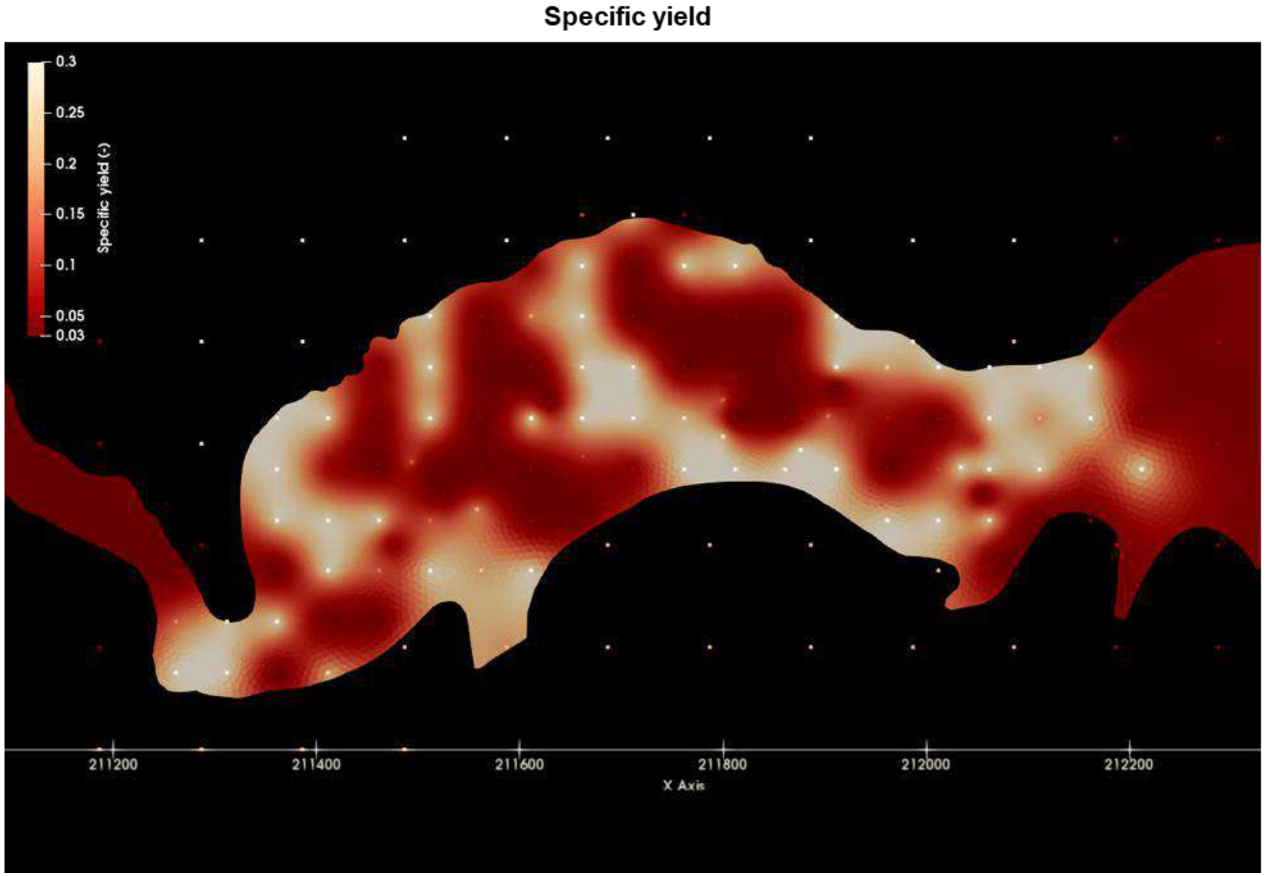


Figure 4-19 Specific yield distribution



Parameter sensitivity

The sensitivity of model outputs (calibration targets) to model parameters is described in this section with reference to parameter sensitivities computed by PEST from the Jacobian sensitivity matrix of the calibrated model. Figure 4-20 shows the sensitivity of each head target group, using the 30 most sensitive parameters. Figure 4-21 shows the sensitivity to the flow target groups.

The parameter sensitivities indicate the following:

- Group 1 head targets show sensitivity to SGB, recharge and EVT parameters of the steady state model (“sgb0”, “rchfac1” and “evtfac1”). This is because Group 1 includes head targets from the wet period of 2019 from upstream bores. The accuracy of heads simulated during the first several months of transient calibration depends on the accuracy of starting heads, which are derived from the steady-state (initial condition) model.
- Group 2 head targets are derived from upstream bores BSBH11 to BSBH18 for the dry period between January and April 2020. High sensitivity to EVT parameters reflects the importance of EVT as a discharge mechanism during the dry period. High sensitivity is also shown for SGB parameters in stress periods 26, 27 and 28, corresponding to a period when the distinctive rising trend is observed in a number of upstream bores. Flow mass balance described in Section 4.4.6 indicates a component of upflow from the SGB during this period, with high parameter sensitivity further supporting the importance of upward flow from the LTA in initiating the recovery of the water table as it falls below a critical level/threshold (when/where the vertical flow direction reverses).
- Group 3 head targets are derived from upstream bores BSBH11 to BSBH18 following the dry period (from April 2020), when the rising trend shifts from upward leakage to rainfall-driven effects (recharge and overland flow). Therefore, high sensitivity is recorded for transient recharge and EVT parameters ("rchfac2" and “evtfac2”) as well as the SGB parameters.
- Group 4 head targets include those from downstream bores BSBH04 to BSBH07. These targets show higher sensitivity to RIV bed hydraulic conductivity pilot points than other groups because bores BSBH06 and BSBH07 are located within the footprint of inundation and are more responsive to leakage from the RIV cells directly above.
- SFR stage and flow observation groups show high sensitivity to SFR parameters, hydraulic conductivity and, to lesser extent, specific yield and RIV bed hydraulic conductivity. The Group 2 flow observations (Flow2) as well as flow difference observations are also sensitive to the SGB parameters during the dry period, which is expected as the recovery of the water table is initiated by the vertical upflow from the LTA and this affects the interaction between groundwater and surface water.

It should be noted that Figure 4-20 and Figure 4-21 compare the sensitivity ranking of model-wide parameters such as recharge, EVT and SGB parameters against pilot point parameters. As each pilot point only affects the model outputs locally, the figures give the impression that model outputs are less sensitive to pilot point parameters than to model-wide parameters. This is not necessarily correct and when considered on an aggregate (parameter group) basis, the majority of the head observation groups show similar or higher sensitivity to hydraulic conductivity and this is supported by the number of hydraulic conductivity pilot point parameters that appear in each figure.

Another important observation is the moderate sensitivity of head targets to RIV bed hydraulic conductivity pilot points. This could partly be due to the key upstream bores located outside of the simulated extent of inundation, which means the modelled response is more sensitive to horizontal hydraulic conductivity that controls the resistance to flow in the horizontal direction as the pressure propagates laterally from the point of leakage to the location of bores. This does not mean the modelled heads are insensitive to RIV bed hydraulic conductivity. The rate of leakage also depends on the RIV stage and location of RIV cells, which are derived from the TUFLOW model and are not incorporated as adjustable parameters in the calibration process. The model calibration performance is highly sensitive to the accuracy of the TUFLOW model outputs, which has been identified during iterative exchange of outputs between the TUFLOW and USG-Transport models.

Figure 4-20 Head observation group parameter sensitivities

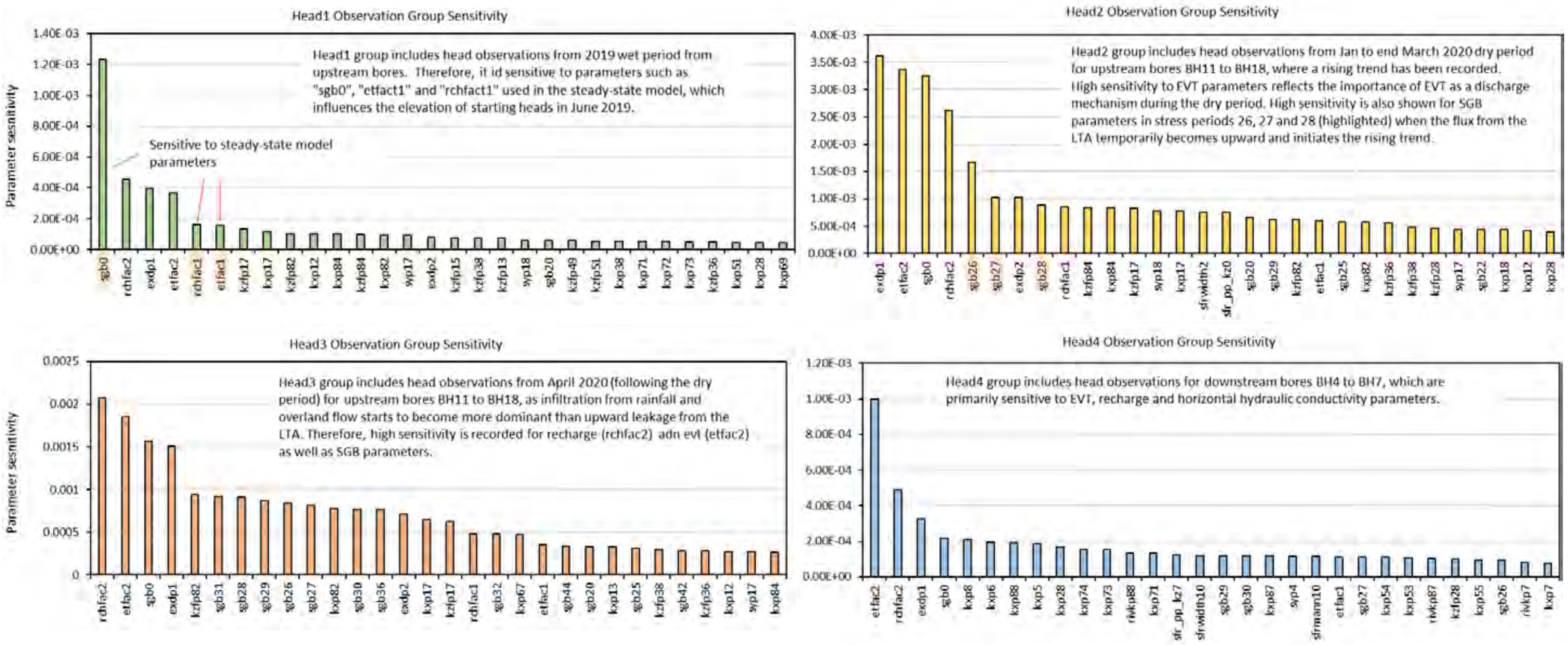
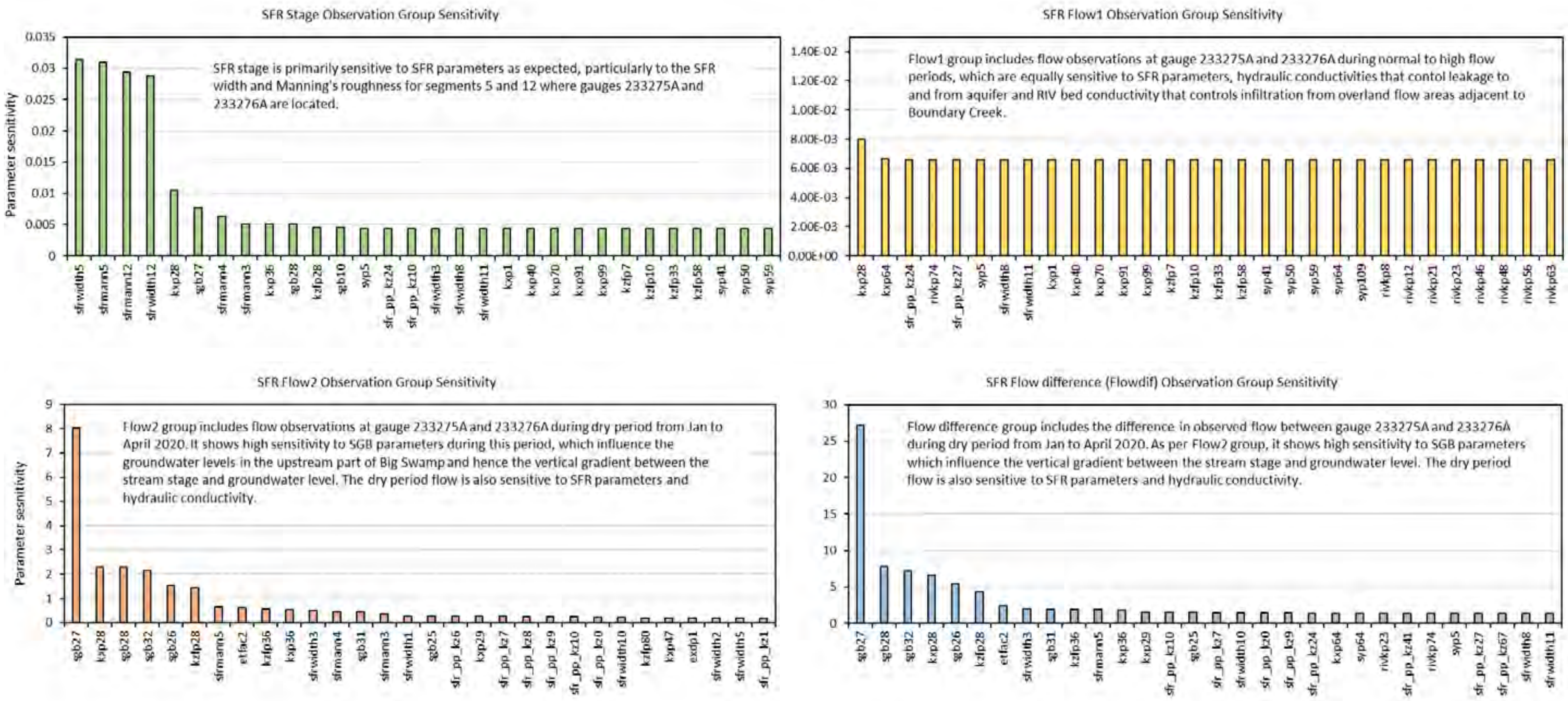


Figure 4-21 Stage and flow observation group parameter sensitivities



4.4.6 Mass balance

The cumulative mass balance error is 0.05 % and the mass balance error for all time steps is less than 0.01 % except for a small number of time steps between stress periods 25 and 28 (14-day long stress periods during the dry period), where the error ranges from 0.3 to 1.5 %. These mass balance errors can be minimised by controlling the time step size in the auto-time stepping function of USG-Transport, although implementing a tighter time step control made no material difference to the model outputs and quality of calibration.

Table 6 provides a breakdown of the model-wide transient water balance, including the average and cumulative inflow and outflow in ML/d. The model-wide water balance is also shown graphically in Figure 4-22. Table 6 indicates that inflow into the QA is currently dominated by leakage from Boundary Creek (stream) and overland flow (flood inundation) and flow out of the QA is predominantly leakage into the underlying LTA (flow out of SGB). However, fluxes into and out of the QA are spatially and temporally variable. In topographically elevated areas in the upstream reaches of Boundary Creek (upstream of Big Swamp), the water table is deeper and there is net leakage from the creek and flooded areas. Across Big Swamp, the water table becomes shallower, and parts of the aquifer becomes fully saturated during wet periods resulting in more variable flow dynamics.

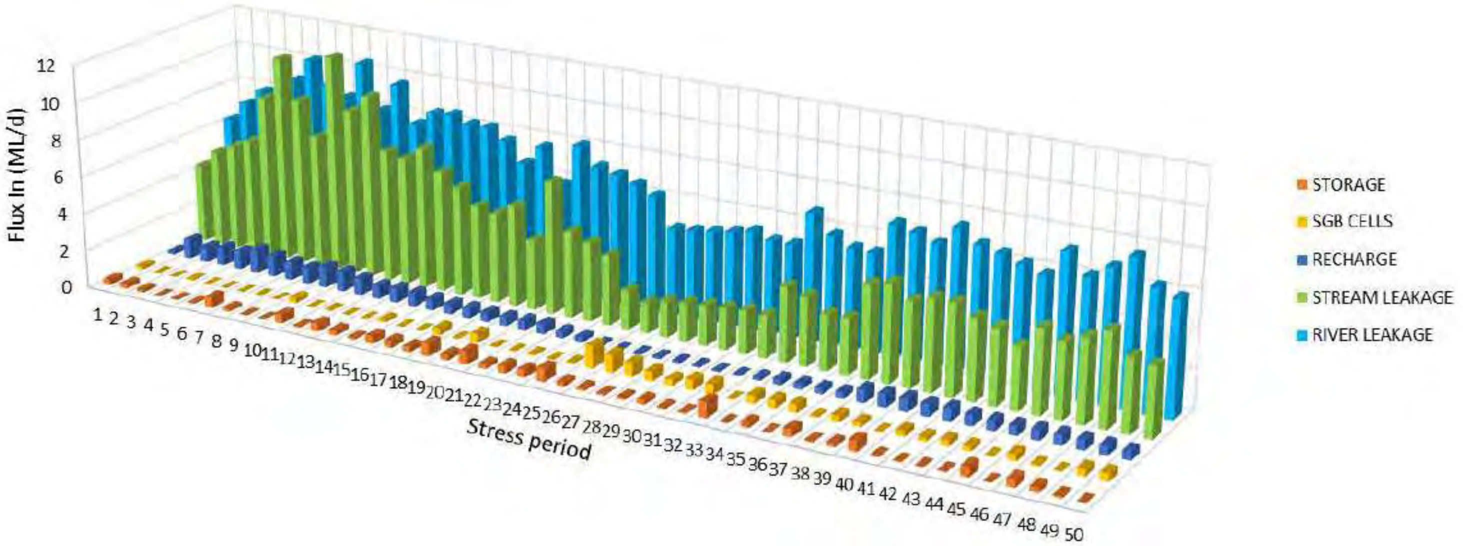
The local water balance of Big Swamp, between gauges 233275A and 233276A, has been extracted using the ZONBUDUSG utility. Figure 4-23 shows the fluxes into and out of Big Swamp from the SGB, recharge and EVT boundaries. During the dry period from stress period 25 to 32, when EVT is greater than recharge, there is net flux into the swamp from SGB. This represents the component of upflow from the LTA, which initiates the rising trend observed in the upstream bores in the middle of the dry period. This is consistent with the model sensitivity to the SGB parameters during this period.

Figure 4-24 shows the fluxes into and out of Big Swamp from the RIV and SFR boundaries. The figure shows almost as much fluxes leaving the RIV boundaries as they are entering from the RIV boundaries; however, the majority of inflow from the RIV boundaries are occurring in the upstream area where the water table is deeper whereas the outflow is occurring in the downstream areas and within the vicinity of Boundary Creek where the water table is shallower and the aquifer becomes fully saturated regularly. This effect can be seen in Figure 4-25, which compares the RIV fluxes from sub-areas within Big Swamp and how they vary spatially. The implication is that net leakage is likely to be limited in the downstream area, which becomes frequently inundated by overland flow as well as through-flow of groundwater accumulated from upstream.

Table 6 Average and cumulative model water balance

Component	Avg. IN (ML/d)	Avg. OUT (ML/d)	Cuml.IN (ML)	Cuml.OUT (ML)
RIV leakage	7.13	3.73	2843.11	1335.29
SFR leakage	5.02	0.16	1886.75	63.49
SGB	0.21	8.39	109.52	3446.84
Recharge	0.55	0	212.2	0
EVT	0	0.39	0	185.76
Drain	0	0	0	1.86
Storage	0.44	0.68	149.49	170.47
Total	13.35	13.36	5201.07	5203.7

Figure 4-22 Model water balance



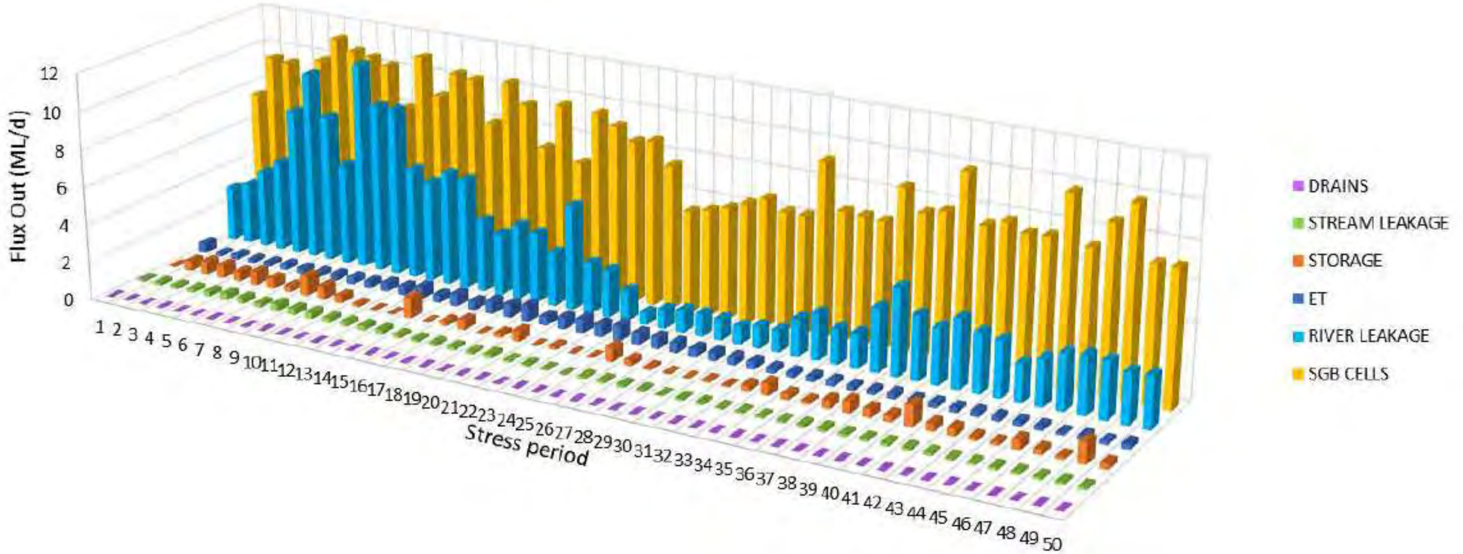


Figure 4-23 Big Swamp local water balance – vertical flux, recharge and evapotranspiration

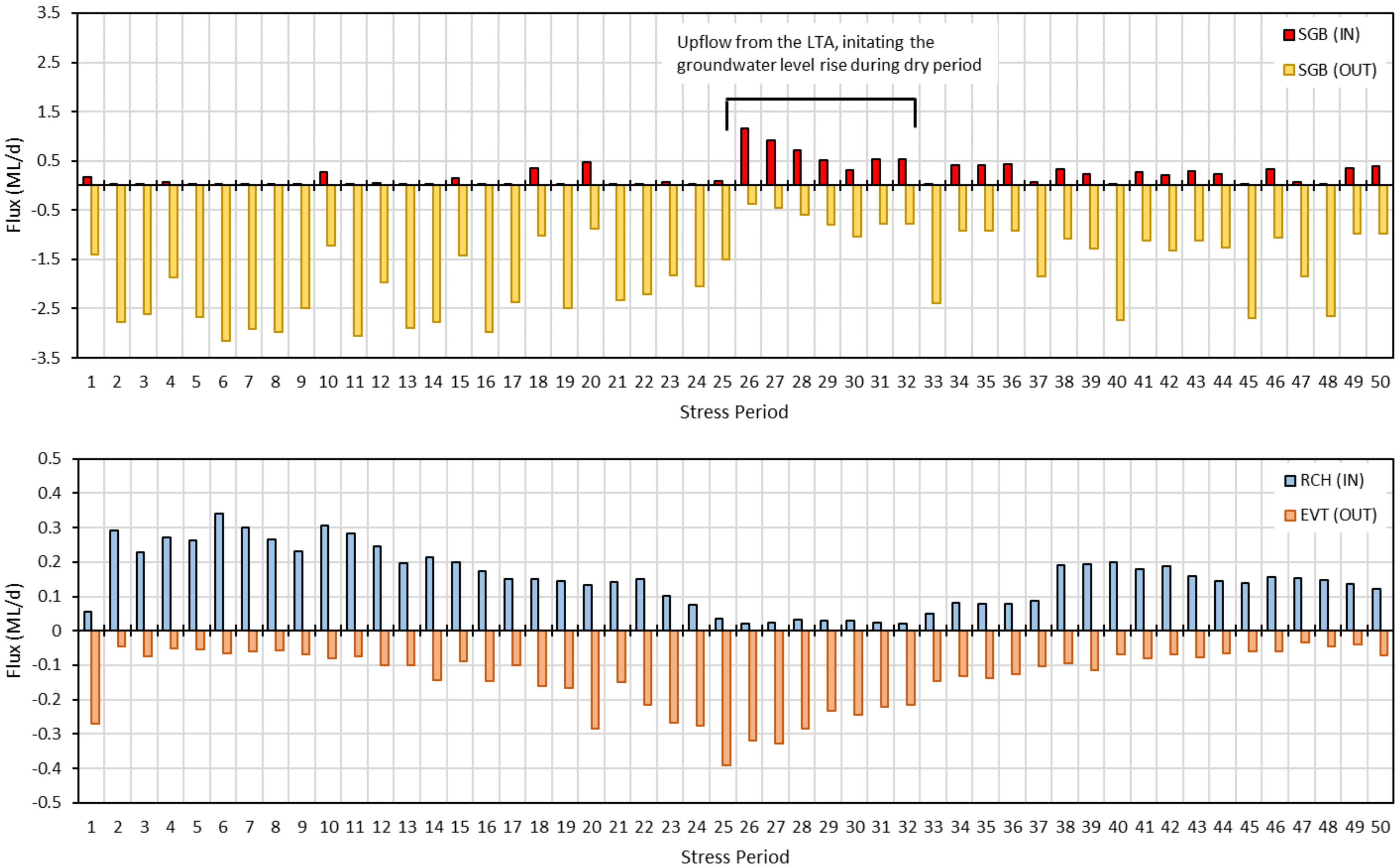


Figure 4-24 Big Swamp local water balance – RIV and SFR fluxes

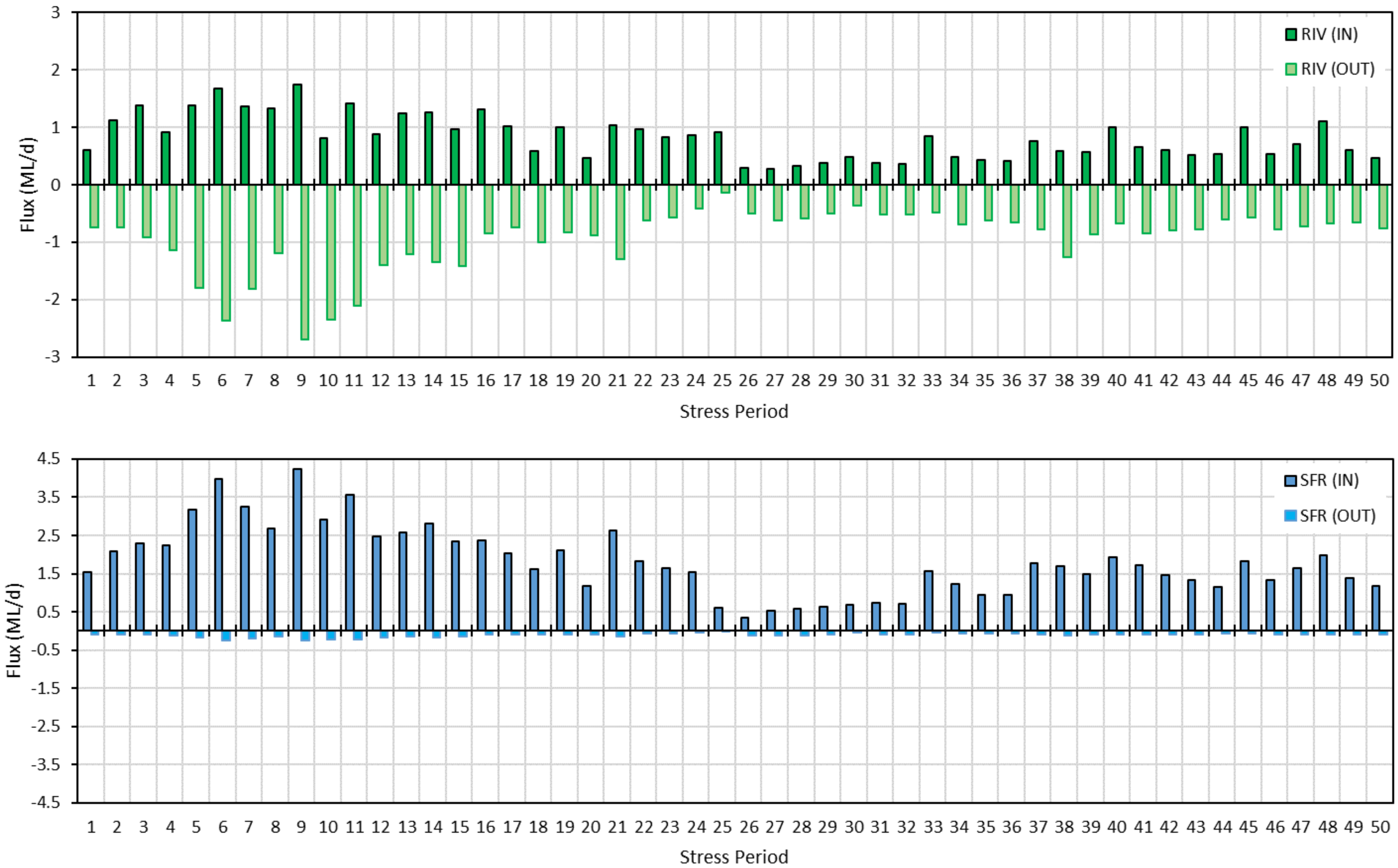
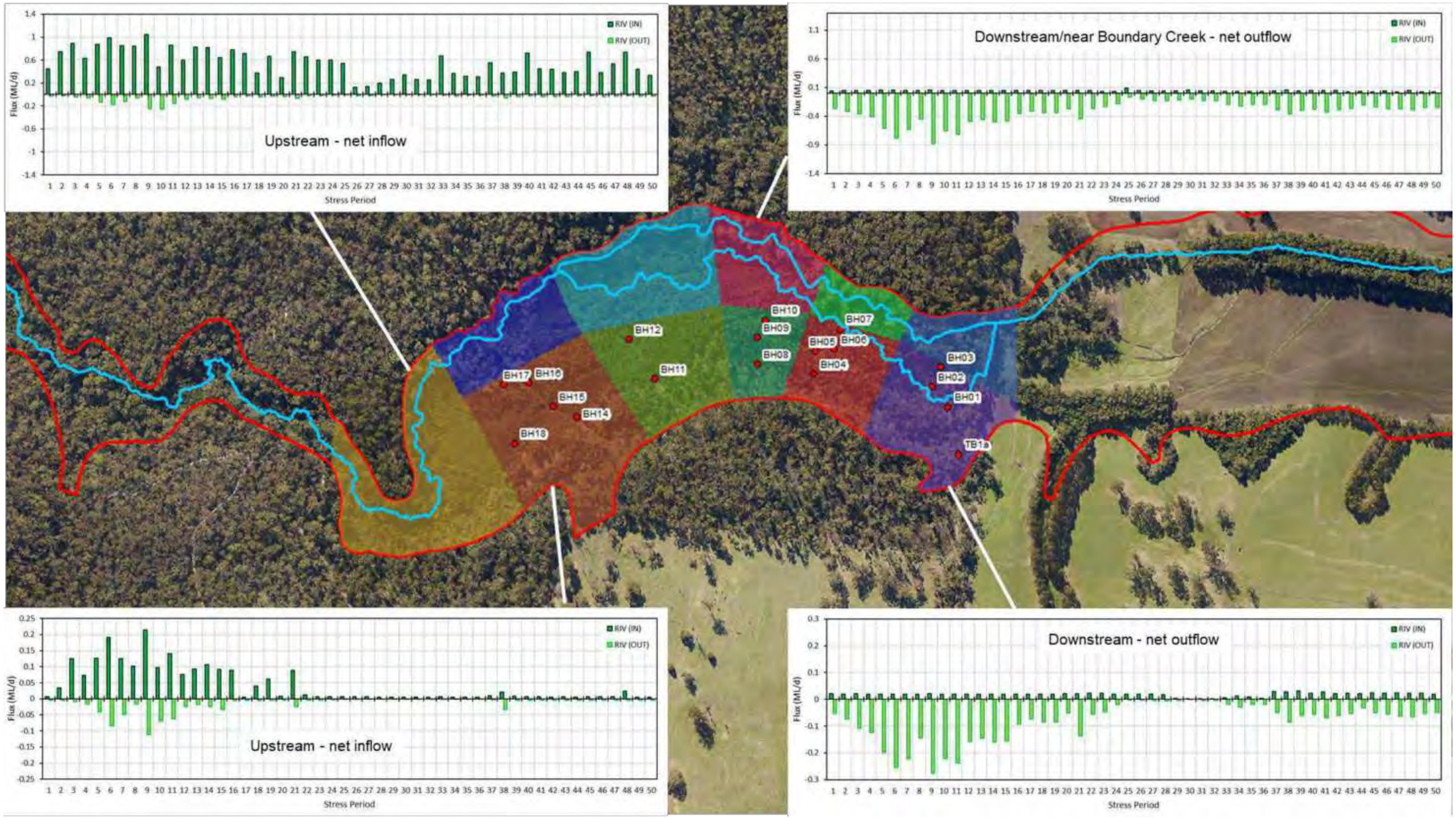


Figure 4-25 Big Swamp local water balance – RIV flux spatial variability



5. Model predictions

5.1 Predictive modelling objectives and approach

The purpose of predictive modelling is to derive hydraulic barrier configurations and supplementary flow regimes that would:

1. Maintain the water table near constant at or above the target groundwater levels defined for key monitoring bores to minimise further activation of acid sulfate soils.
2. Maintain a minimum stream flow of 0.5 ML/d at Yeodene gauge (233228) downstream of Big Swamp.

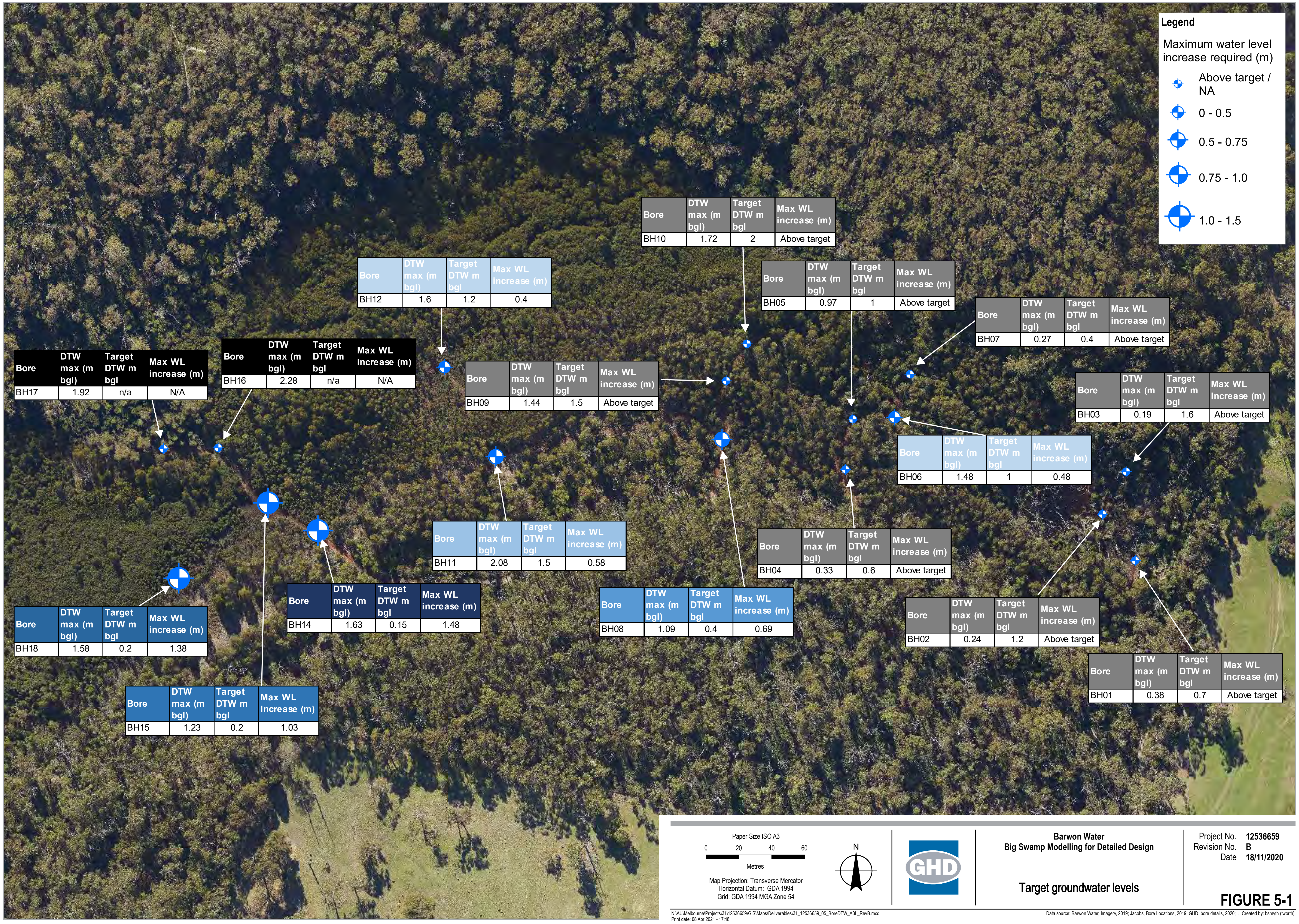
The target water level required for each of the key monitoring bore is summarised in Table 7. It is understood that these target water levels are designed to minimise the amount of sulfate available for oxidation at each bore, based on the concentration of sulfate recorded in soil cores collected during drilling. Also included in the table is the maximum increase in groundwater level required to meet the target level at each bore based on their maximum depth to water (DTW) recorded to date. Figure 5-1 shows how this varies spatially. More than 1 m of increase in groundwater level is required at upstream bores BSBH14, BSBH15 and BSBH18, where the swamp is more elevated and depth to groundwater is deeper. This decreases in the downstream area of the swamp, where the aquifer becomes frequently inundated and groundwater levels in many of the bores currently remain above the target levels.

The process of arriving at the preferred hydraulic barrier configuration has been iterative. Several hydraulic barrier configurations were initially tested in TUFLOW based on the need to redistribute surface water to the areas of critical bores and the level of ponding that may be required to maximise the increase in groundwater level. Once a barrier configuration with the most effective redistribution of surface water was identified, its effectiveness on maintaining the groundwater level was assessed using the USG-Transport model. The outputs from the USG-Transport model were then used to refine the number, location, length and height of the barriers. This was followed by examining the effects of different supplementary flow regimes on maintaining the required flow during the dry period, including the effect of different flow diversions within Boundary Creek.

The following sections provide detailed descriptions of model iterations and key findings. All predictive model outputs are based on the climate data from the 14-month calibration period.

Table 7 Target groundwater levels for managing acidification

Bore ID	Target GWL (mAHD)	Target DTW (mbgl)	Max DTW (mbgl)	Maximum increase (m)
BH01	141.16	0.7	0.38	Above target
BH02	140.55	1.2	0.24	Above target
BH03	140.14	1.6	0.19	Above target
BH04	142.77	0.6	0.33	Above target
BH05	142.08	1	0.97	Above target
BH06	141.9	1	1.48	0.48
BH07	142.1	0.4	0.27	Above target
BH08	144.22	0.4	1.09	0.69
BH09	142.86	1.5	1.44	Above target
BH10	142.31	2	1.72	Above target
BH11	145.6	1.5	2.08	0.58
BH12	146	1.2	1.6	0.4
BH14	147.52	0.15	1.63	1.48
BH15	147.22	0.2	1.23	1.03
BH16	N/A	N/A	2.28	N/A
BH17	N/A	N/A	1.92	N/A
BH18	148.52	0.2	1.58	1.38



Barwon Water
Big Swamp Modelling for Detailed Design

Target groundwater levels

Project No. 12536659
Revision No. B
Date 18/11/2020

FIGURE 5-1

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Print date: 08 Apr 2021 - 17:48

Data source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020; . Created by: bsmyth (tworth)

5.2 Flood (TUFLOW) model results

5.2.1 Predictive TUFLOW model set up

The predictive modelling in TUFLOW involved making several modifications to the calibrated model described in Section 4.3, including:

- placing hydraulic barriers to redistribute surface water and improve surface water connectivity at critical locations within Big Swamp.
- modifying the upstream inflow to simulate the effect of different supplementary flow rates
- filling the fire trench, as currently planned. This results in local tributary runoff from the area south of the swamp flowing out into the middle of the swamp instead of getting diverted along the southern boundary of the swamp and ultimately joining Boundary Creek at the downstream end.

As indicated in Section 5.1, the process of arriving at the preferred hydraulic barrier configuration has been highly iterative. This process is described briefly in the sections to follow, including different barrier configurations tested and how their outputs were used to progressively refined the barrier configurations. All TUFLOW outputs presented in this section assumed the existing supplementary flow of around 2 ML/d during the dry period, although the model has been run with higher supplementary flow rates to inform the USG-Transport model (see Section 5.3.3).

5.2.2 Initial testing of barrier configurations

The initial sets of hydraulic barriers were placed primarily based on topography and the locations of bores. Given the focus of the remedial system on meeting the target level at each bore, the barriers configurations are biased towards maintaining the groundwater levels elevated at these specific locations. This means the barrier configurations may be less optimal for other parts of the swamp, such as along the northern boundary where the presence of potential acid sulfate soils is not well understood.

A total of 18 different barrier configurations have been tested in TUFLOW, although many of these are slight variations of the same basic design. These barriers configurations focused on diverting water from Boundary Creek and then encouraging surface water ponding around the upstream bores where the largest increase in groundwater levels is required to meet the targets. When a direct barrier is placed over the main channel, the blockage of flow results in Boundary Creek going dry during low flow periods. Adding a weir at this location, set as a rectangular cut-out of 0.5 m in width with an invert at 148.4 mAHD, partially alleviates this problem by letting some flow pass down the channel during dry periods while allowing surface water to build up around the barrier during wetter periods, diverting some flows overland through the swamp.

Three initial barrier configurations were found to produce modest results, with reasonable amounts of ponding when run over a short test period. The first two of these (Group 1 and Group 2) used three barriers; one to divert flow, one to encourage ponding around BSBH11, BSBH14 and BSBH15 and one to encourage ponding around BSBH08 to BSBH10. The third option (Group 3) was aimed at creating a series of ponds using seven barriers, each blocking the primary flow path through the low point in the swamp to create small ponds. To improve the extent of ponding achieved, a second version of Group 3 configuration was developed whereby the height of the barriers was increased and the barriers were connected together to prevent the loss of flow around the side or back.

This version of barrier configurations was aimed at generating as much ponding as possible in critical areas, to assess whether or not the target groundwater levels are attainable and then scale back the design as required. The barrier locations and maximum ponded depths reached during the 4 week test period (in July 2019) are shown in Figure 5-2, Figure 5-3 and Figure 5-4 for barrier configuration Groups 1, 2 and 3 (the second version) respectively.

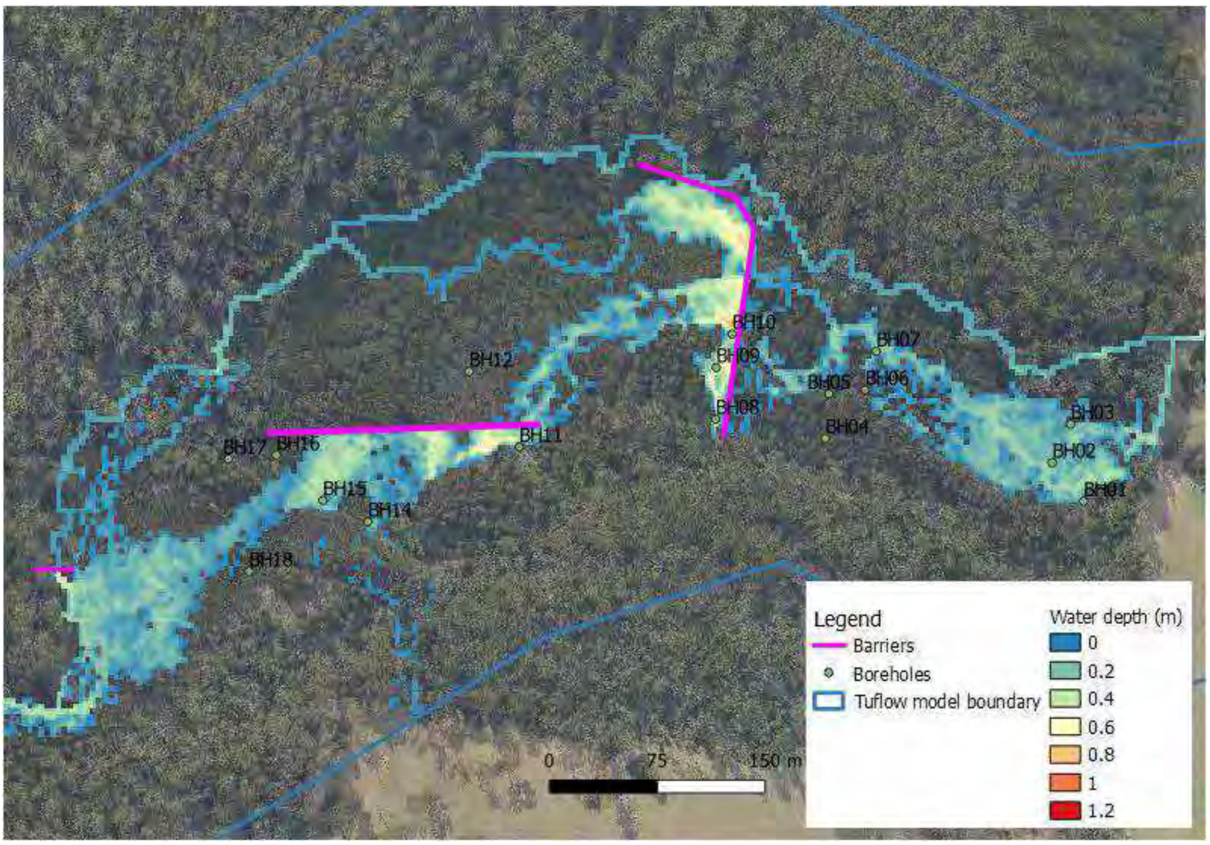


Figure 5-2 Barrier configuration Group 1 and maximum ponding depth

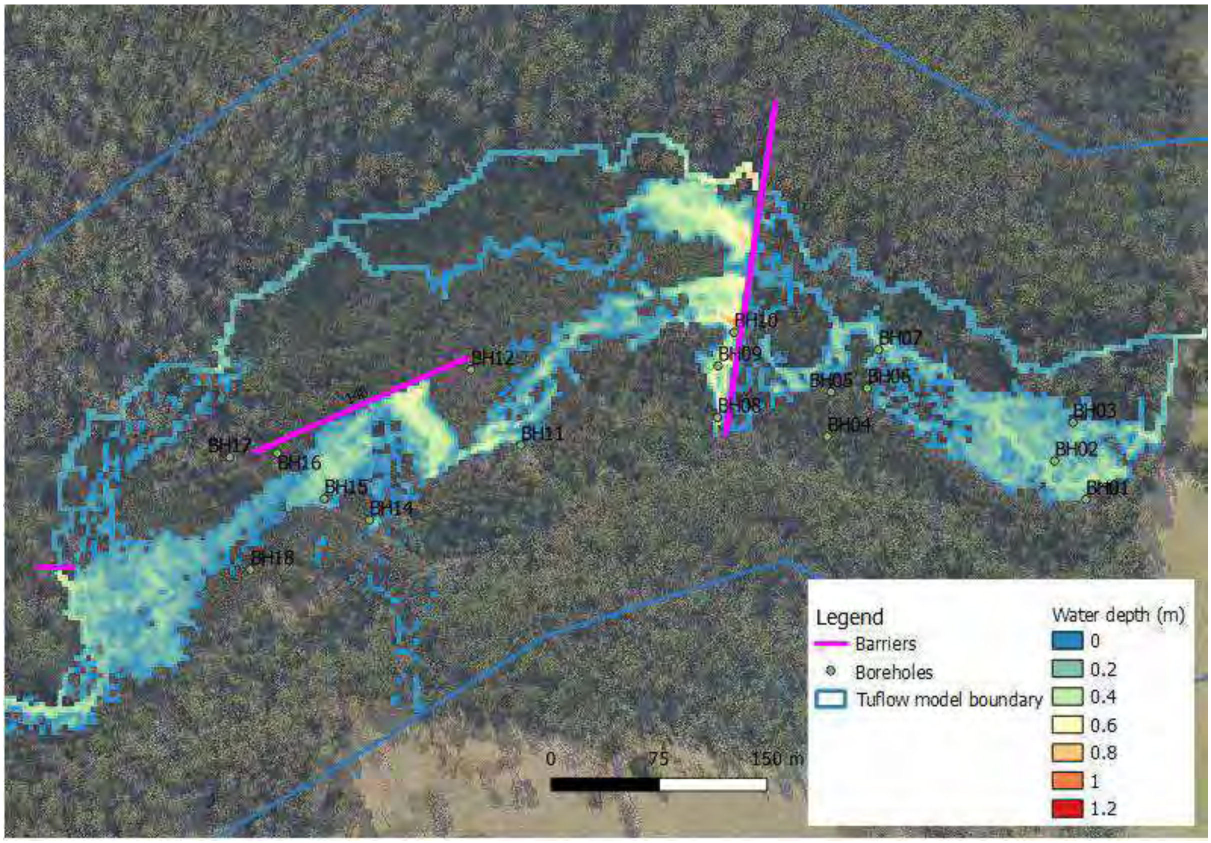


Figure 5-3 Barrier configuration Group 2 and maximum ponding depth

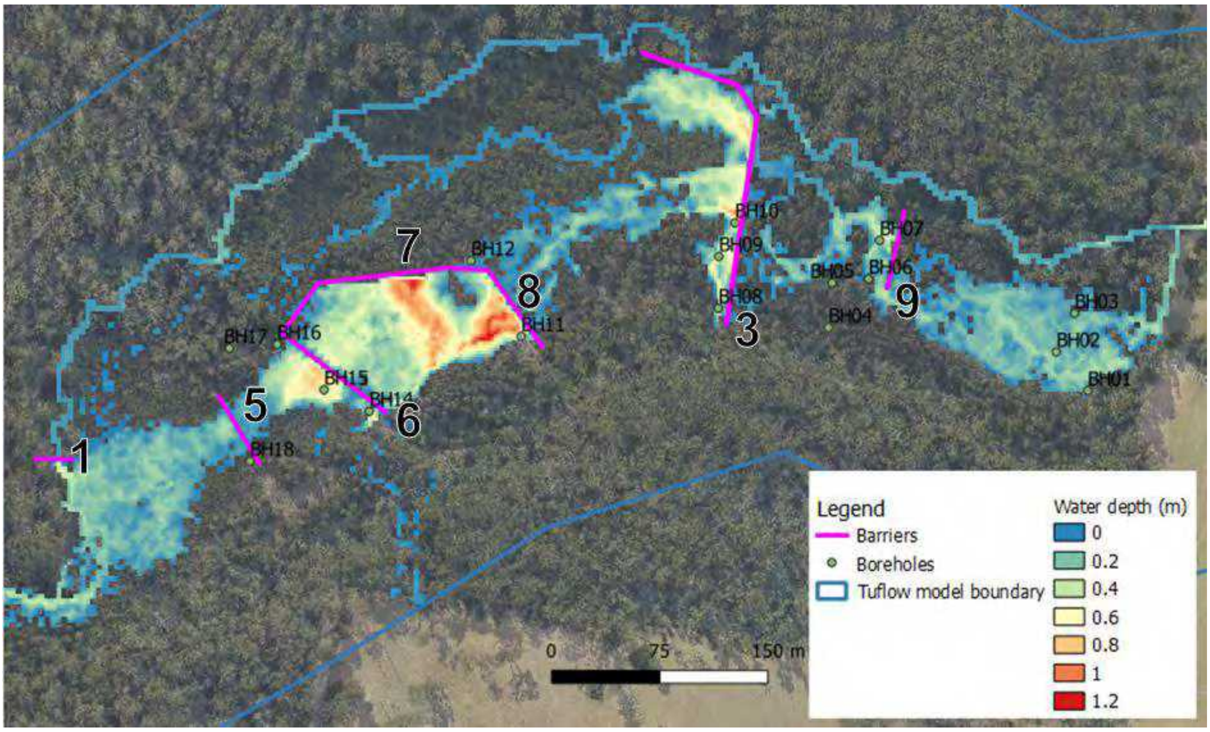


Figure 5-4 Barrier configuration Group 3 (second version) and maximum ponding depth (including barrier numbers)

5.2.3 Further testing of barrier configurations in conjunction with USG-Transport model

Based on the outcomes of short-term test runs, the effect of a slightly improved version of Group 3 barrier configuration was examined in TUFLOW for the entire 14-month calibration period and the results were incorporated into the calibrated USG-Transport model to assess their potential effect on groundwater levels. The outputs from the USG-Transport model indicated that the modified Group 3 barrier configuration is effective albeit far exceeding the required target levels at upstream bores BSBH11 to BSBH15 while inducing a slight lowering of the groundwater level at downstream bores BSBH4 to BSBH6. The USG-Transport model also indicated only a slight increase in the groundwater level at BSBH18, which remained below its target level.

One important finding of the initial testing of the barrier configuration was the maintenance of flow to keep the ponded areas topped up and overflowing. As longs as sufficient flow is maintained to keep the barriers topped up at a rate greater than infiltration and evaporation losses, then the groundwater levels would remain elevated, effectively resulting in near constant groundwater levels.

Based on the insights gained from the preliminary outputs of the USG-Transport model, four new barrier configurations were developed and simulated over the full 14-month calibration period in TUFLOW. These barrier groups are described in Table 8 and were aimed at improving efficiency whilst addressing some of the shortfalls of Group 3 barrier configuration (such as not meeting the target levels at bores BSBH04 to BSBH06 and BSBH18). These are variations of Group 3 (Version 2) barriers, utilising more realistic lengths and heights of barriers where changes to these attributes were considered unlikely to detrimentally influence their performance (refer to Figure 5-4 for barrier numbers).

The Group 5 barriers and their variants were generally found to be effective when incorporated into the USG-Transport model. The exception was for Group 8 barriers, where the 0.2 m increase in the height of Barrier 5 to encourage more ponding at BSBH18 resulted in insufficient flow passed down to other barriers further downstream i.e. the increased barrier height prevented overtopping during the dry period. This resulted in the ponded areas going dry when the flow in Boundary Creek was reduced (see Figure 5-5), resulting in the lowering of groundwater levels back towards their existing levels. This indicated that sufficient flow should be maintained at all times to keep the ponded areas topped up due to the tendency for the groundwater levels to decline to their natural levels relatively quickly as soon as the ground surface becomes dry. It also highlighted that even with a taller barrier, the simulated incremental increase in the groundwater level at BSBH18 remained below its target level. Therefore, the small incremental benefit gained from placing a taller barrier at BSBH18 is unlikely outweigh the risks of detrimentally impacting the performance of the barriers further downstream.

Table 8 Additional barrier configurations

Barrier group	Description
5	Realistic version of Group 3 (Version 2), with a reduced length for barriers 7 and 8 and increased length for barrier 9.
6	Based on Group 5 with barrier heights reduced by 0.3 m
7	Based on Group 6 with barriers 5,6, and 9 removed
8	Based on Group 5 but barrier 5 is 0.2 m taller

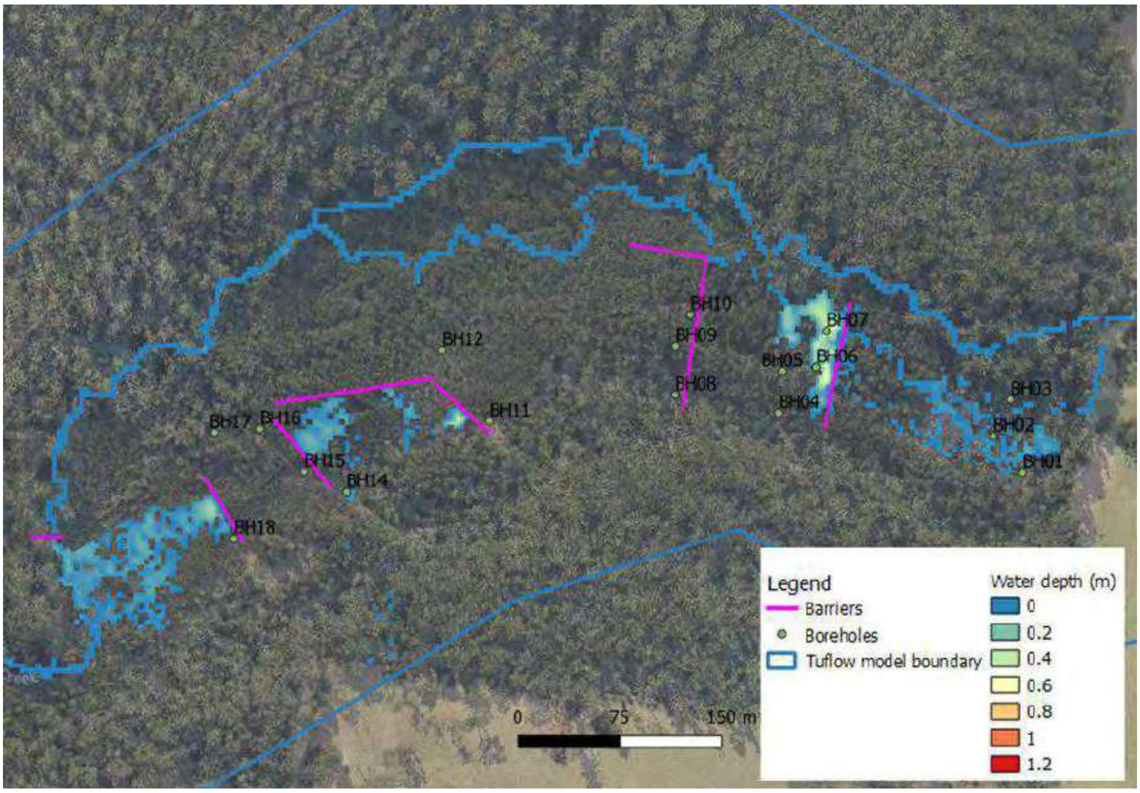


Figure 5-5 Barrier configuration Group 8 and dry period ponding depth

5.2.4 Flow split and supplementary flow

The barrier configurations presented up to this point have focused on maximising the ponded areas to meet the target groundwater levels at the bores. However, maintaining as much flow as possible in Boundary Creek is also an important design consideration for meeting the minimum flow target as well as minimising the lowering of groundwater levels along the northern boundary of Big Swamp. The modelling of barrier configurations up to this point indicates that between 70 and 90% of the stream flow is diverted from Boundary Creek in wet periods and around 30 to 50% is diverted in the dry period. This occurs because the weir to allow flow down the main channel is assumed to be 0.5 m wide, so only a small flow rate can pass through. Encouraging more flow down Boundary Creek during wet periods is likely to have some beneficial effects, potentially reducing the stress during the early stages of dry periods. From a practical point of view, it is unlikely to be necessary for up to 70 and 90% of water to be diverted during the wet period to maintain the ponded areas.

To provide a more even flow split at Barrier 1, the weir level can be increased to encourage more ponding upstream of the diversion such that surface water could flow freely out of the ponded area and down the main channel as well as along the diversion. Figure 5-6 shows the relationship between the barrier heights and topography. By setting the weir at 148.4 mAHD (area of blue contours), the flow rate needed to be constricted to ensure that the water level rose up to a level (148.5 mAHD) required to flow down the diverted path. Setting the weir level at 148.5 mAHD removes this constriction, allowing ponding between Barriers 1 and 5. This means the size of weirs put on these barriers can be used to determine the flow split.

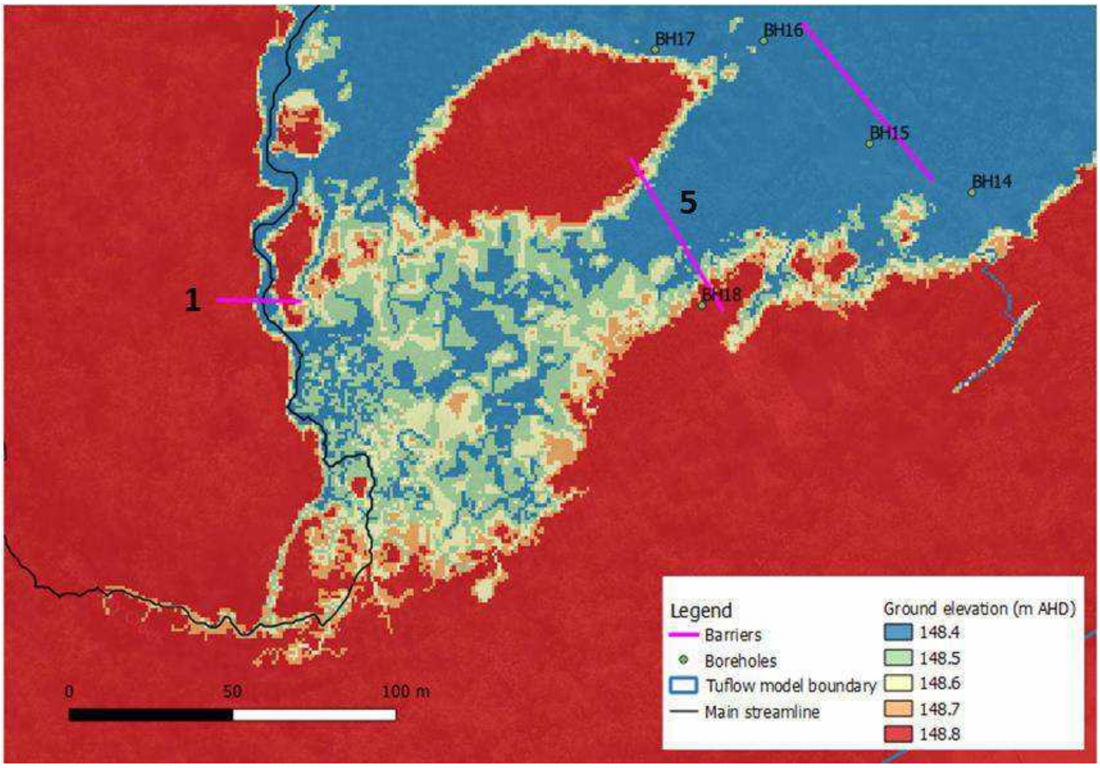


Figure 5-6 Topography around Barriers 1 and 5

5.2.5 Preferred hydraulic barrier configurations

The preferred hydraulic barrier configuration has been developed from Group 5 barriers, with modifications to encourage more ponding at BSBH18 (without incurring drying at the downstream barriers) and to improve the flow split at Boundary Creek (to pass more flow downstream). This has been achieved by increasing the height of the weir at the main channel flow diversion (Barrier 1) to 148.5 mAHD (increasing it by 0.1 m) and placing an identical weir at Barrier 5 downstream of BSBH18 (Figure 5-7). Both weirs are set to 2 m wide and the height of both barriers are set to 148.7 mAHD. This configuration causes surface water to pond up to 148.5 mAHD, which would then flow out from the two identical weirs, thereby ensuring the same flow rate down the main channel and the diversion. This setup has the added benefit of introducing direct control over the flow split, as the weir widths can be easily altered to produce any desired flow splits. These weirs could also be constructed as a series of stop logs, such that the flow split can be adjusted by simply adding and removing stop logs. This is considered important in the context of optimising the usage of supplementary flow for maintaining both the ponded areas and flow downstream of the swamp.

Because the land above BSBH18 is relatively flat, this configuration creates a relatively large ponded area upstream of the bore as well as increasing the depths in the area immediately adjacent to the bore. In this sense, the ponding generated under this configuration is considered as high as practically feasible.

The TUFLOW model results of the preferred barrier configuration are shown in Figure 5-7, including the modelled ponded depths at the driest and wettest points in the 14-month calibration period. The estimated barrier lengths, levels and maximum heights are presented in Table 9. Note that there are 7 barries in total, albeit the numbering is not currently sequential due to the iterative process involved in developing the preferred barrier configuration, whereby some barriers were removed or added.

It is important to note that the preferred barrier configuration is derived using outputs from the modelling that relies on the available DEM data. If the actual topography differs, then the barrier lengths and locations may need to be adjusted to ensure that the ponded areas are not bypassed by surface water flowing around them. This is examined further as part of sensitivity analysis (see Section 6.1.2).

Table 9 Barrier specification for preferred configuration

Barrier	Level (m AHD)	Max Height (m)	Length (m)
Barrier 1	148.7	0.9	75
Barrier 5	148.7	0.6	54
Barrier 6	147.9	0.7	62
Barrier 7	147.7	1	115
Barrier 8	147.6	1.1	51
Barrier 3	144.9	1	169
Barrier 9	142.7	0.7	92

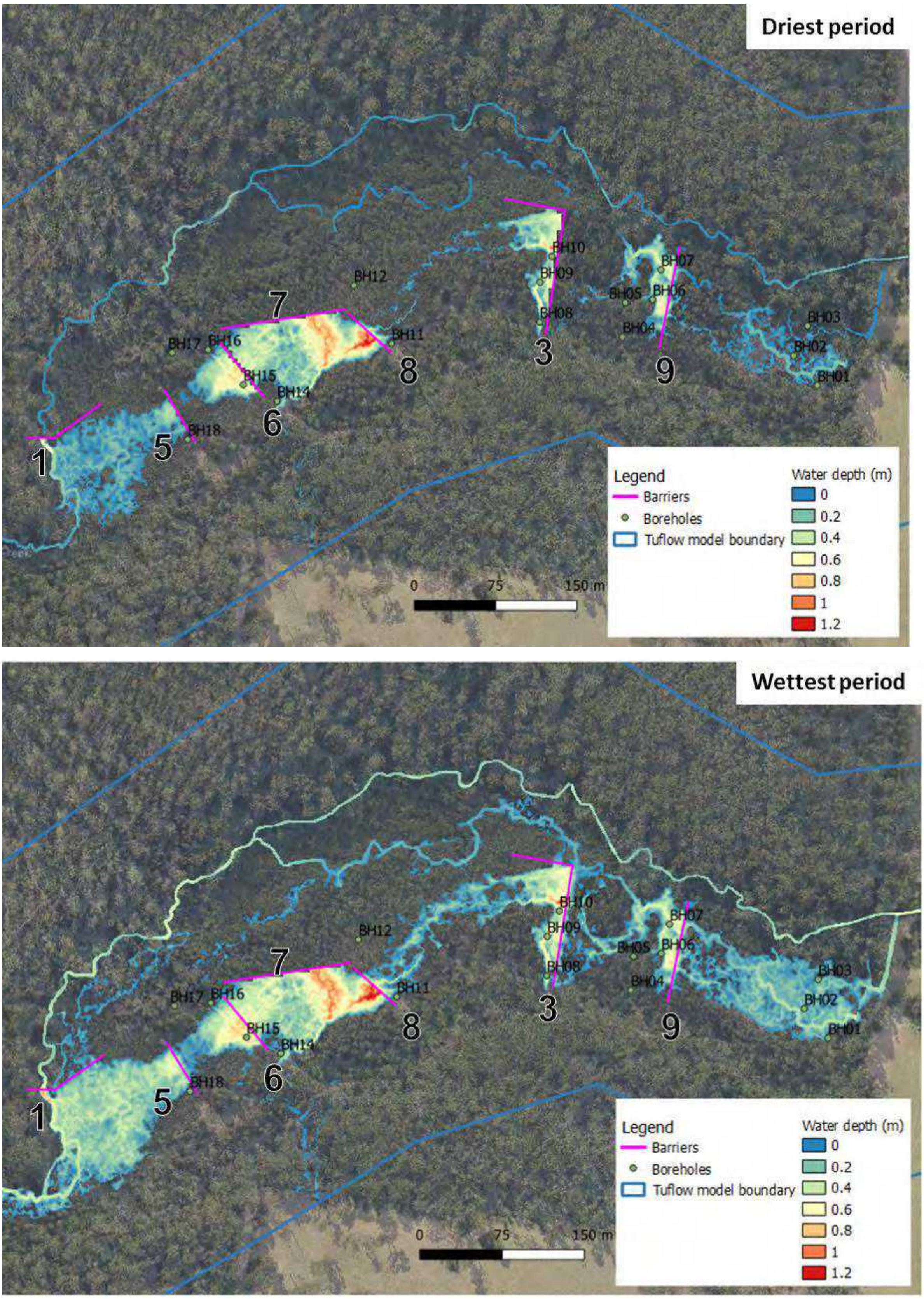


Figure 5-7 Preferred barrier configurations and predicted water depths

5.3 Groundwater (USG-Transport) model results

5.3.1 Predictive USG-Transport model set up

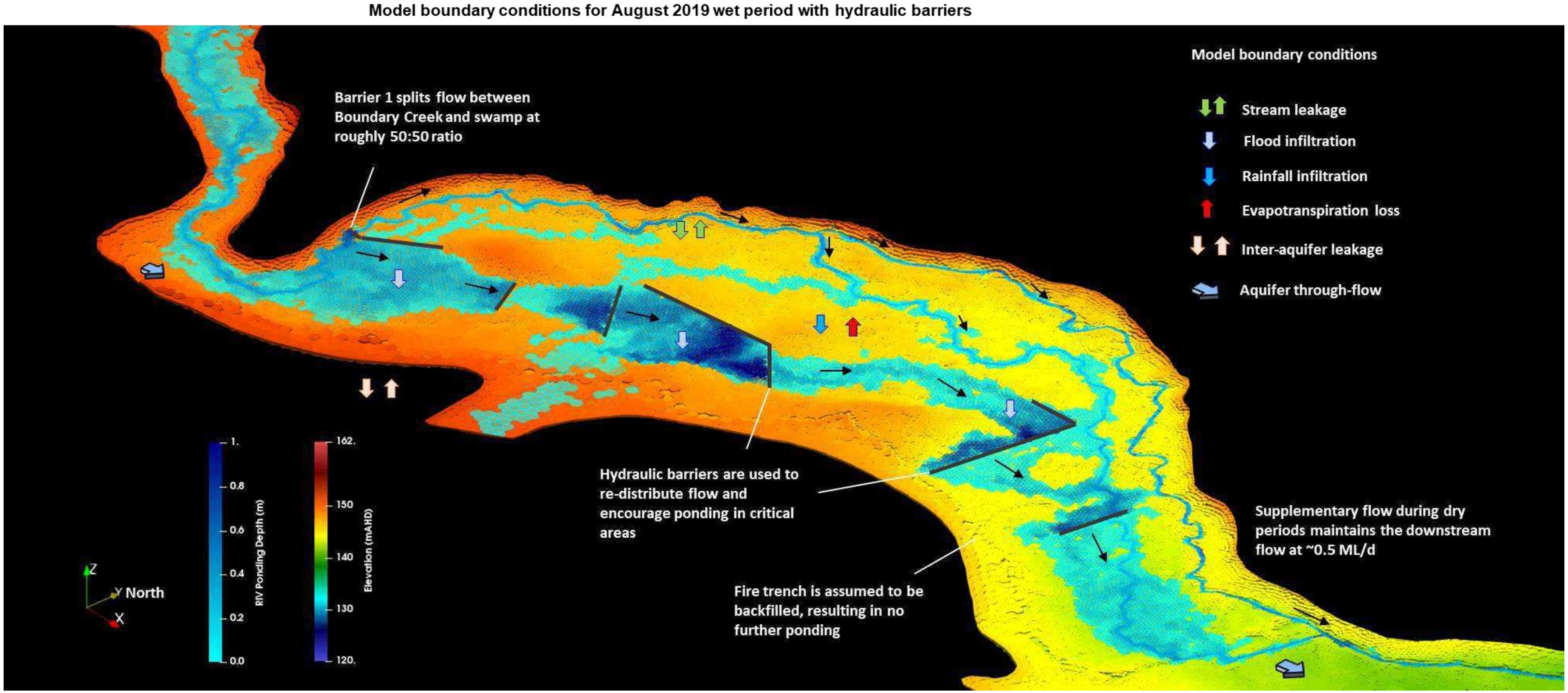
Although the USG-Transport model has been used in conjunction with the TUFLOW model to test the effectiveness of different barrier configurations, the predictive modelling outputs are presented only for the preferred barrier configuration described in Section 0 due to the very large amount of model outputs generated.

The USG-Transport model for predictive modelling uses the same simulation period and boundary conditions applied to the calibration model except for the following modifications:

- The RIV boundary condition has been updated based on the flood extents and ponding depths modified by the hydraulic barriers, as computed using the TUFLOW model.
- The RCH and EVT boundary conditions are updated with zero rates assigned to the revised location of RIV cells.
- The SFR boundary condition has been updated to include a new segment at the location of Barrier 1, to simulate the diversion of water from Boundary Creek. In this case, water diverted to the swamp is assumed to be no longer part of the flow in the creek. This is achieved by diverting water to a new segment specified at the last reach of the SFR boundary, such that diverted flow is lost from the steam flow. The diversion is specified as time-varying ratios, based on the flow splits computed by the TUFLOW model. This currently equates to around 50:50 split, although different flow splits have been explored using the TUFLOW model.
- The inflow into the most upstream segment of the SFR boundary, representing flow downstream of McDonald's Dam, has also been modified to explore the effect of different supplementary flow regimes.
- The DRN boundary condition is not used in the predictive model, as the fire trench is assumed to be backfilled.

Figure 5-8 shows the model boundary conditions and processes for the predictive conditions, including the changed extent and depth of flood inundation and the final location of hydraulic barriers used for predictive modelling.

Figure 5-8 Model boundary conditions and processes – predictive condition



5.3.2 Effect of hydraulic barriers on groundwater levels

The effect of hydraulic barriers on maintaining the groundwater levels at each monitoring bore is demonstrated using hydrographs of existing and changed heads, and how they compare against the target groundwater level. These hydrographs shown in Figure 5-9 and Figure 5-10 are based on the model run with the full supplementary flow (4.4 ML/d during the dry period) and 50:50 flow split, as discussed further in Section 5.3.3. It should be noted that the extent and depth of flooding are not particularly sensitive to different supplementary flow regimes (for 50:50 flow split). This means the hydraulic barriers generally have similar effects on the groundwater levels at lower supplementary flows.

The hydrographs indicate that the hydraulic barriers are effective in raising the groundwater levels at the location of monitoring bores. At the majority of bores, the computed heads are at or above the target groundwater levels for the entire 14-month period. The exception is at BSBH18 where the computed heads are consistently lower than the target level by around 0.3 m. The hydraulic barriers have been adjusted to maximise the amount of ponding at BSBH18 without limiting the flow to other bores further downstream. This means there is likely to be a practical limit to forcing flow upgradient to BSBH18 without unduly influencing the performance of the barrier system further downstream.

Where flooding/ponding is maintained near constant, the QA becomes fully saturated and the groundwater level becomes equilibrated with the pond level. This explains why the model simulates little to no variability in the computed heads at a number of bores such as BSBH10 and BSBH15.

Figure 5-11 and Figure 5-12 are head frequency duration curves, showing the fraction of time within the 14-month simulation period when the computed heads are above the values indicated on the Y-axis. Also shown on the Figures are the duration curve of computed head differences with and without the barriers and the target groundwater level. At BSBH08, the head duration curves indicate that the hydraulic barriers have the potential to maintain the groundwater levels at or above the target level 60 to 70% of the time, and there is the potential for the groundwater level to fall below the target level about third of the time albeit by a very small amount.

The spatial differences in the effect of hydraulic barriers are also demonstrated with reference to several depth to groundwater contour maps. Figure 5-13 compares the depth to water contours for the historical case (calibrated model) and remedial case (predictive model) in the presence of hydraulic barriers and supplementary flow. These are statistical maps derived from water table depth frequency during the 14-month simulation period, and include the wet (upper 5th percentile), dry (lower 95th percentile) and typical (50th percentile) climatic conditions.

The effectiveness of the remedial system can be quantified for each climatic condition by calculating the difference between the historical case and predictive case. This is shown in Figure 5-14, where the negative change represents areas where the water table is shallower and the positive change represents areas where the water table is deeper. The largest negative change is simulated in the flooded areas under the dry climatic condition, where the remedial system has been specifically designed to meet the target levels at critical upstream bores.

The modelling indicates that hydraulic barriers and associated redistribution of flow has the potential to cause slight lowering (<0.5 m) of the water table along Boundary Creek under the wet and typical climatic conditions due to less flow passed down the creek. However, during the critical dry period the modelling indicates no further lowering of the water table in areas along Boundary Creek, with the potential for a slight increase in the downstream area. This is partly due to the flow maintained by 4.4 ML/d supplementary flow, which results in a net increase in leakage into the underlying QA.

The modelling indicates a possible lowering of the water table along the southern boundary of Big Swamp, due to the filling of the fire trench. The fire trench currently forms a local low point where surface water ponds during wet periods, resulting in localised infiltration. The filling of the fire trench means this source of recharge is no longer present, resulting in the lowering of the water table by 0.5 to 1 m.

Figure 5-15 shows the range of seasonal variability in the groundwater levels across Big Swamp for the historical and remedial cases. Also shown in the Figure is the difference between the two contours, which represents the effect of the remediation system on the seasonal variability in the groundwater levels. The areas of negative change represent areas where the seasonal variability has been reduced by the remediation system and vice versa. For example, in the flooded area near bores BSBH14 to BSBH16, the historical case indicates a natural seasonal variability of around 2 m whereas the variability is <0.1 m in the remedial case, as the groundwater level equilibrates with the near constant pond level. This means the modelling indicates a reduction in seasonal variability by up to around 2 m in this area.

Figure 5-9 Predicted bore hydrographs – BSBH01 to BSBH09

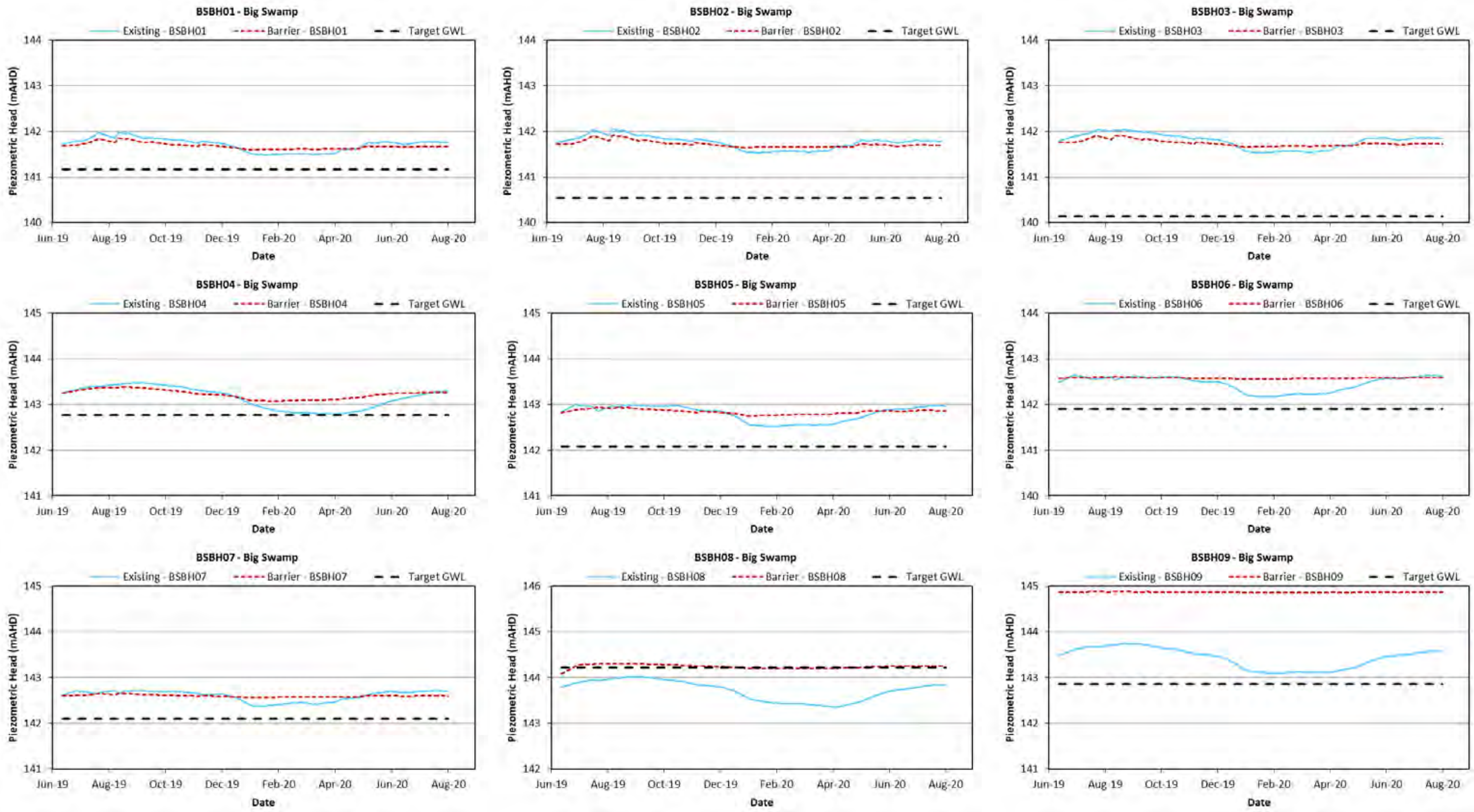


Figure 5-10 Predicted bore hydrographs – BSBH10 to TB1A

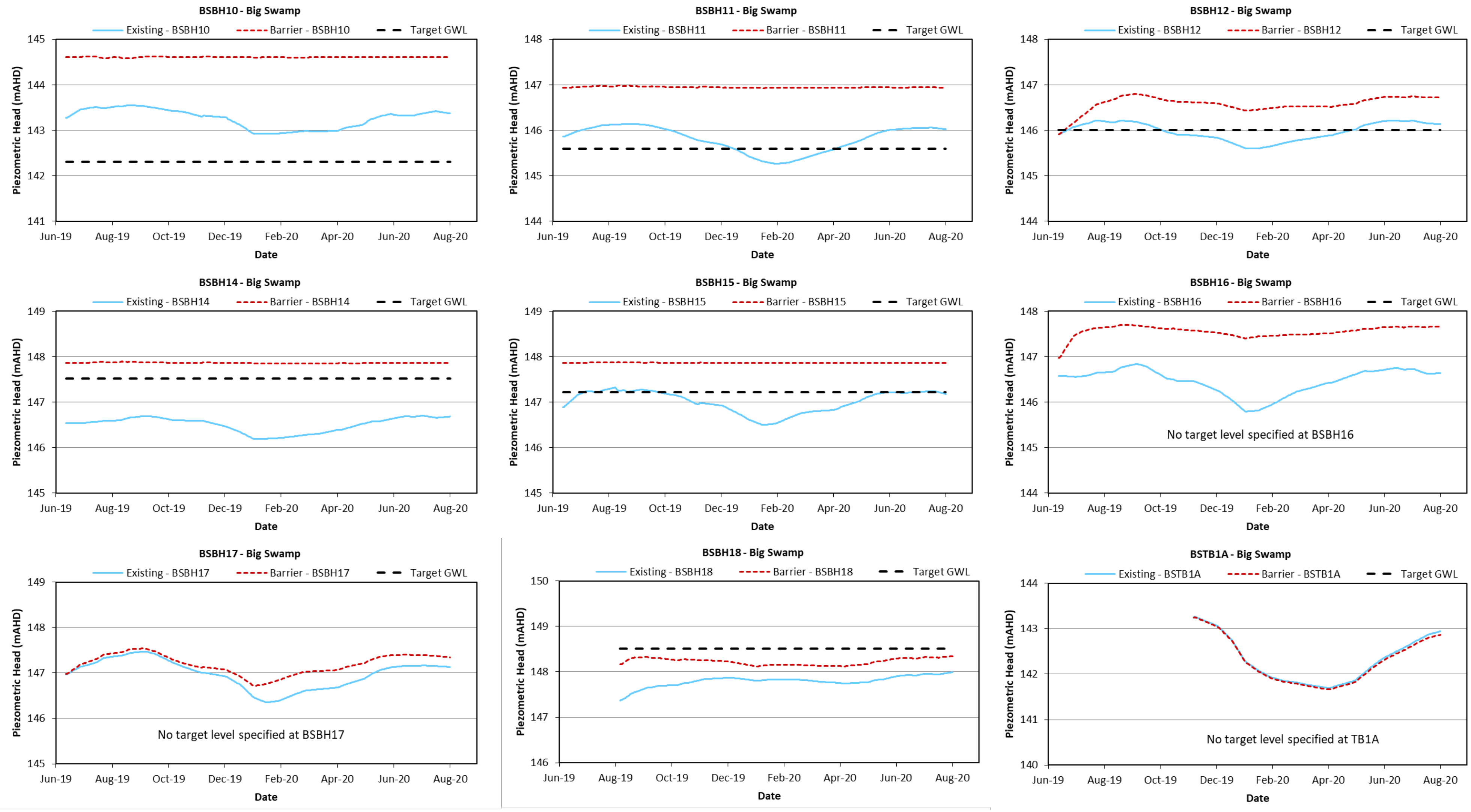


Figure 5-11 Head frequency duration curves – BSBH01 to BSBH09

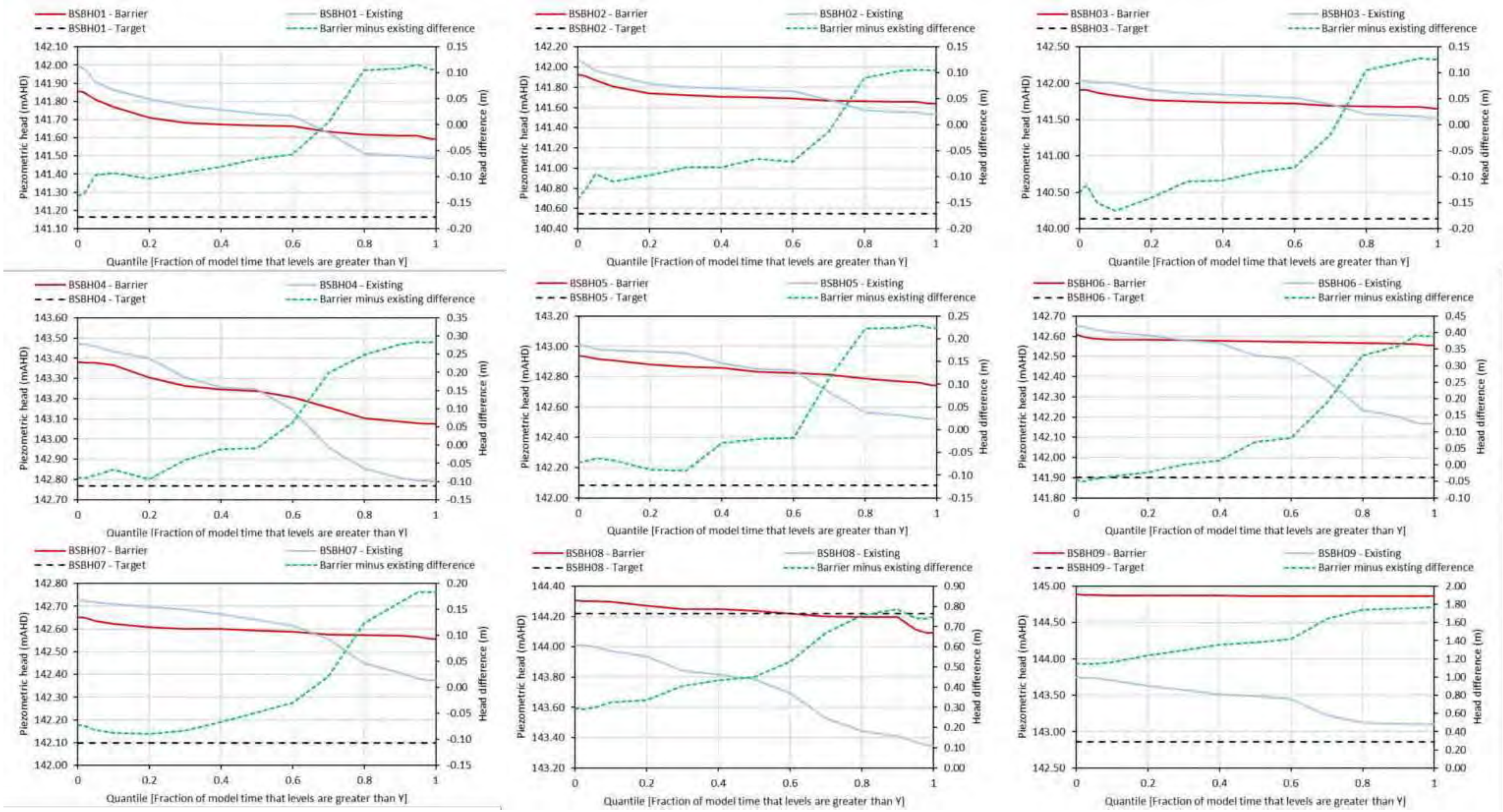


Figure 5-12 Head frequency duration curves – BSBH10 to TB1A

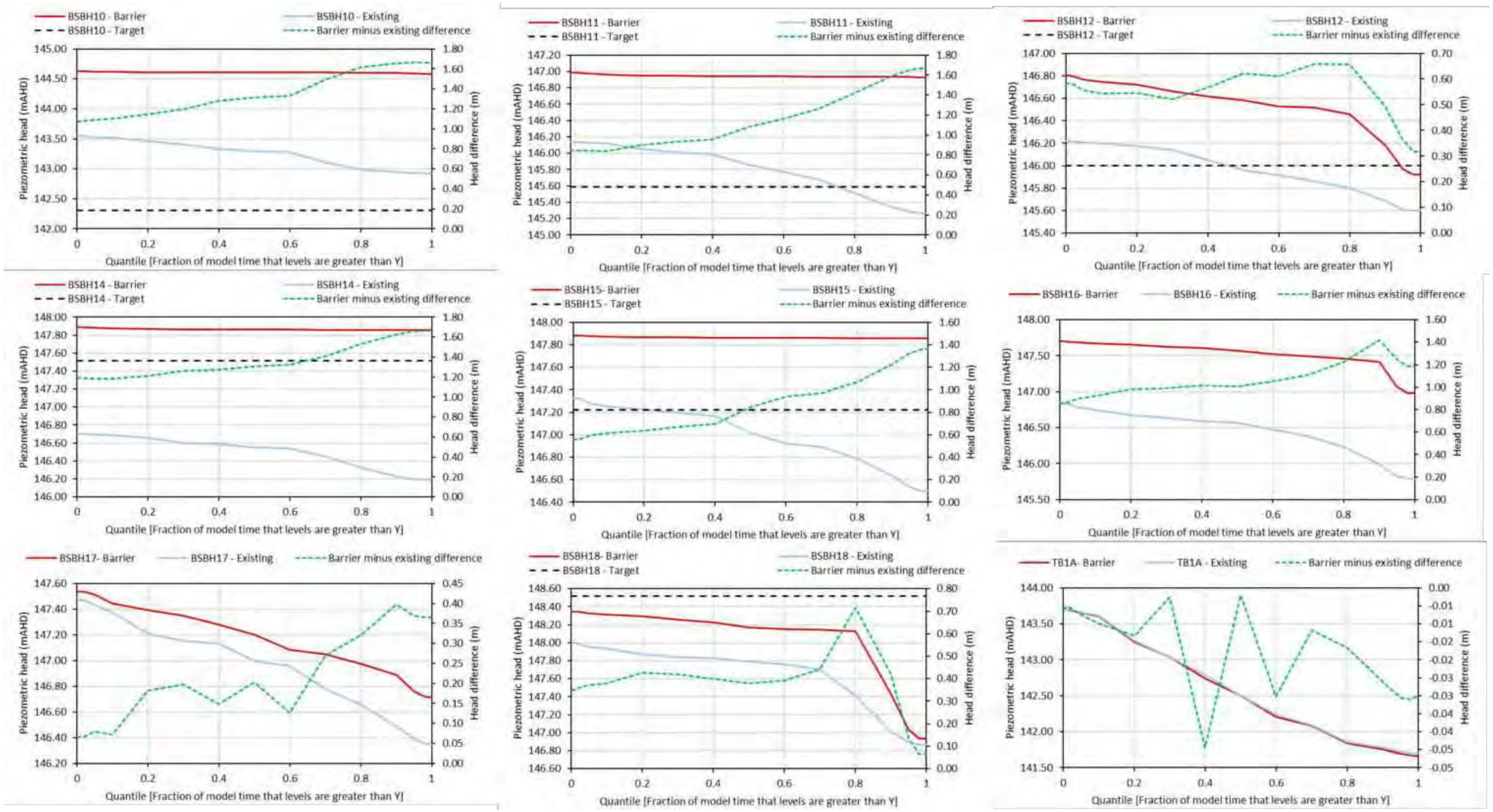


Figure 5-13 Modelled seasonal depth to water variability

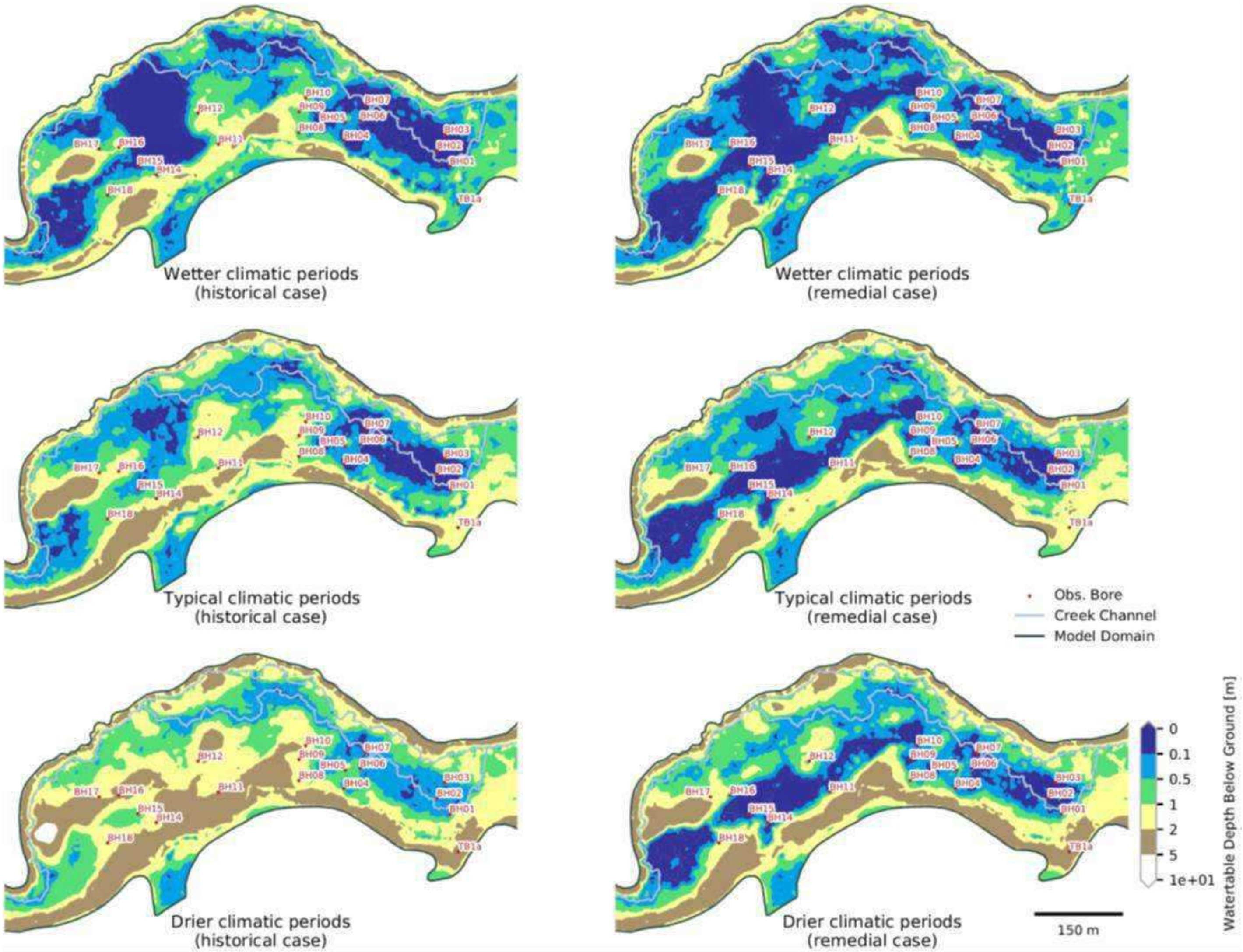


Figure 5-14 Effect of remedial system on depth to water variability

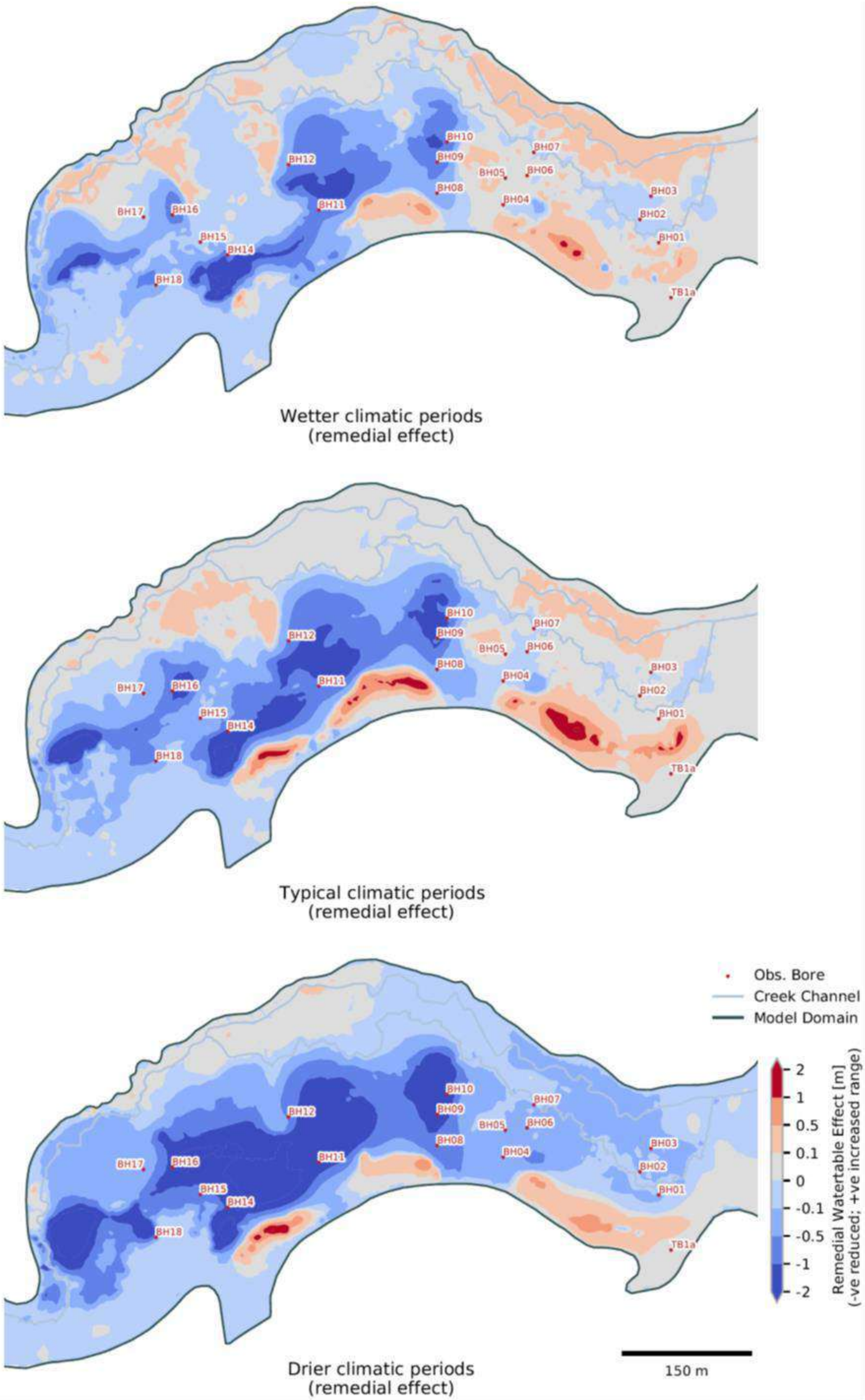
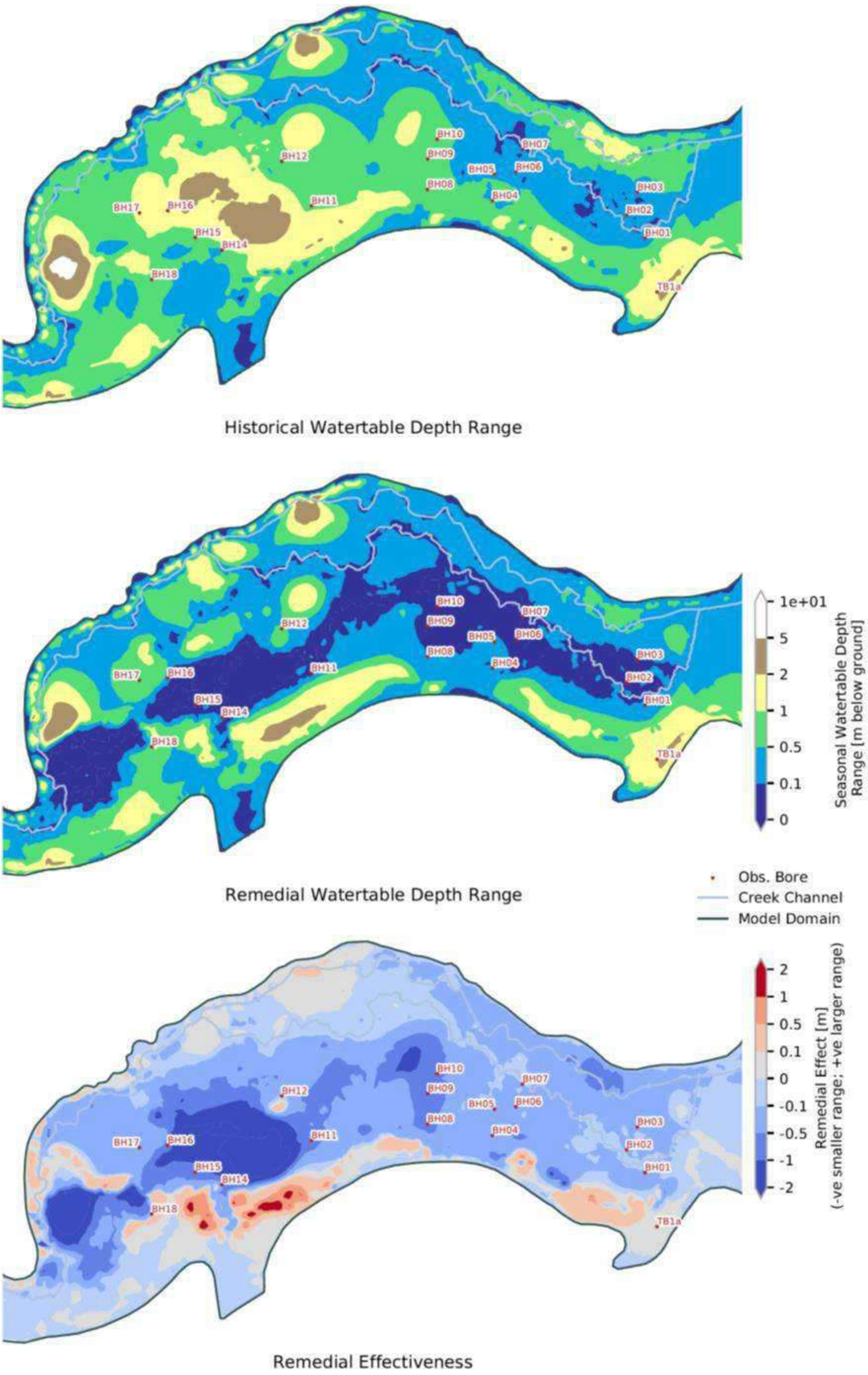


Figure 5-15 Modelled seasonal water table range and remedial effect



5.3.3 Effect of supplementary flow on downstream flow

During the dry period of 2019 to 2020, supplementary flow was used to maintain flow downstream of McDonald's Dam at around 2 ML/d. Even with the extra flow, a complete loss of stream flow was recorded at gauge 233267A, indicating that 2 ML/d is insufficient to maintain 0.5 ML/d at 233267A and further downstream at 233228, particularly after the flow is re-directed to the swamp to maintain the groundwater levels.

It is understood that up to 500 ML of supplementary flow can be made available in a given year. The analysis of flow data indicates that there were around 114 days when the flow downstream of McDonald's Dam was either at or less than 2 ML/d. Assuming that 2 ML/d of supplementary flow was already utilised, it would be possible to use the remaining flow volume over 114 days to increase the supplementary flow to up to 4.4 ML/d. To explore the effect of further increasing the supplementary flow, the flow into the upstream segment of the SFR boundary was increased to 3, 4 and 4.4 ML/d. For each supplementary flow rate, the calibrated TUFLOW model has been re-run to provide revised flood extents and depths, as well as the flow splits, which are used to update the RIV and SFR boundary conditions of the USG-Transport model.

Figure 5-16 shows the hydrographs of stream flow computed at gauge 233267A and 233228. The critical dry period is highlighted in green. The hydrographs compare the flow computed under the existing condition with the flow computed in the presence of hydraulic barriers, with supplementary flow of 2, 3, 4 and 4.4 ML/d. The flow under the existing condition is greater during the wet period because roughly 50% of the flow is diverted to the swamp by Barrier 1.

The hydrographs indicate that almost all of supplementary flow would be required to meet the flow target of 0.5 ML/d during the dry period (generally met when the supplementary flow is between 4 and 4.4 ML/d). The flow duration curves presented in Figure 5-17 indicate that flow would be greater than 0.5 ML/d for 90% of the 14-month simulation period, assuming the maximum supplementary flow rate of 4.4 ML/d during the dry period.

It should be noted that the results presented in this section assume a 50:50 flow split at Barrier 1, which may be considered conservative. Further testing in TUFLOW indicates that when the maximum supplementary flow is used, it may be possible to relax the flow split to as much as 80:20 (only 20% diverted to the swamp) to maintain near constant ponding at the location of bores. The implication is that it may be possible to divert more flow to Boundary Creek or achieve the 0.5 ML/d flow target with less supplementary flow by adjusting the flow split at Barrier 1.

Figure 5-16 Predicted flow hydrographs at downstream gauges

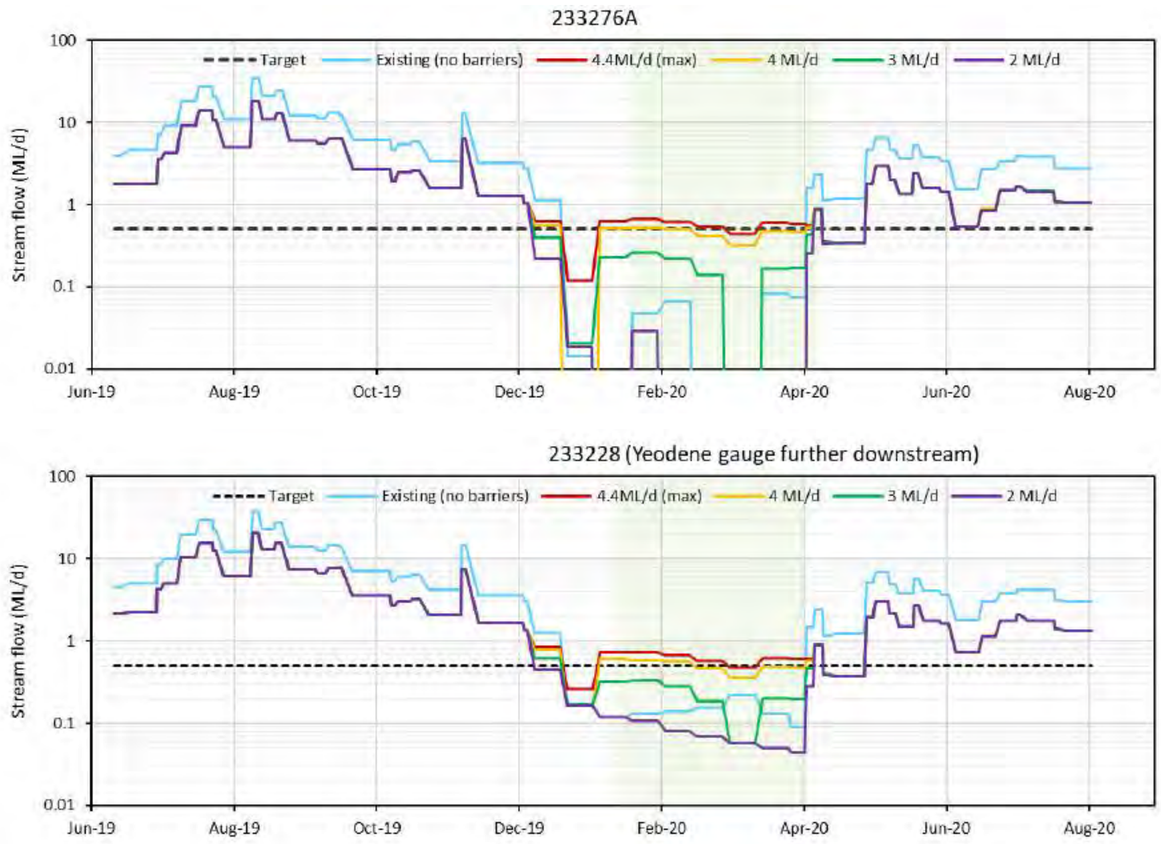
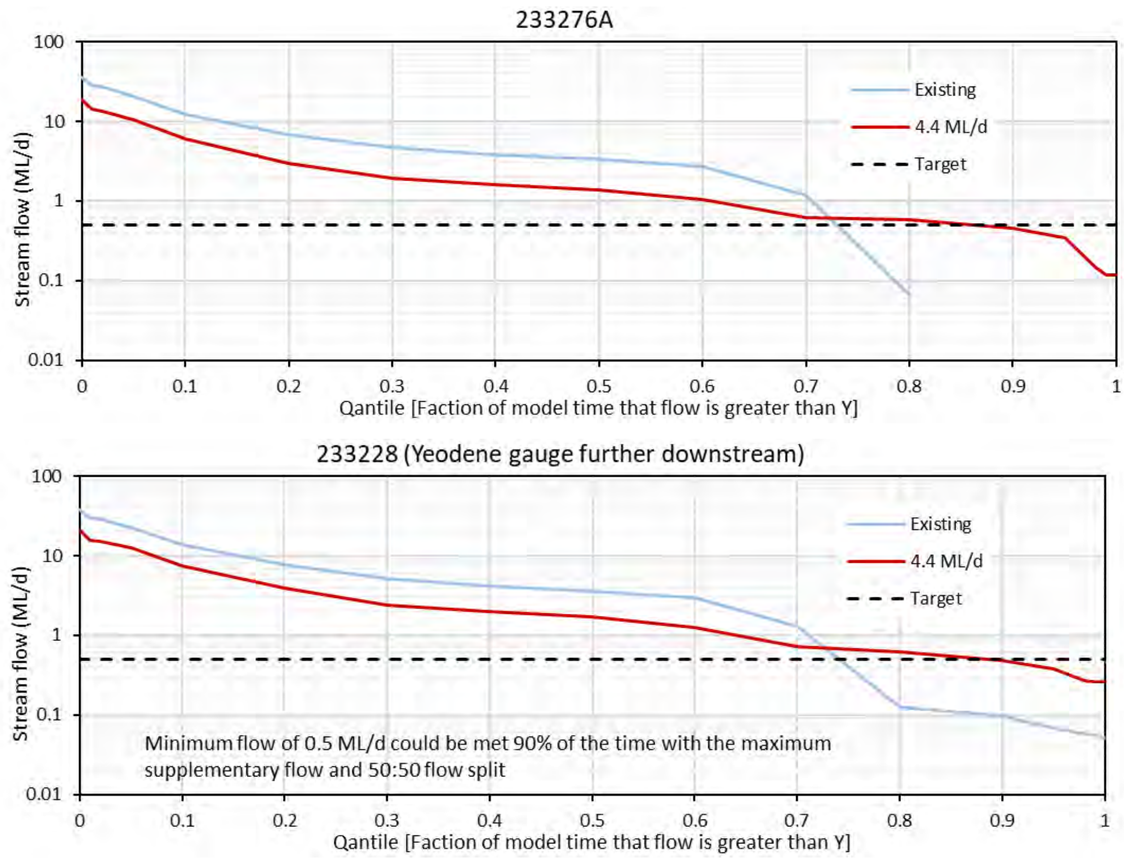


Figure 5-17 Predicted flow duration curves at downstream gauges



6. Sensitivity and uncertainty analysis

6.1 Flood (TUFLOW) model sensitivity analysis

6.1.1 Sensitivity to soil infiltration losses

A sensitivity analysis of soil infiltration losses is considered important due to uncertainties associated with this parameter and the differences in the way infiltration is treated in the TUFLOW and USG-Transport models. The effect of different infiltration losses can be demonstrated using afflux plots that show the differences in the simulated flood levels (ponding depths) when the infiltration loss is varied from 25 to 40 mm/d i.e. the difference between the calibrated and the upper bound estimate.

Figure 6-1 shows the afflux plots of ponded depths at the wettest and driest points in time within the 14-month calibration period. These afflux plots show that both the extents and depths of water are not significantly different, varying by less than 0.01 m in depth with minimal changes to the flood extents. The afflux plots comparing the 10 and 25 mm/d showed similar results, with less than 0.01 m higher ponding depths at the lower infiltration rate. The implication is that the TUFLOW water depths are not particularly sensitive to the variations in infiltration losses within the plausible range of 10 to 40 mm/d, as the ponded areas are generated by surface water flows that are much greater than the rate of loss via infiltration.

The results of the barrier configurations also show low sensitivity to the assumed infiltration losses, as the size of the ponds created is governed primarily by the level of the barriers and the topography. The modelling shows that the ponds fill up rapidly in the wet season, and as long as the inflows to the ponds match or exceed the losses to evaporation and infiltration, the ponds would remain full and retain their size.

To further understand the risk of the ponds drying out due to higher than expected soil infiltration rates, the TUFLOW model has been run with the preferred barrier configuration using the following infiltration losses: (1) 32 mm/d over the ponded areas, (2) 40 mm/d over the ponded areas, and (3) 40 mm/d over the ponded areas and 80 mm/d along Boundary Creek (as opposed to 35 mm/d used for all other runs). All three sensitivity runs assume the existing supplementary flow of 2 ML/d with a flow split of approximately 50:50. The results from Sensitivity Run (1) shows little difference to the based case with infiltration set at 25 mm/d (the version used to inform the USG-Transport model). However, at the infiltration rate of 40 mm/d the flow ceases at the last barrier (Barrier 9) during the driest point in the simulation period, resulting in the drying of the pond furthest downstream. For Sensitivity Run (3), with 80 mm/d infiltration along Boundary Creek, the last two ponds at Barrier 3 and Barrier 9 become dry.

Figure 6-2 shows the ponding depths at the driest time for Sensitivity Run (2), showing the drying of the pond adjacent Barrier 9. The last pond along the diverted flow path is the furthest downstream and is the first pond to start drying when the losses upstream prevent the flow from reaching this point. Figure 6-3 shows the relationship between the rate of flow diverted (in this case, after Barrier 5) and the pond water levels simulated adjacent to Barrier 9 for the base case (25 mm/d) and each of the three sensitivity runs. At 25 and 32 mm/d infiltration rates, the pond water level remains just above 142.7 mAHD for the entire simulation period and the flow downstream of Barrier 9 is maintained. At 40 mm/d infiltration, the pond water level starts dropping for a few weeks through January 2020 as the diverted flow drops below 0.45 ML/d. When the infiltration rate along Boundary Creek is increased to 80 mm/d, the pond becomes dry for around 3 months as the diverted flow drops below 0.49 ML/d.

The sensitivity analysis indicates that if the infiltration rates are higher than expected (up to around 40 mm/d), then a relatively small additional flow of around 0.2 ML/d would be required to maintain all of the ponds wet. This could be achieved by adjusting the flow split or increasing the supplementary flow, which is likely to be required for meeting the downstream flow target of 0.5 ML/d according to the findings of groundwater modelling. Even at the infiltration rate of up to 80 mm/d along Boundary Creek, only around 0.8 ML/d of additional flow would be required to keep the last pond topped up, which is well within the range of supplementary flow.

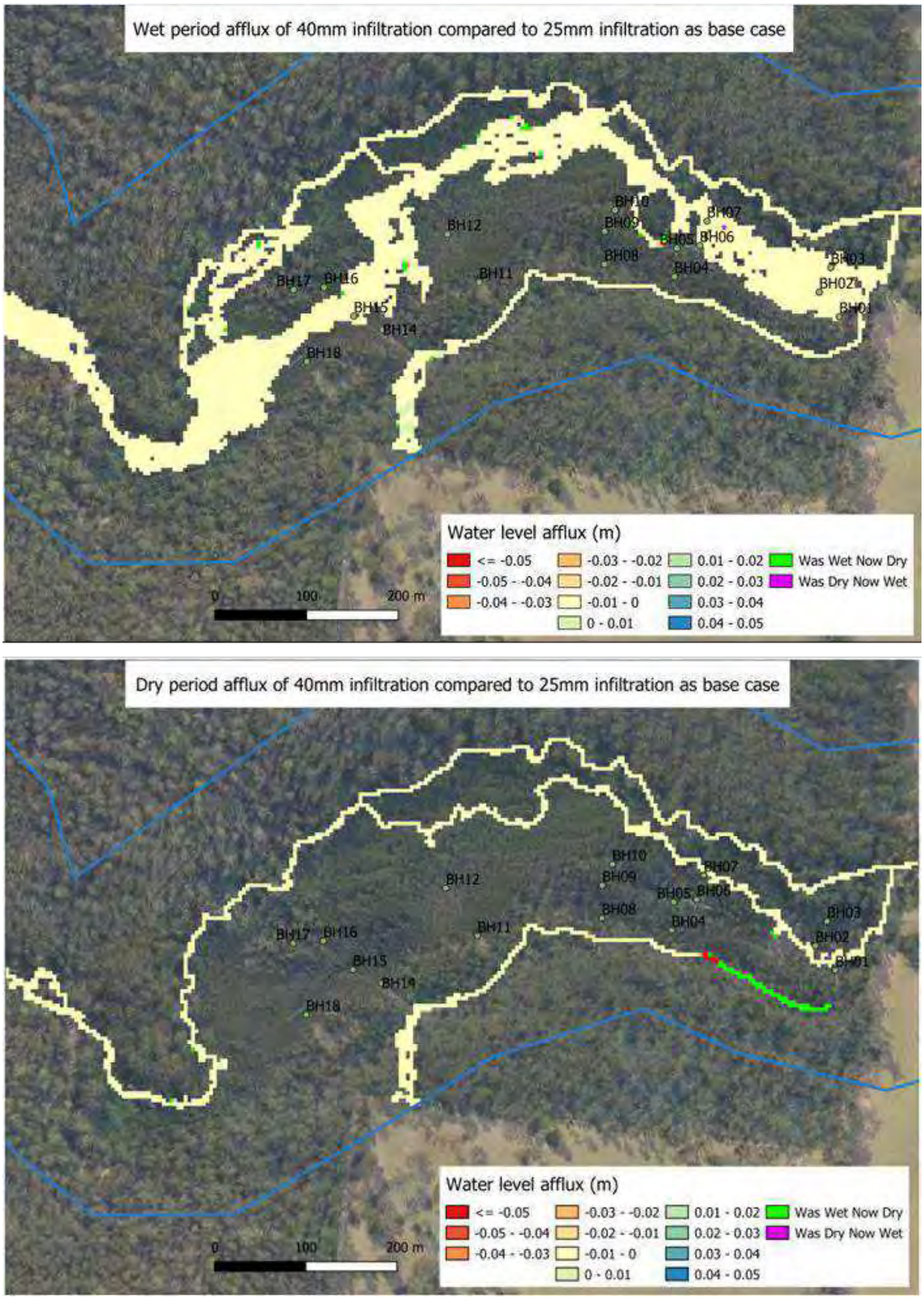


Figure 6-1 Sensitivity analysis – afflux plots

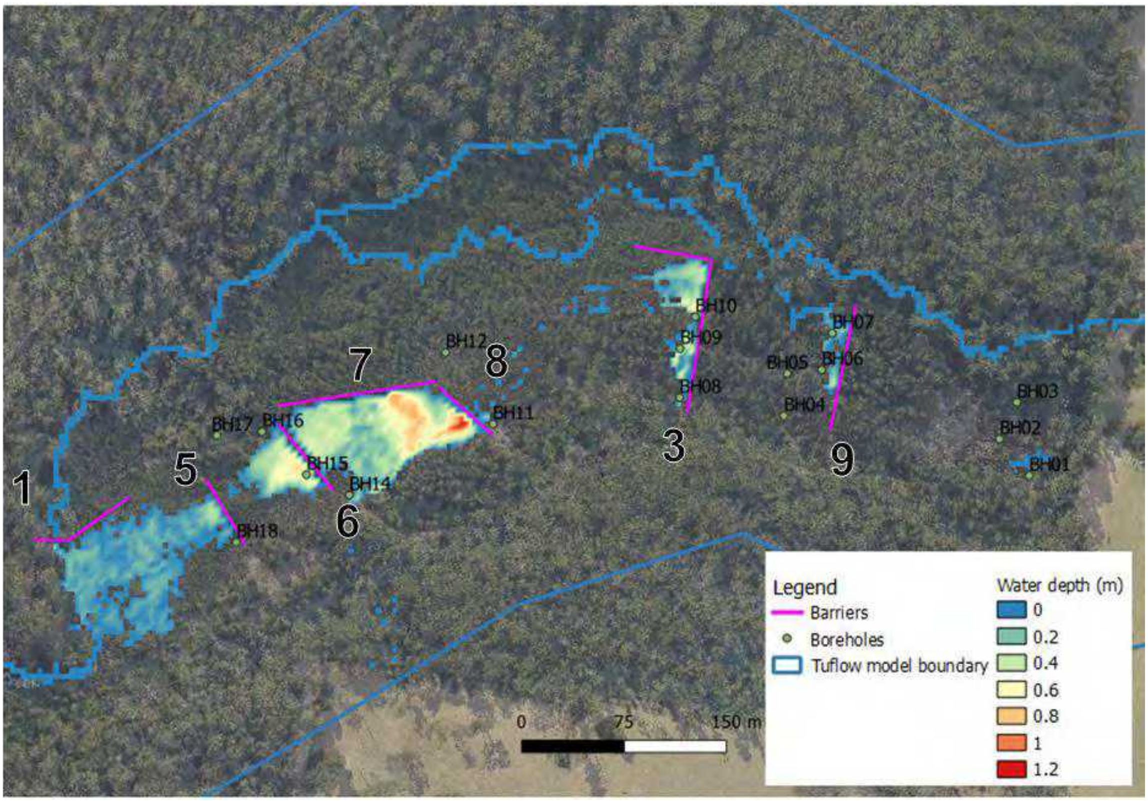


Figure 6-2 Sensitivity Run 2 dry period ponding depth at 40 mm/d infiltration

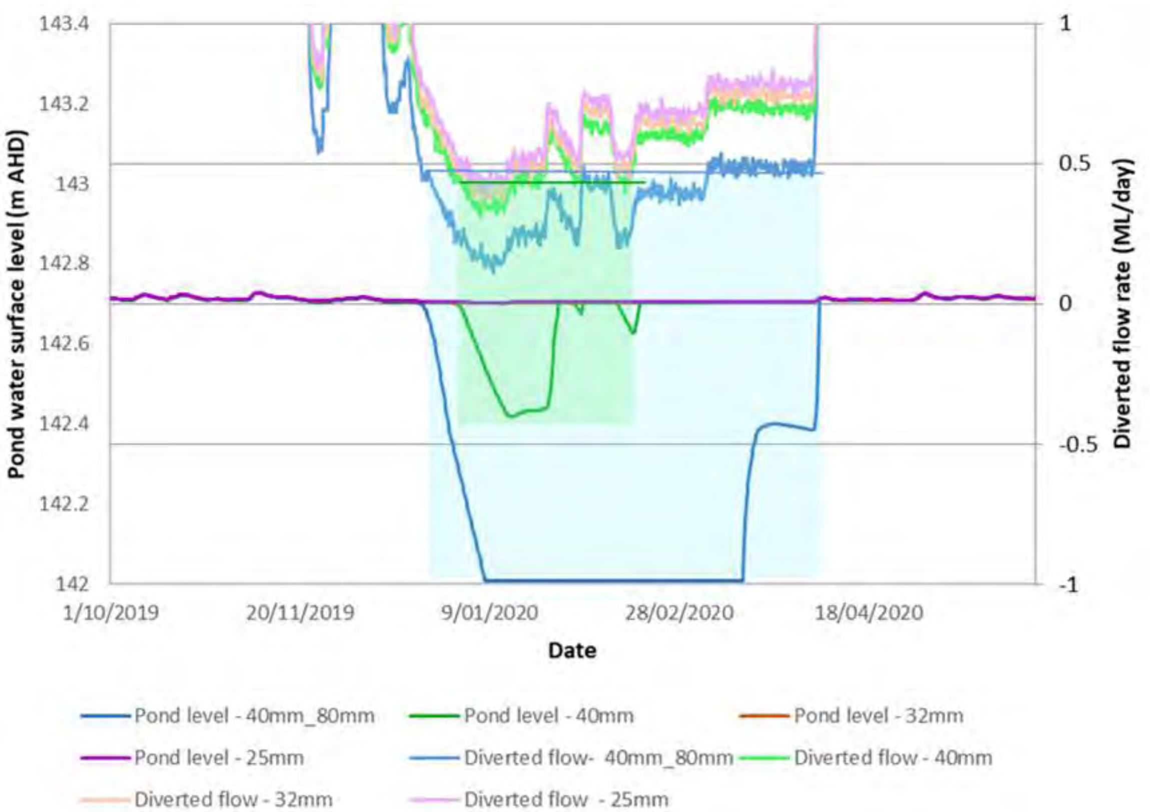


Figure 6-3 Sensitivity of pond adjacent to Barrier 9

6.1.2 Sensitivity to other parameters

Several additional sensitivity runs have been undertaken to examine the effect of altering the model configuration and input parameters where these changes are considered to have potential effects on model outcomes. These sensitivity runs include:

- Reducing the TUFLOW grid cell size from 4 to 1 m.
- Reducing the timestep of upstream inflow data from daily to 15 minutes.
- Using outputs from the GR4J model as the upstream inflow (rather than gauge data)
- Using TUFLOW's double precision computation (rather than single)
- Removing the gully shaping along the main channel to examine the effect of changes to the terrain.

The additional sensitivity analyses indicate the following:

- 1 m grid appears to produce outputs that are largely similar to those from the 4 m grid. Boundary Creek appears to be slightly thinner with the finer spatial grid, as expected, otherwise using a coarser grid of 4 m to improve run time efficiency has not materially affected the accuracy of TUFLOW model outputs.
- The 15-minute timesteps for the upstream inflow result in only minor differences, primarily slightly larger flooded extents during the wettest period. This is unlikely to change the effectiveness of the hydraulic barrier configuration, given the likelihood of failure (ponds drying) is most sensitive to the flow maintained during dry periods.
- Similarly, using a slightly different upstream inflow data derived from the GR4J model has only minor effect on increasing the flood extent during both the wet and dry periods.
- Using double precision has a negligible impact on the results, with a few additional wet cells with very small ponding depths that are generally below the threshold applied in the USG-Transport model.
- Removing gully (z-line) shaping has the largest effect. Without this, Boundary Creek becomes dry in many places and different flow paths occur. The afflux plot between the calibrated model with and without gully shaping is shown for the wet period in Figure 6-4. These differences highlight the importance of accurate terrain data, with errors in the existing terrain data significant enough to change the modelled flow paths within Big Swamp. This is important because if the actual topography differs from that represented in the existing terrain data, then the shape and location of hydraulic barriers may need to be modified to achieve the required pond sizes and depths to maintain the groundwater levels.

A comparison of the calibrated TUFLOW model (base case) against the various sensitivity runs at the gauge locations is shown in Figure 6-5 and Figure 6-6 for flows and water levels respectively. The flow results show that both the 15-minute timestep run and the GR4J inflow run result in higher peak flows in the wet period. For the GR4J inflow run, significantly higher flows are also simulated during dry periods which is due to difficulties in correctly calibrating the GR4J model to simulate low flows. The 1 m grid has shifted the simulated stage at 233276A, although the magnitude of changes is larger, with deeper peaks and troughs that appear to better replicate the observed data. Removing gully-shaping has the largest effect on the simulate stage at downstream gauge 233228.

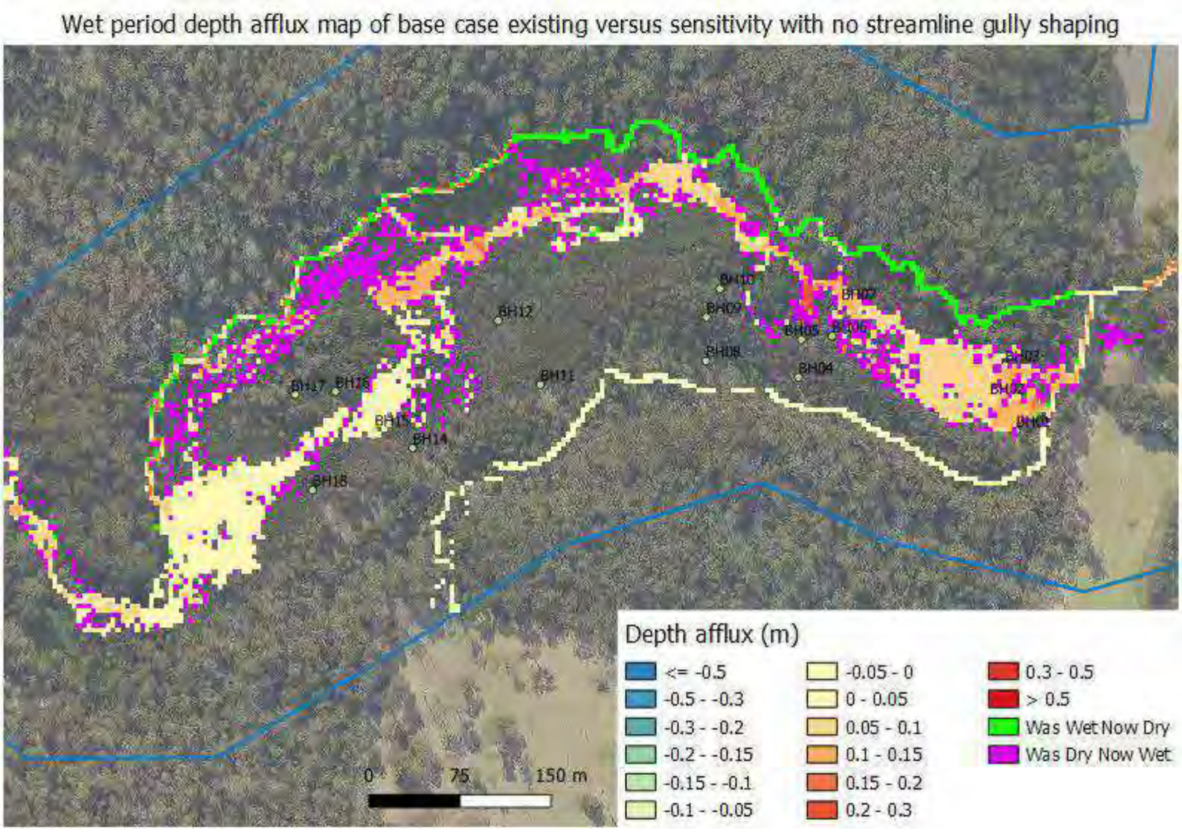


Figure 6-4 Sensitivity analysis – afflux plot with and without gully shaping

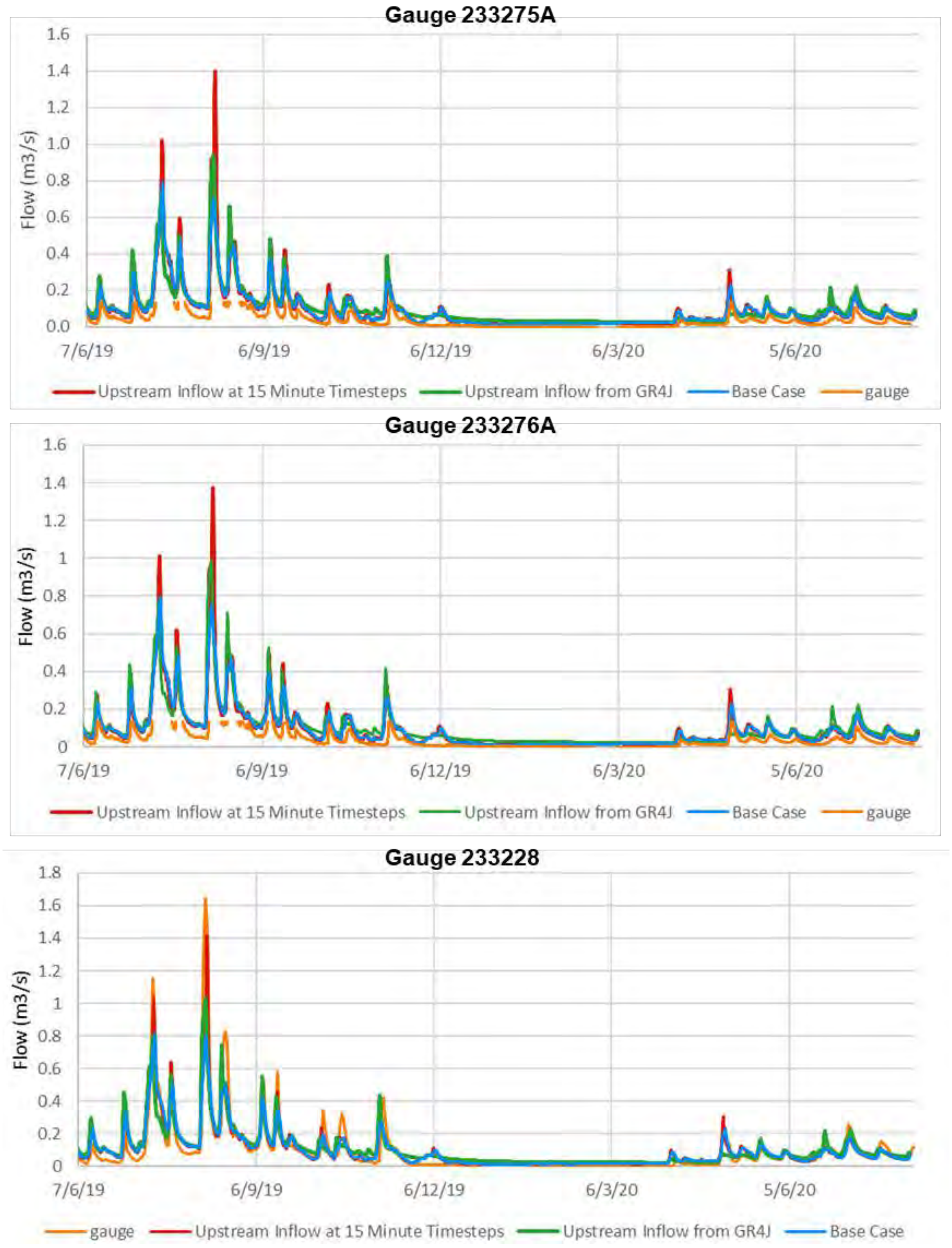


Figure 6-5 Sensitivity analysis – simulated flow at key gauges

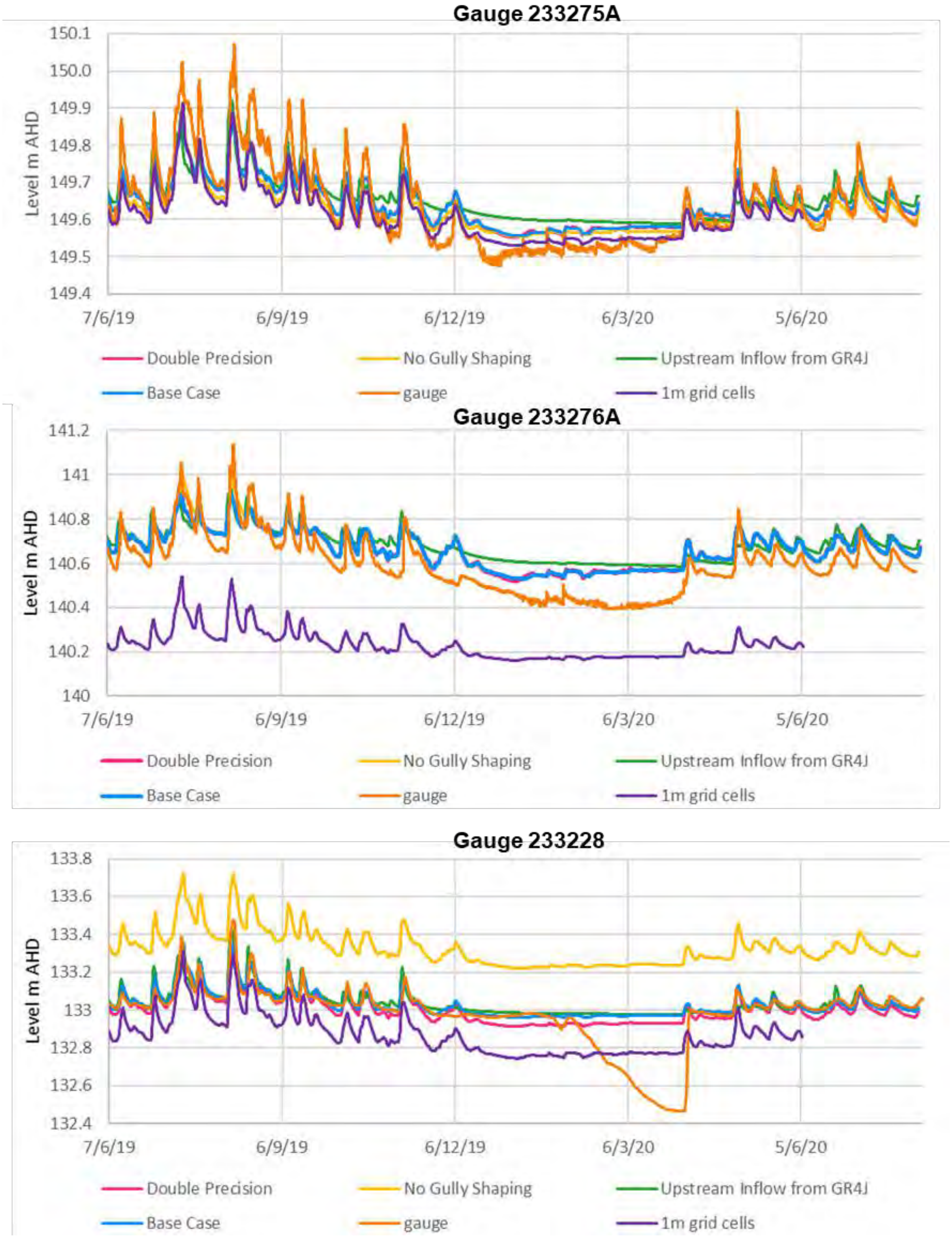


Figure 6-6 Sensitivity analysis – simulated stage/level at key gauges

6.2 Groundwater (USG-Transport) model uncertainty analysis

6.2.1 Overview

The USG-Transport model used for forecasting potential swamp remediation effectiveness, as outlined in prior sections of this report, has been subjected to a process of rigorous model parameter and predictive uncertainty analysis.

This involved the development of many model parameter sets that each provides an acceptable level of agreement between historical observations of creek flow and groundwater levels, and their modelled counterparts. Those parameter sets are then used to batch run and post-process many different versions of the historical and forecast (remedial) models. This approach is referred to as non-linear uncertainty analysis, which is the most comprehensive form of uncertainty analysis (Group 3 uncertainty quantification technique, according to Middlemis and Peeters, 2018).

Results from these models have been aggregated to present measures of the level of confidence that can be expected in the primary conclusions, made using the optimally history-matched model in Section 5.3, given the available observation data with which to constrain the models, and other limitations as outlined in Section 7.3.2.

6.2.2 Uncertainty analysis method

The iterative ensemble smoother code PESTPP-IES (White et al., 2018; PEST++ Development Team, 2020) has been used to sample the allowable parameter ranges outlined in Section 4.4.5, and to develop an ensemble of calibration-constrained model parameter sets. This process has been initiated from the optimally calibrated (minimum error variance) parameters developed through the application of PEST_HP, which is outlined in Section 4.4. In this way, the parameter ensemble optimised by PESTPP-IES is centred on the minimum error variance parameter set.

In this case, no observation error (“noise”) has been added to the model calibration targets for the following reasons:

- The requirement for an abnormally low level of absolute head history-matching error, given the absolute nature of the groundwater level (head) remediation targets that are sought to be met and assessed. Introduction of greater error margins to the models would have unnecessarily complicated the assessment of remedial effectiveness.
- The expected centimetre-scale measurement error for most groundwater level observations is smaller than the expected level of structural model error, and hence, its removal from the process is not expected to have significant practical implications.
- To keep the uncertainty analysis workflow relatively simple and rapid.

Parameter variances have been defined as one quarter of each parameter’s allowable range (Section 4.4.5), thereby implying a 95% confidence interval. For spatially correlated (pilot point) parameters, such as those defining aquifer hydraulic properties, RIV and SFR conductance (Section 3.4.3), covariances are defined using distance-based factors developed using PEST tools MKPPSTAT and PPCOV_SVA; these distance-based settings have been applied for interpolation of those same parameters to the model mesh (Section 3.4.3). The same 95% confidence limit per-parameter variance assumptions are applied to these covariance matrices (along the diagonal).

PESTPP-IES was first used to develop an ensemble of acceptably well history-matched models. This process was initiated with an ensemble of 300 models. Of this, by the end of the optimisation process (eleven iterations; 3845 runs), only seven of the 300 had failed, indicating a very numerically stable model. The remaining 293 history-matched models were subject to a manual filtering process, in which all groundwater level and flow-related observation sub-groups were assessed for quality; this resulted in a final history-matched model ensemble of 135 members. In this way, all groups in the final ensemble are well-history matched to each of the flows, flow losses and gains, creek stage, groundwater levels (at target bores, and at non-target bores), and hydraulic gradients observation groups. No one observation group is poorly history-matched in any of the 135 ensemble members.

In this filtering process, care was taken to ensure parameter ranges across the ensemble are not unexpectedly narrow. In fact, the final parameter ranges did not differ significantly from the initial ranges, which is a preferable outcome for examining uncertainty across the full parameter ranges. Ensemble parameter means and ranges are presented in Appendix B.

6.2.3 Stochastic history-matching quality

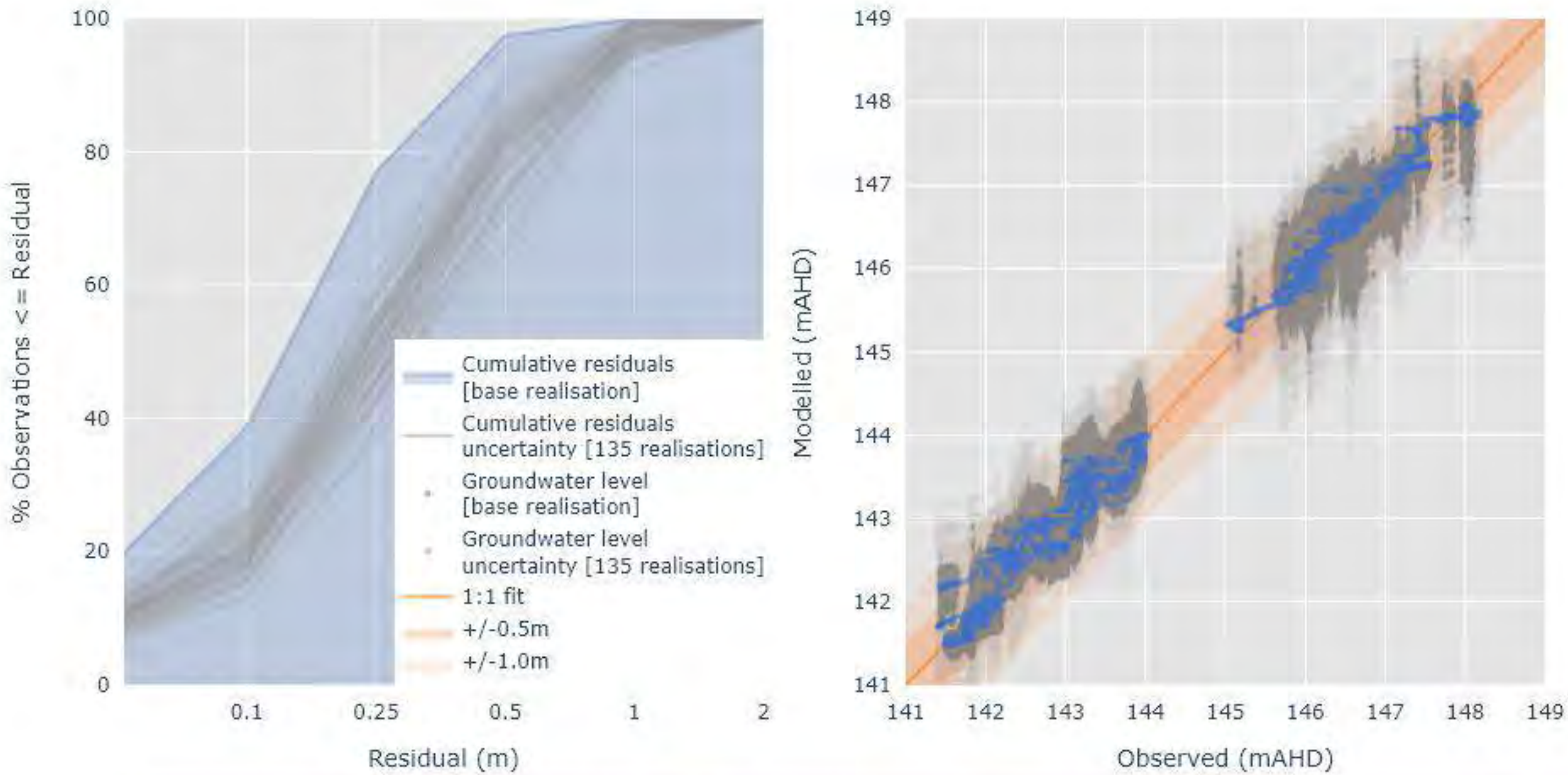
Figure 6-7 summarises the stochastic history-matching outcomes of the PESTPP-IES process. It shows that all 135 model realisations exhibit a generally good match to the groundwater level observation data, and that the history-match quality statistics are very good:

- Mean absolute residual errors range from 0.16- to 0.42 m, with a mean 0.31 m.
- Normalised root mean square error ranges from 3.1 % to 7.7 %, with a mean of 5.9 %.
- 90 % of the cumulative residual errors are within 1 m or the observation data across all 135 models.

Figure 6-8 shows a selection of history-matched hydrographs, for the base model, and the other realisations. These are plotted along with the remedial target levels (shown as the pale red band) for practical context. The hydrographs for all bores are presented in Appendix C.

Figure 6-9 compares the modelled flow from the 135 stochastic realisations against the observed flow data for gauges 233275A (upstream of the swamp) and 233276A (downstream). These are generally of similar quality to those of the minimum error variance (“base”) model reported in Section 4.4.4. However, for the downstream gauge 233276A, the period of low to no flow between January and April 2020 is slightly overestimated by many of the stochastic models, with more persistent flows than those observed. Although it may be tempting to eliminate these realisations from the ensemble, this could be detrimental to the comprehensiveness of the uncertainty analysis. A better approach, but one requiring more project time than is available, would be to investigate structural model issues that may be contributing to this effect, particularly in the GR4J model that generally overestimates flows, including at the upstream gauge, in the preceding period. It may be beneficial to conduct such assessment once a longer period of flow and swamp groundwater level data become available to make it a worthwhile exercise.

Figure 6-7 Calibration statistics of uncertainty realisations



Model / Statistic of 135 realisations:	Number of Observations:	Sum of Squared Residuals:	Root Mean Square (RMS) Residual (m):	Normalised RMS (nRMS) residual:	Mean Absolute Residual (m):
Base realisation:	7339	322	0.21	3.1%	0.16
Minimum:	7339	327	0.21	3.1%	0.17
Mean:	7339	1220	0.40	5.9%	0.31
Maximum:	7339	2022	0.52	7.7%	0.42

Figure 6-8 Example calibration hydrographs from 135 model realisations

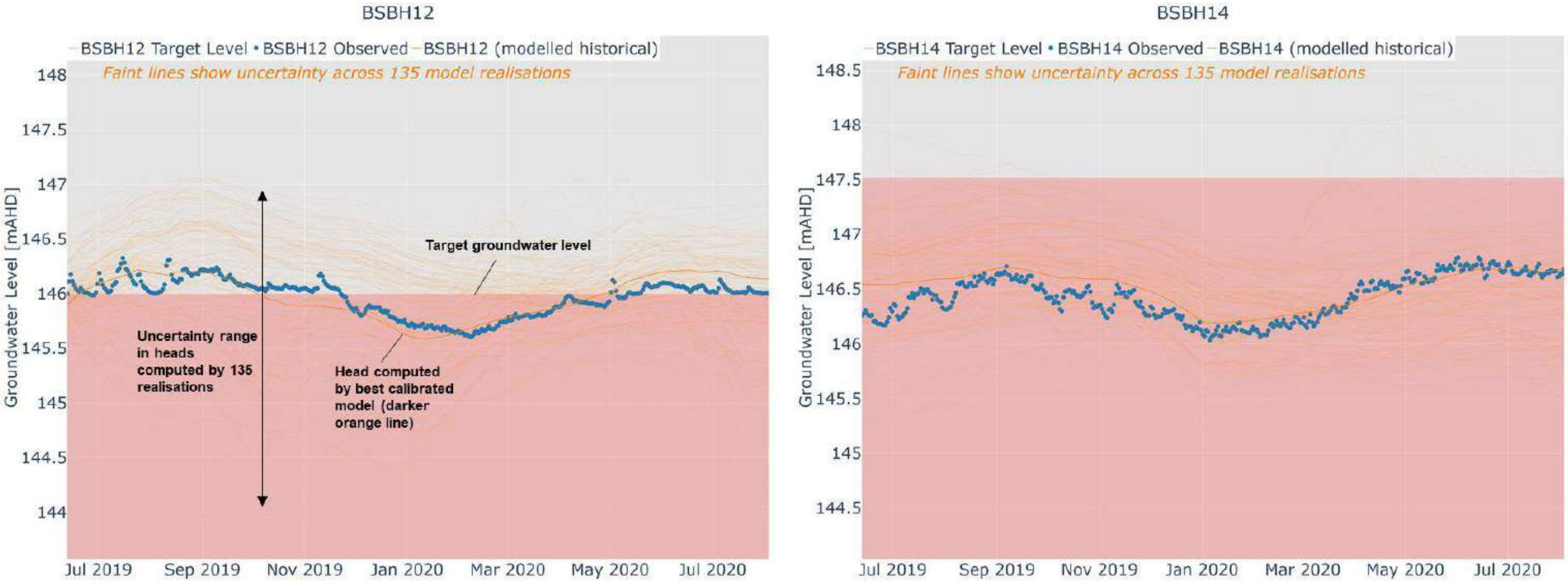
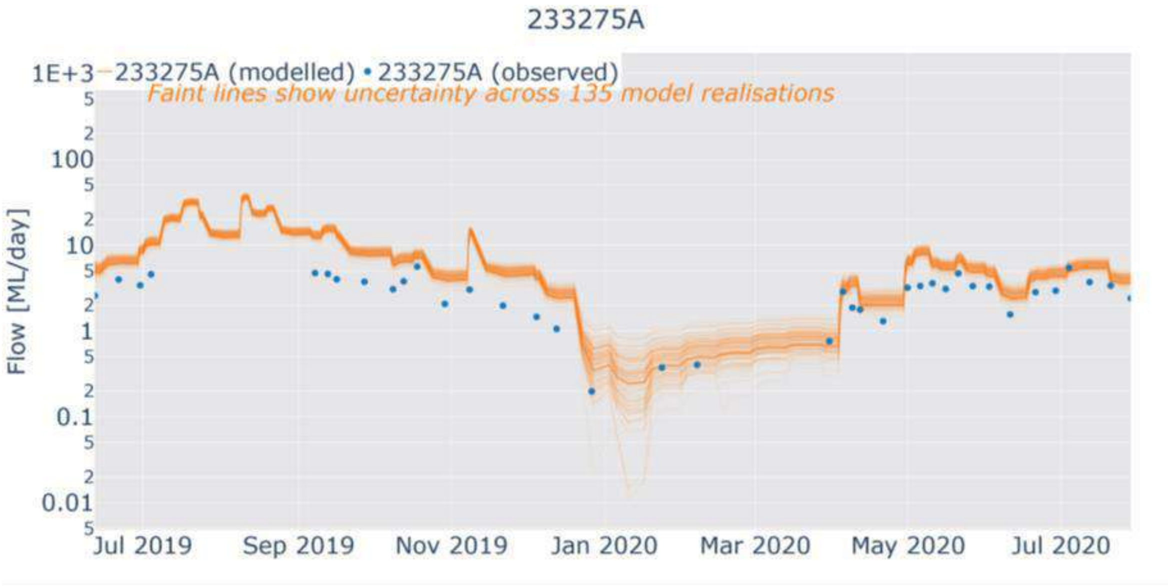
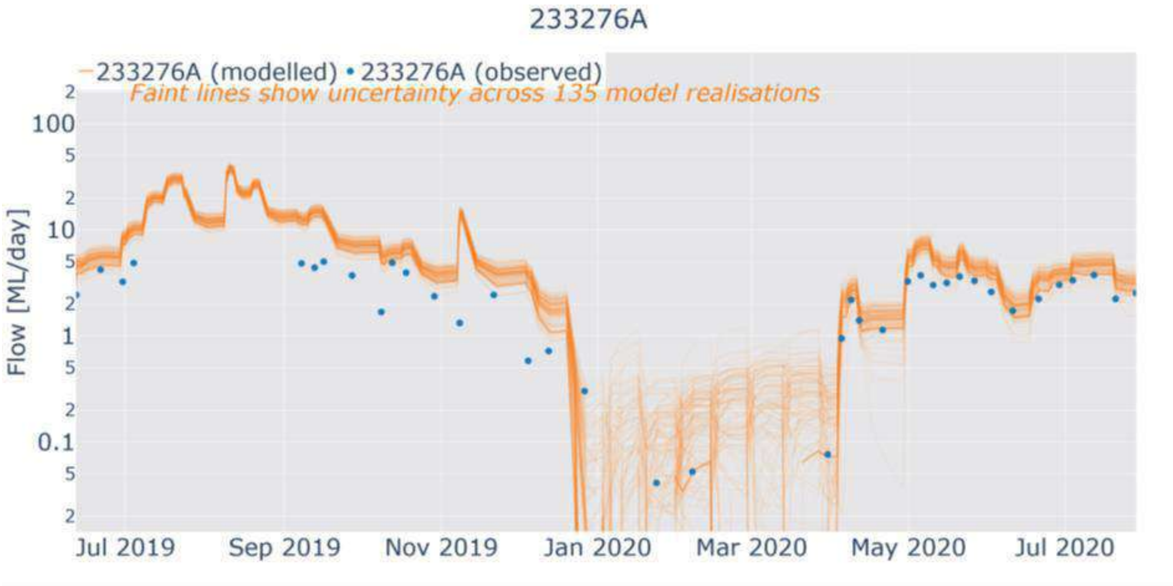


Figure 6-9 Stochastic history match for flow observations





6.2.4 Model uncertainty analysis outcomes

The 135 history-matched model parameter set realisations were used to batch run the historical and forecast models, and to process key outcomes relating to potential swamp remedial effectiveness, relative to historical conditions. This has been undertaken using the code PESTPP-sweep (PEST++ Development Team, 2020).

Uncertainty of groundwater levels at bores

Figure 6-10 and Figure 6-11 present example water table hydrographs, including model uncertainty, at selected observation (and remedial target level) bores. Each chart shows the modelled historical groundwater level (in blue), and the modelled forecast water level under the modelled remedial scenario (in orange, with the thick line representing the “base” model realisation, and faint lines representing uncertainty across the 135 history-matched model realisations). These modelled hydrographs are compared with each bore’s remedial target level (as a pale red band).

Figure 6-10 shows that at bores BSBH14 and BSBH15 there is very little model uncertainty; this is the result of local inundation (by the remedial design) controlling the water table as it equilibrates with the pond level. In both cases, the remedial target level is met across all 135 model realisations. This means where the bores (or adjacent areas) are fully inundated, there is low model uncertainty since the water table is controlled by the ponding (inundation) level irrespective of parameter uncertainty. This also means that understanding the nature of interaction with the underlying LTA may not be as critical in some places as long as ponding can be maintained to control the water table.

In contrast, Figure 6-11 shows the same information but for bores BSBH08 and BSBH12, which exhibit a more visible uncertainty range. In both cases, the target level is met for most of the time across most model realisations but not all, with the modelled level falling below the target level for some periods in some realisations. In general, these are by relatively small amounts and for limited time, indicating a low likelihood of occurrence.

Similar results are presented for all observation bores in Appendix D. These plots indicate that the target level can be met with the simulated remedial system for most bores, for most of the time, over most of the 135 model realisations. Exceptions are:

- BSBH04: some model realisations suggest the target level may be slightly exceeded during dry periods, although the model tends to underestimate the observed dry period groundwater levels at this bore (see Appendix D).
- BSBH08: some model realisations suggest that the target level may be slightly exceeded most of the time, although the vast majority of the realisations show a significant persistent increase in the simulated groundwater levels at this bore under the remedial scenario.
- BSBH12: some model realisations suggest the target level may be slightly exceed, although during the critical dry period all realisations simulate groundwater levels above the target level.
- BSBH18: most model realisations suggest that the simulated remedial measures are insufficient to persistently meet the desired target level. However, the uncertainty analysis does show that the uncertainty range of groundwater levels at this bore is much reduced compared with the historical conditions (compare BSBH18 charts between Appendix C and Appendix D). The same charts also indicate that the simulated remedial measures are likely to achieve a persistent rise in groundwater levels at this bore in the order of 0.3 to 0.5 m.

For bore BSBH06, whilst the model indicates that the remedial target level is likely to be met, it should be noted that the calibrated model overestimates groundwater levels generally, but particularly during dry periods at this bore. This also appears to be the case across the majority of 135 model realisations, although there are a few realisations that better simulate the dry period groundwater levels. Despite this, given that the model error during the dry period is in the order of 0.5 m at this bore, and the remedial systems across 135 realisations consistently achieves an increase of greater than this amount, the remedial target is still likely to be met (but possibly not by as large a margin as that shown in Figure 5-9). In practice, the effectiveness of the remedial system would need to be verified at bore BSBH06, which may identify the need for some adjustments.

Uncertainty of groundwater levels across Big Swamp

Figure 6-12 and Figure 6-13 present maps showing the lower and upper bound uncertainty estimates of depth to groundwater, both for the historical conditions (left side) and remedial conditions (right side). These lower and upper uncertainty estimates are taken as the lower 5th and upper 95th percentile (on a cell-by-cell basis) across the 135 model realisations.

The upper end estimate in Figure 6-13 represents a more conservative view of the potential remedial effectiveness, with lesser area affected by the remedial inundation shown on the right-hand side. However, even under this conservative case, the depth to water is maintained at significantly shallower levels over much broader areas of the swamp compared to the historical conditions (left hand side), irrespective of the prevailing (dry, typical, or wet) climatic conditions. This is particularly the case in the upstream (western) end of the swamp (around BH11 through BH18), where the remediation system has been designed to encourage ponding.

Under the more optimistic (lower uncertainty estimate) case presented in Figure 6-12, the remediation system is shown to result in a more widespread shallow water table, as shown in the plots on the right-hand side of this figure.

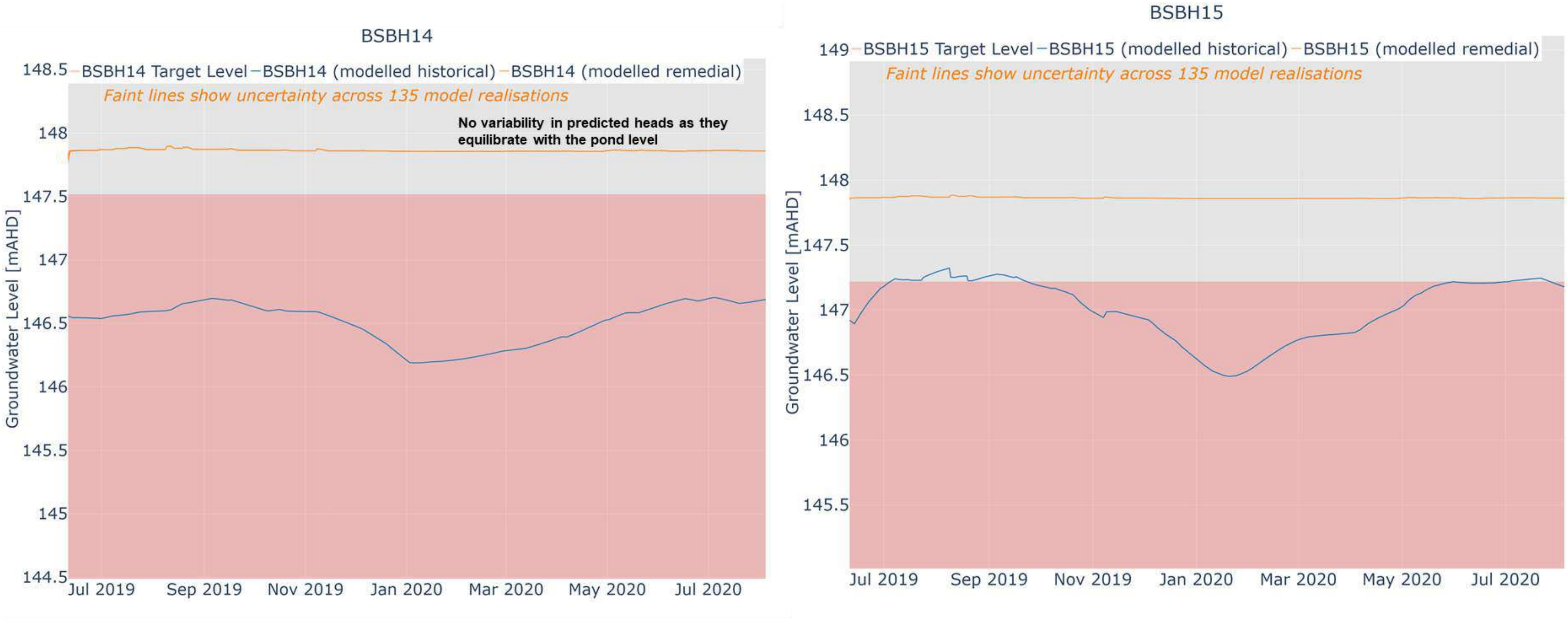
Figure 6-14 presents maps of model uncertainty in the simulated effect on depth to water variability, which can be used as a proxy measure of acid generating potential, and for illustrating the general effectiveness of the remediation system on maintaining moist conditions across the swamp. The figure better illustrates the incremental effect of the remediation system than Figure 6-12 and Figure 6-13. This is most clearly demonstrated by the broad areas of blue colour that are persistent in all six plots (across different climatic conditions and parameter uncertainty range), which correspond to areas where the water table has been increased by the remediation system. This means there is high confidence that the remediation system would be effective across much of the critical areas of the swamp, where the system has been designed to achieve as much ponding as possible, as long as the ponds can be maintained (as currently simulated by the TUFLOW model). It also shows that the upper uncertainty (conservative) estimate of the potential incremental lowering of the water table during the critical dry period is generally <0.5 m, with only localised areas where larger declines may be possible.

Uncertainty in stream flow

Figure 6-15 presents the simulated flow hydrographs under historical and remedial cases, including uncertainty, for the two downstream gauges (233276A and 233228). The vast majority of the 135 stochastic model realisations meet or exceed the minimum flow target of 0.5 ML/d at gauge 233228, with more persistent flow during the dry period maintained by the supplementary flow of 4.4 ML/d.

It should be noted that some realisations of the model do not meet the 0.5 ML/d flow target at all times, highlighting a small but nonetheless identifiable risk. This level of uncertainty should be considered in conjunction with the flow splits that could be optimised to allow more flow down Boundary Creek as required to maintain the flow.

Figure 6-10 Example of predicted hydrographs – low uncertainty range in constant ponded areas



Modelled heads appear as a single line as all 135 model realisations simulate very similar heads, which are constrained by the pond level

Figure 6-11 Example of predicted hydrographs – higher uncertainty range in variably ponded areas

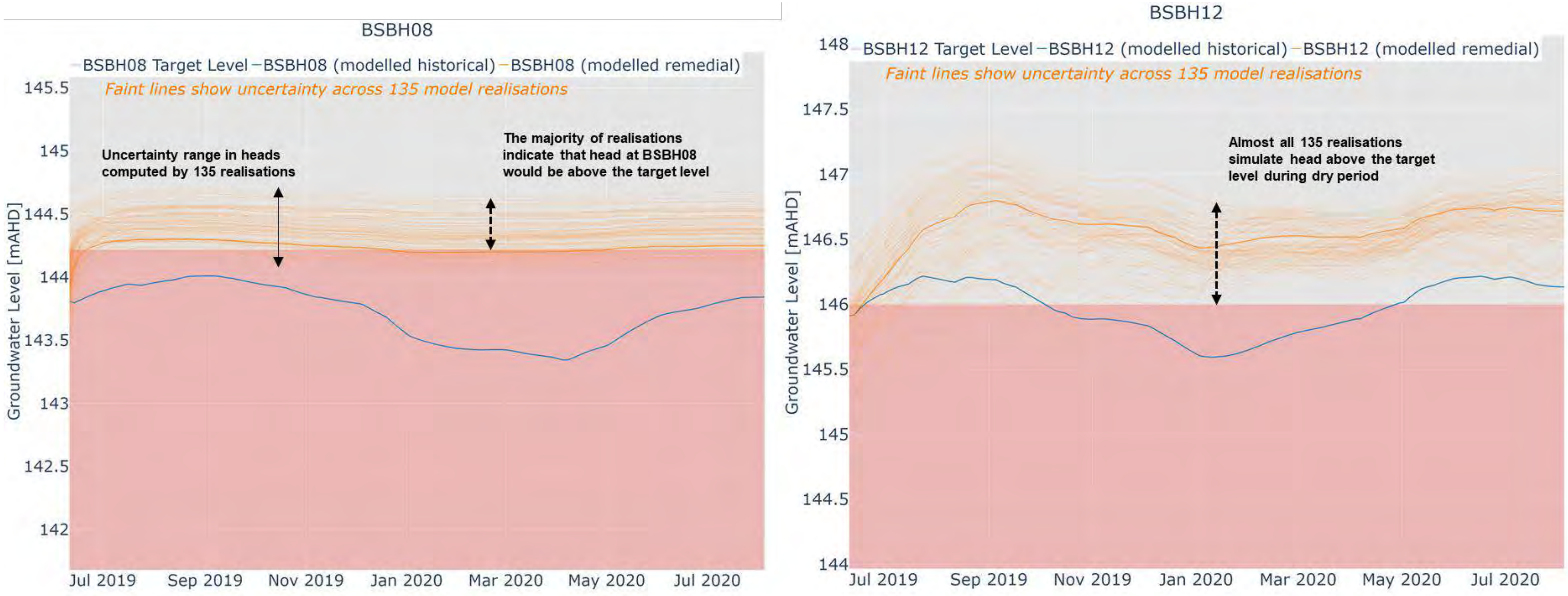


Figure 6-12 Lower uncertainty estimate of modelled seasonal depth to groundwater variability and remedial effect

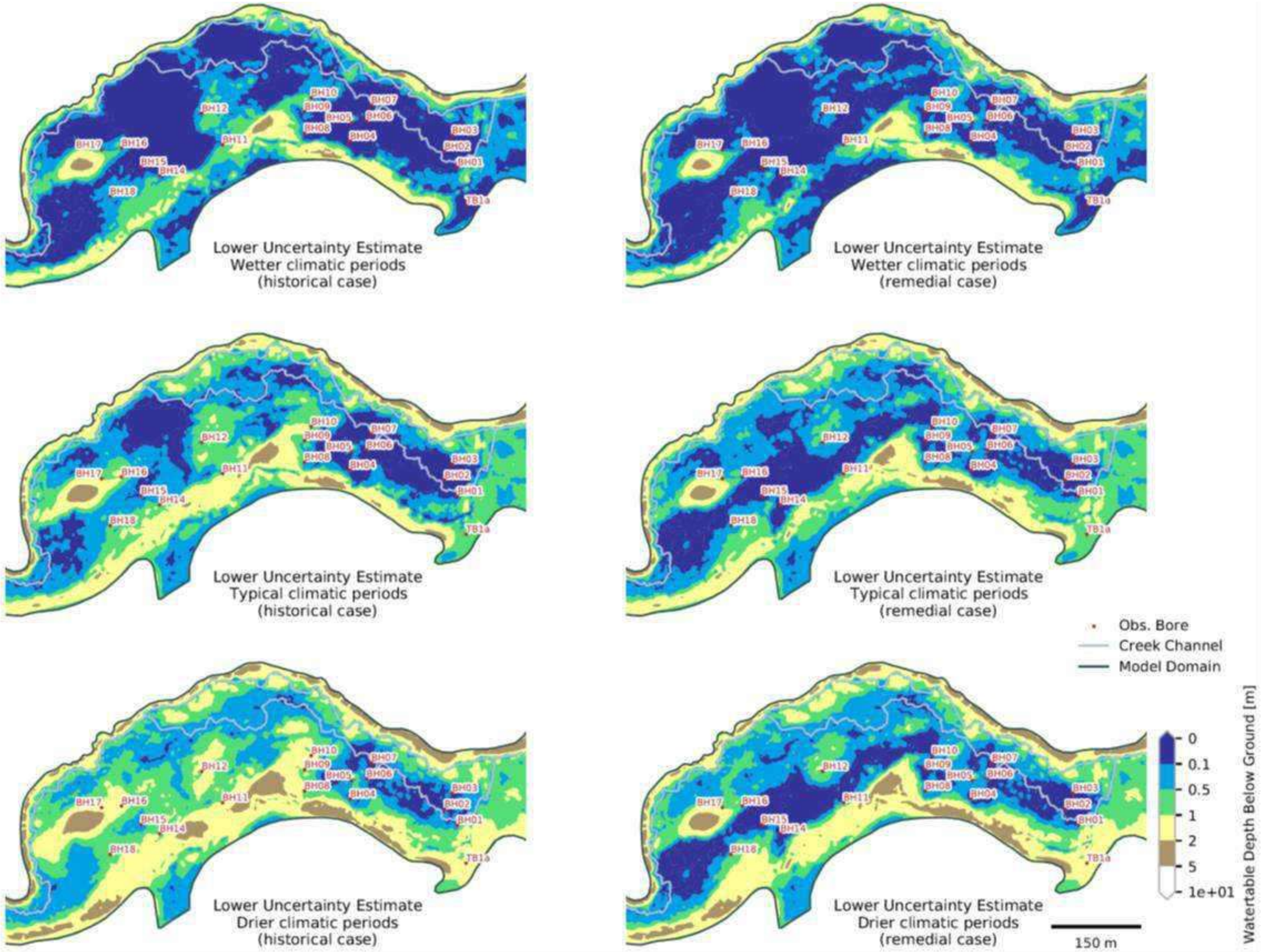


Figure 6-13 Upper uncertainty estimate of modelled seasonal depth to groundwater variability and remedial effect

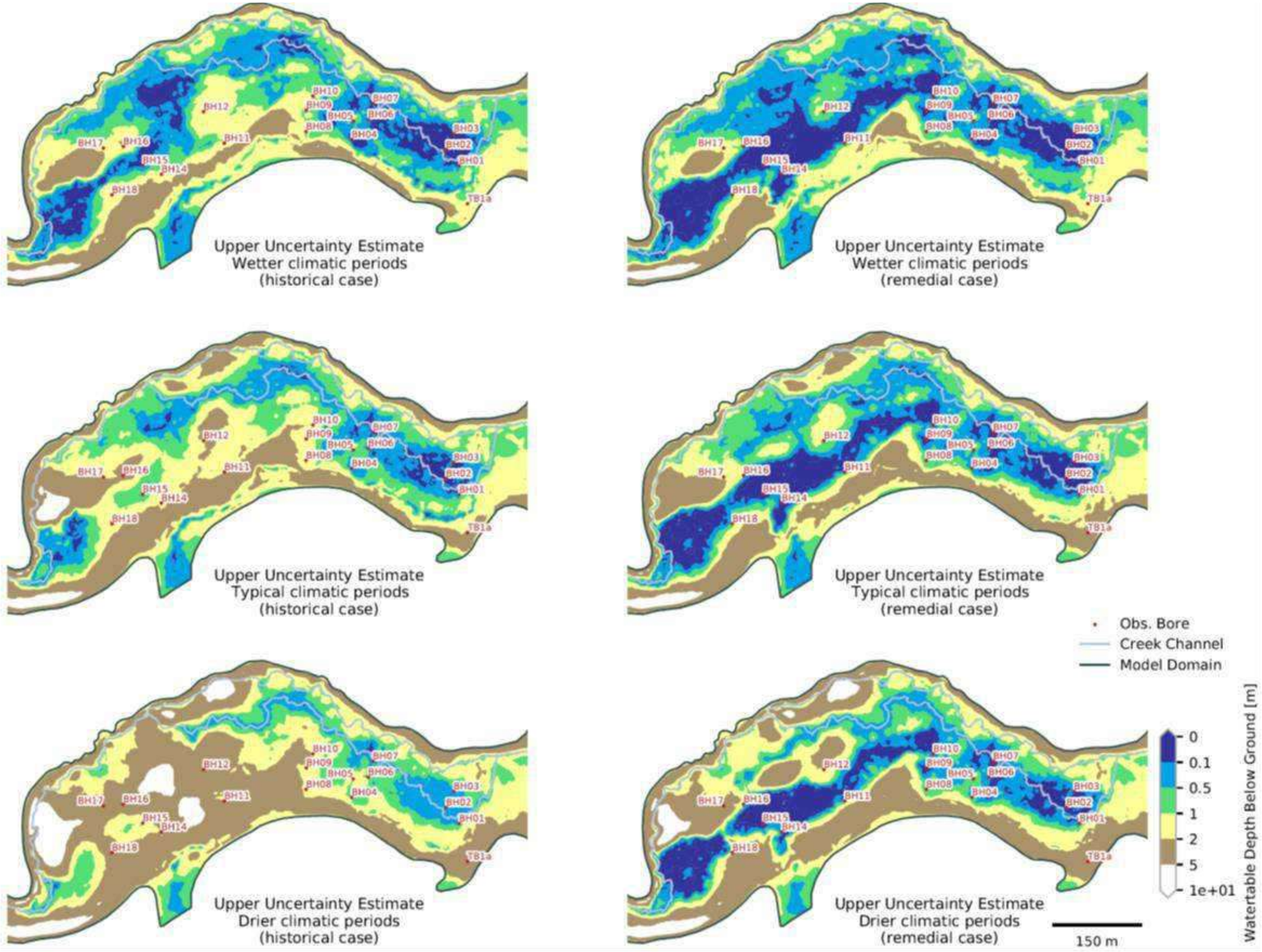


Figure 6-14 Uncertainty in remedial effectiveness on depth to groundwater variability

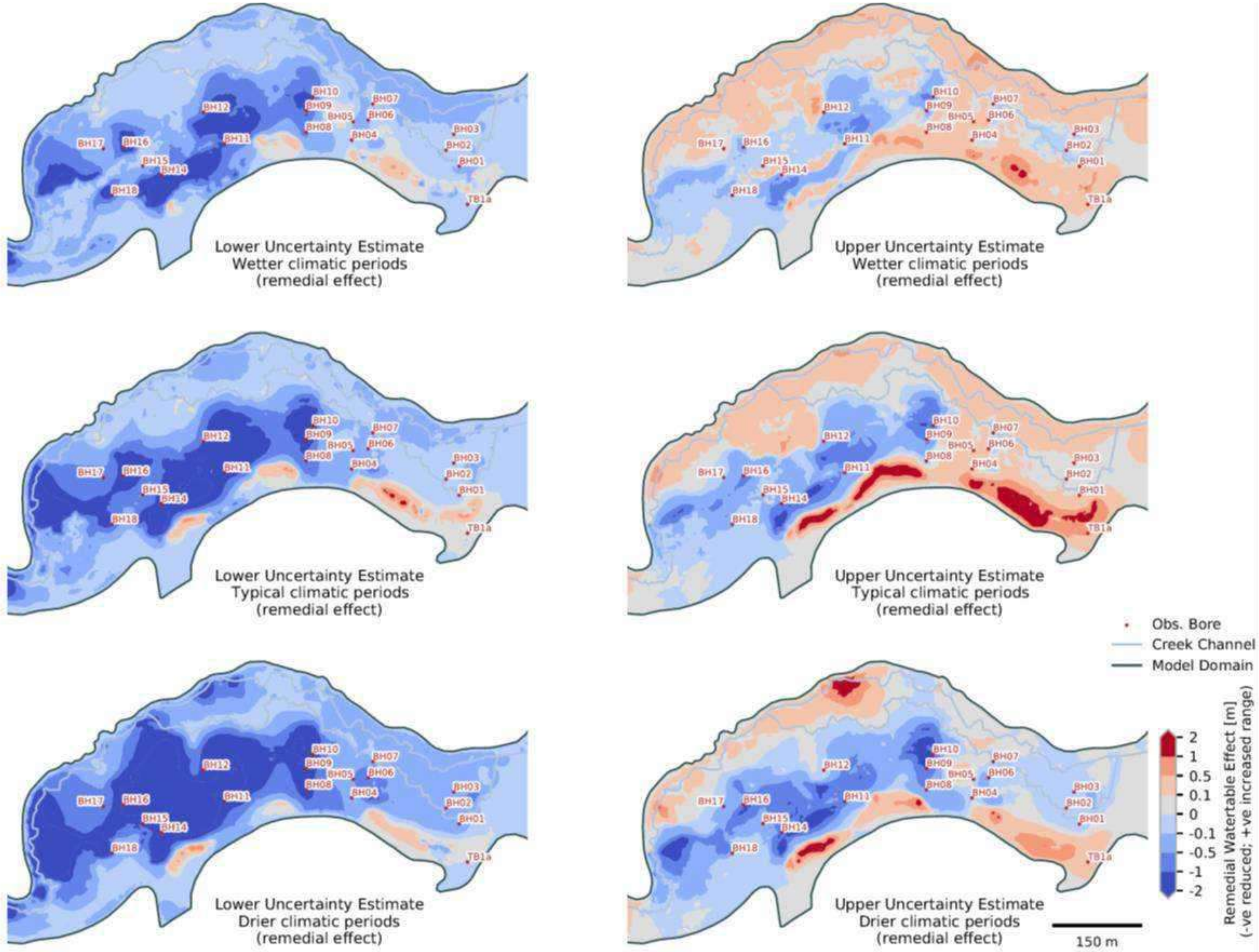
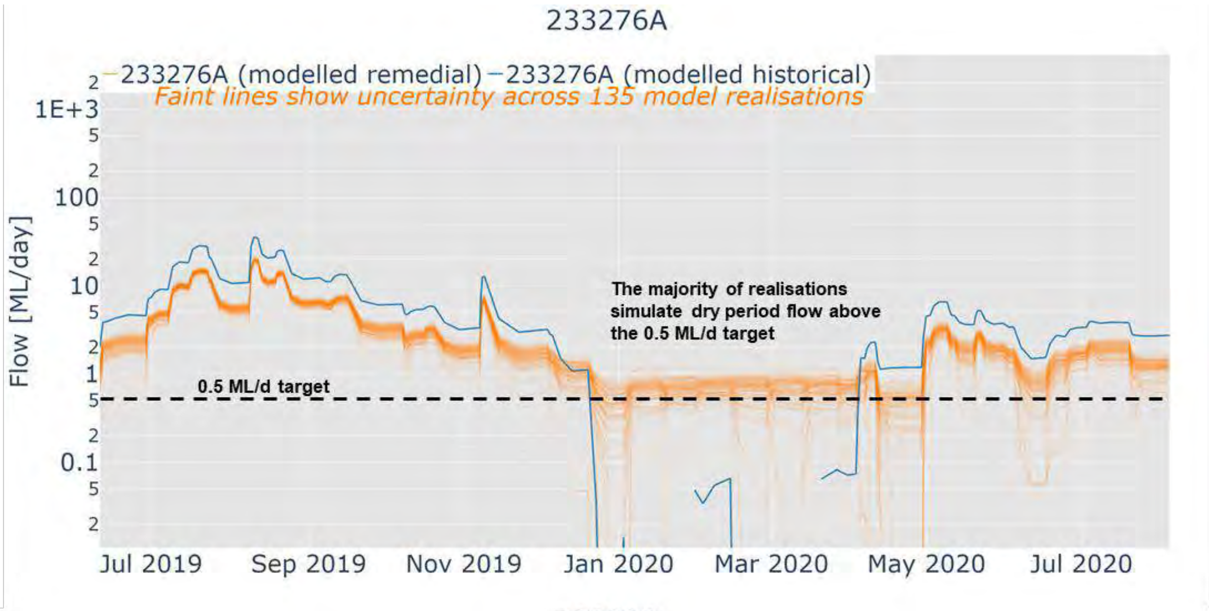
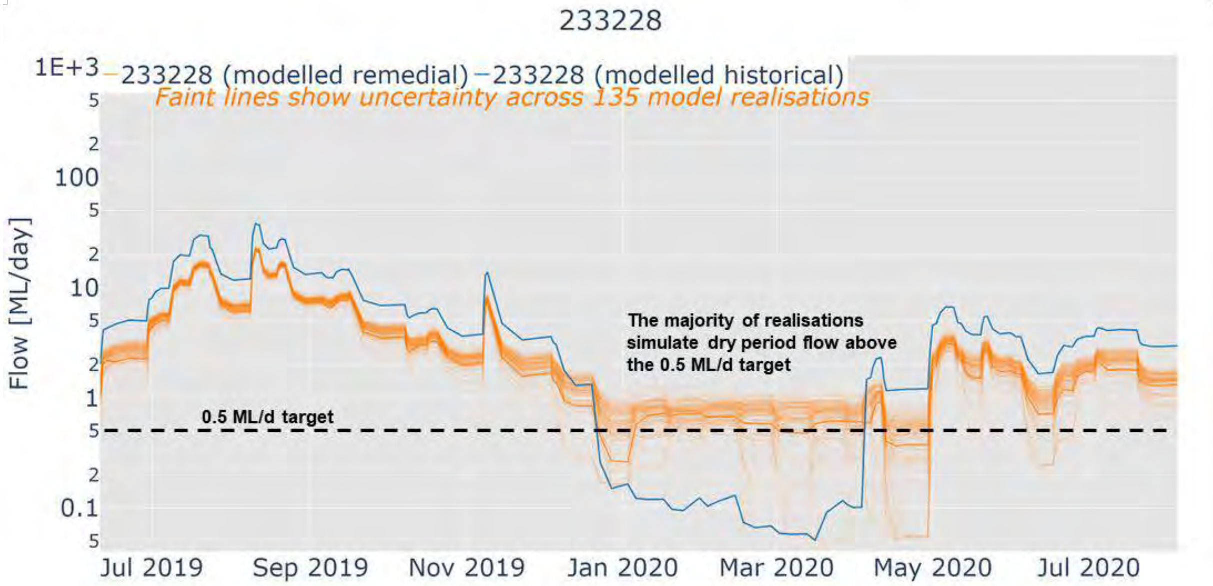


Figure 6-15 Predicted flow hydrograph uncertainty





7. Conclusions

7.1 Summary of key findings

Integrated modelling of surface water and groundwater systems of Boundary Creek and Big Swamp has been undertaken by loosely coupling GR4J, TUFLOW and USG-Transport models. The models have been rigorously calibrated to monitoring data collected over a period of 14 months, which included measurements of groundwater levels in 18 monitoring bores and stage and flow data at key stream gauges. The calibrated models have been used to examine the effectiveness of different hydraulic barrier configurations and supplementary flow regimes in maintaining the groundwater levels in Big Swamp and flow in Boundary Creek downstream. The uncertainty in the effectiveness of the remedial strategy has been quantified through sensitivity analysis and non-linear uncertainty analysis.

The integrated modelling indicates the following:

- The water balance of the Big Swamp aquifer system is dominated by inflow from overland flow (flood inundation) as well as stream flow along Boundary Creek and outflow (downward leakage) into the underlying regional aquifer. This means the accuracy of ponded areas and depths derived from the TUFLOW model is important for simulating the water table response during wet periods. The inflow (infiltration) from ponded areas is largest in the upstream area of the swamp, where the water table is deeper. In the downstream area, the water table is shallower and the aquifer becomes fully saturated frequently, acting as the point of discharge for groundwater from further upstream.
- During dry periods, evapotranspiration becomes an important groundwater discharge mechanism. In upstream bores, a distinctive rising groundwater level trend is observed in the middle of the dry period when there is negligible overland flow and recharge. The model calibration indicates that this is due to upflow from the underlying regional aquifer, which occurs when the water table falls to a critical level and results in a temporary reversal in vertical hydraulic gradient that initiates upward leakage.
- The preferred hydraulic barrier configuration comprises of 7 barriers and these are likely to be very effective in maintaining inundation in critical areas within Big Swamp, which results in near-constant groundwater levels at or above the target levels at the majority of bores. The exception is at BSBH18, where the groundwater level may remain around 0.3 m lower than the target level. As this bore is located on higher ground, there are likely to be practical limitations on how much flow can be forced upgradient without compromising the performance of the barrier system at bores further downstream.
- Sufficient inundation and ponding could be maintained under the existing flow regime with a supplementary flow of 2 ML/d during dry periods. However, this is unlikely to meet the minimum flow of 0.5 ML/d required downstream of Big Swamp due to stream loss/leakage to the underlying aquifer. The amount of supplementary flow needed to maintain the required minimum flow depends on the proportion of stream flow diverted towards the swamp to maintain inundation. At 50:50 flow split/diversion, the modelling indicates that almost all of the 500 ML supplementary flow would be required to maintain flow at 0.5 ML/d or more downstream of the swamp most of the time (around 90% of the 14-month simulation period). However, at the maximum supplementary flow rate, the modelling suggests that inundation could be maintained with a flow split as low as 80:20. The implication is that there is an opportunity to optimise the flow split to enable more flow to be passed down Boundary Creek, potentially achieving the 0.5 ML/d minimum flow with lower supplementary flow rates.

- Barriers 1 and 5, located in the upstream end of Big Swamp, should be constructed as weirs that allow some level of control over their width, for example by using stop logs that can be added or removed. This will allow some flexibility in the future for optimising the usage of supplementary flow to maintain both the ponded areas and flow downstream of the swamp. For example, in the event that the future climate is drier than that experienced over the past 14 months or that the infiltration losses are greater than those modelled, then the flow split can be adjusted to keep the ponds topped up.
- The supplementary flow is also likely to be important in preventing the water table in the northern part of the swamp from declining during drier periods. The modelling indicates that under a typical climatic condition, the diversion of flow from Boundary Creek has the potential to slightly lower the water table by <0.5 m along and in the vicinity of Boundary Creek. During drier periods, however, supplementary flow and associated leakage into the underlying aquifer has the potential to prevent further lowering of the water table (i.e. not make the condition any worse than it currently is), possibly resulting in some increase in the downstream area. This may be important for managing acidification in the northern area of the swamp, where there is currently limited information on its acid generating potential.
- The fire trench currently forms a local low point, where surface water ponds and acts as a localised source of recharge. When the fire trench is filled in the future, this localised source of recharge would no longer be present, resulting in a possible lowering of the water table by 0.5 to 1 m. This may be important, depending on the acid generating potential of swamp sediments in this area.
- Although the method of handling infiltration in the TUFLOW and USG-Transport model is different, this is unlikely to have a material effect on the key findings of the modelling. The sensitivity analysis indicates that if infiltration rates were higher than that assumed in the calibrated TUFLOW model, then there is a risk that the pond generated adjacent to the barrier furthest downstream would go dry under dry climatic conditions. However, this could be mitigated by allowing small volumes of additional flow diverted to the swamp to keep the ponds topped up, which can be achieved by adjusting the flow split or increasing the supplementary flow (which would be required for maintaining the 0.5 ML/d flow anyway).
- The sensitivity analysis indicates that the accuracy of the terrain data is very important in simulating the flooded areas and extents and, by extension, the hydraulic barrier configurations required to maintain desired ponding. If the actual topography differs from that represented in the existing terrain data, then the shape and location of hydraulic barriers may need to be modified to achieve the required pond size and depth to maintain the groundwater levels.

7.2 Confidence level classification

When a groundwater model is used to inform the outcome of a particular future scenario, the level of confidence in model's outputs depends fundamentally on the data used to calibrate the model and their relevance to the hydrological processes of future scenarios. It follows that a model that is required to predict response to hydrological stresses that are similar to those of the past and for a period of time similar to the period of historical observations would have high confidence in its predictions, provided that the model has been adequately calibrated and the results of the model are mathematically sound. This forms the basis of the confidence level classification in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

In the context of the Big Swamp integrated modelling, the future stresses associated with the construction of hydraulic barriers are primarily related to the changed extents, duration and depths of inundation. This means the future stresses are similar to those of the past (associated with the same hydrological processes), albeit slightly larger due to the greater ponding depths introduced in certain areas over a longer duration. The period of predictive modelling chosen for this project is also the same as the period of calibration. In this sense, the USG-Transport model developed for the purpose of informing the proposed remediation strategy can be said to satisfy, at least partially, some of the key criteria for the highest (Class 3) confidence level classification of the Australian Groundwater Modelling Guidelines (see Figure 7-1).

While the magnitude of stress and period of predictive simulation are not excessive compared to those of the past, recognised data gaps and model limitations outlined in Section 7.3.2 mean the USG-Transport model would be considered generally a Class 2 model with some attributes of Class 3.

It is important to note that moderate to high confidence in the USG-Transport model outputs relates specifically to their intended use, which is to assess the effectiveness of different hydraulic barrier configurations and supplementary flow regimes on meeting the groundwater level and flow targets. If the future use of the USG-Transport model is extended to include longer simulation periods or climatic conditions that are very different to those of the period of historical observations, then the level of confidence associated with the model outputs would need to be revised accordingly. This would also be the case if the USG-Transport model is used for purposes other than its intended primary use (for example, to examine the effects of changes in the LTA heads).

7.3 Model limitations

7.3.1 Surface water model limitations

The GR4J model has not been calibrated and validated against flow data from different time periods, which means it is currently not suitable for examining the effects of different or synthetic climate conditions. Further work would be required if the integrated modelling in this report is to be extended to examine different climatic conditions. The model also overestimates flow, with higher peaks and longer declining trends, although part of this is due to the absence of infiltration and evaporative losses which are subsequently accounted for by the TUFLOW model. Inaccuracies in the GR4J model outputs that could not be sufficiently reduced through calibration to existing data are passed onto the TUFLOW and USG-Transport models, although processes within these two models are able to compensate for such inaccuracies to some extent.

Hydraulic models such as TUFLOW are typically used on an even-basis, to examine flood extents and depths over relatively short periods of time. Running TUFLOW for the 14-month period has presented practical challenges, necessitating some simplifications in the model design to provide the outputs required for the USG-Transport model in a timely manner. These include coarser grid resolution and simple time-constant soil infiltration losses, with a sensible number of iterations with the USG-Transport model. Most of these design limitations have been assessed through sensitivity analysis and found to result in minimal effects on model outcomes. One critical limitation relates to the quality of terrain data, to which the TUFLOW model outputs is highly dependent. Due to the presence of dense vegetation in Big Swamp, obtaining reliable topography has been a challenge and this could affect the accuracy of the outputs generated by the TUFLOW model and the effectiveness of the recommended barrier configuration. This limitation should be taken into consideration as part of the detailed design of the remediation system.

7.3.2 Groundwater model limitations

Numerical groundwater models are a mathematical representation of complex real-world systems. The physical domain of interest, comprising layers of rocks and sediments, is discretised into a number of cells and the parameters that control the movement of groundwater through these layers is prescribed to each cell. The governing groundwater flow equations are solved by the code to compute hydraulic head and fluxes into and out of each cell. This mathematical representation of a natural physical system, using a finite number of cells, is a necessary simplification that is inherent in all numerical modelling, the degree of which is influenced by factors including the availability of data, scale of the model, intended model use and computational demand of modelling techniques.

The groundwater model described in this report is designed to simulate the key hydrogeological characteristics of a swamp that has a dimension of approximately 250 m by 800 m. Although it is not feasible to simulate individual discrete sand or clay lenses without adequate supporting information, the model has been designed to account for potential local scale variability in material properties through a rigorous calibration exercise utilising a large number of model parameters. The modelling also considered the effect of parameter uncertainty through a thorough non-linear uncertainty analysis, providing probabilistic indications of the effectiveness of the proposed remediation strategy in meeting the water level and flow targets. In order to provide this level of detail at a fine spatial scale, some simplifications of regional processes have been necessary. The quality of model calibration achieved and the results of predictive modelling indicate that this level of simplification has not limited the intended use of the model, which is to inform the detailed design of the remediation strategy and its effectiveness in meeting the water level and flow targets.

As with all models, the level of uncertainty is larger in parts of the model where observations are not available to constrain the model parameters or benchmark the performance of the model. In this study, a wide range of parameter values have been used in the non-linear uncertainty analysis to addresses this data gap. However, uncertainty remains in areas where data is currently absent or limited, such as the thickness of the QA, distribution of hydraulic heads in the LTA, the location of the MTD boundary and the natures of groundwater interaction between the QA and LTA. As additional data become available over time, the model can be periodically updated and the level of confidence in model’s outputs would increase accordingly.

An important limitation of the modelling and associated conclusions of this report is that the remedial scenario, and model history matching, are both based on observation data from a very limited period of time. As such, the data are only representative of limited climatic conditions, and the system may behave differently beyond those conditions experienced in the limited observation data set. This may have important implications for the effectiveness of the remedial system as modelled in this study. It is recommended that the models are further developed to simulate longer, more variable climate sequences than those modelled to date.

Figure 7-1 Confidence level classification assessment for USG-Transport model

Confidence level classification	Data	Comment
Class 3	• Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.	*Yes for shallow groundwater, which is the focus of this modelling (head data from 18 bores across Big Swamp used in calibration). There is limited data from the LTA to fully characterise the deeper system*
	• Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.	*Partially, bore logs from 18 bores but maximum QA thickness only verified at one location and lateral extents have not been confirmed*
	• Reliable metered groundwater extraction and injection data is available.	*No known groundwater extraction or injection in the model domain*
	• Rainfall and evaporation data is available.	*Yes, rainfall from WMIS gauge*
	• Aquifer-testing data to define key parameters.	*Partially, as data is limited to slug tests of low confidence*
	• Streamflow and stage measurements are available with reliable baseflow estimates at a number of points.	*Yes, gauged stream flow and stage used in calibration*
	• Reliable land-use and soil-mapping data available.	*Partially, eco-hydrological zones*
	• Reliable irrigation application data (where relevant) is available.	*No known irrigation in the model domain*
	• Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	*Yes, DEM processed from LIDAR, surveyed bore and flow gauge elevations*

Confidence level classification	Calibration	Comment
Class 3	• Adequate validation* is demonstrated.	*No, as all data is fully utilised in calibration*
	• Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable.	*Yes, but limited to shallow groundwater (3.08% SRMS for all head observations)*
	• Long-term trends are adequately replicated where these are important.	*Partially, as observations are only available for 14 months*
	• Seasonal fluctuations are adequately replicated where these are important.	*Yes, but only for the period of observations (14 months)*
	• Transient calibration is current, i.e. uses recent data.	*Yes, up to August 2020*
	• Model is calibrated to heads and fluxes.	*Yes, heads, stage and stream flow*
	• Observations of the key modelling outcomes dataset is used in calibration.	*All observation data used in calibration inform barrier configurations and supplementary flow*

Confidence level classification	Prediction	Comment
Class 3	• Length of predictive model is not excessive compared to length of calibration period.	*Yes, as the predictive model uses the same 14-month calibration period to inform the barrier configuration and supplementary flow regime*
	• Temporal discretisation used in the predictive model is consistent with the transient calibration.	*Yes, the same stress periods used*
	• Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.	*Partially, while the magnitude of change in groundwater levels are similar, the level of ponding is greater and over longer duration in the predictive model*
	• Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	*No, all available observations have been fully utilised in calibration due to the limited length of monitoring. Post-calibration validation would need to be undertaken when additional data become available*

This table assesses the USG-Transport model against the key indicators of Class 3 confidence level in the context of its intended use, which is to assess whether the hydraulic barriers and supplementary flow could be effective in meeting the groundwater level and stream flow targets. For this purpose, the predictive model utilises the same length and climatic conditions of those of the calibrated model. While the model is considered fit for this purpose, satisfying some of the key indicators of Class 3 confidence level, there are recognised limitations with the model due to gaps in data which are also identified in the table above. This means the model may be classified as Class 2, with some attributes of Class 3. If the USG-Transport model is used to predict potential outcomes of the future, using longer simulation periods and different climatic conditions, or for purposes other than its intended primary use, then the confidence level classification would be revised accordingly.

8. Recommendations

This section provides a number of recommendations that may assist in further improving the performance of the integrated models and the effectiveness of the proposed remediation strategy:

- There is currently limited lithological data to inform the geometry of the QA, with only one nested drilling site in the downstream area of Big Swamp. In particular, the boundary of the MTD and the top of the underlying LTA are currently not well understood. Given the influence of LTA fluxes on the dry period water levels in the upstream area of the swamp, further drilling works to improve the knowledge of the QA thickness and its contact with the underlying geology is considered beneficial.
- Similarly, installing nested monitoring bores in the QA and the underlying LTA at several locations within Big Swamp would assist in improving the understanding of vertical interactions between these two aquifers and how they very spatially and over time. For example, deeper monitoring bores could be constructed in the LTA near some of the existing bores in the QA to form nested sites. Depending on the thickness of the QA, it may also be beneficial to place additional bores near the base of the QA to understand the vertical gradient within the QA and how the hydraulic heads vary across the interface between the QA and LTA.
- There are currently no monitoring bores in the northern area of Big Swamp, near Boundary Creek, and along the southern boundary near the fire trench where the modelling has identified potential lowering of the water table due to redistribution of flow. Additional shallow bores in these areas, if accessible, would assist in model calibration and any risks associated with activation of acid sulfate soils.
- The potential rate of infiltration of surface water could be further constrained, for example, by undertaking infiltration tests using a double ring infiltrometer.
- The modelling presented in this report has been limited to the climatic condition of the 14-month monitoring period. Further testing of the proposed remediation strategy under different climatic conditions (for example, successive dry years) would assist in understanding its sensitivity to future climate. Similarly, the modelling has assumed time-constant LTA heads. Over much longer timeframe, the LTA heads are expected to change slowly depending on the rate of recovery from pumping and the influence of future climate. Further sensitivity analysis of different LTA heads is recommended, for example by incrementally shifting the LTA heads in the SGB cells.
- Additional hydraulic assessments should be completed if the actual topography is found to be significantly different from what is currently indicated in the terrain data, to ensure that the preferred barrier configuration is able to achieve its intended purpose. For example, if there are any low points that are currently not known, then water could bypass the barriers and let flow through before desired levels of ponding could be achieved.
- The findings of integrated modelling detailed in this report should be reviewed in conjunction with the available hydrogeochemical data of Big Swamp to assess potential groundwater and surface water quality changes that may result from the proposed remediation strategy.

9. References

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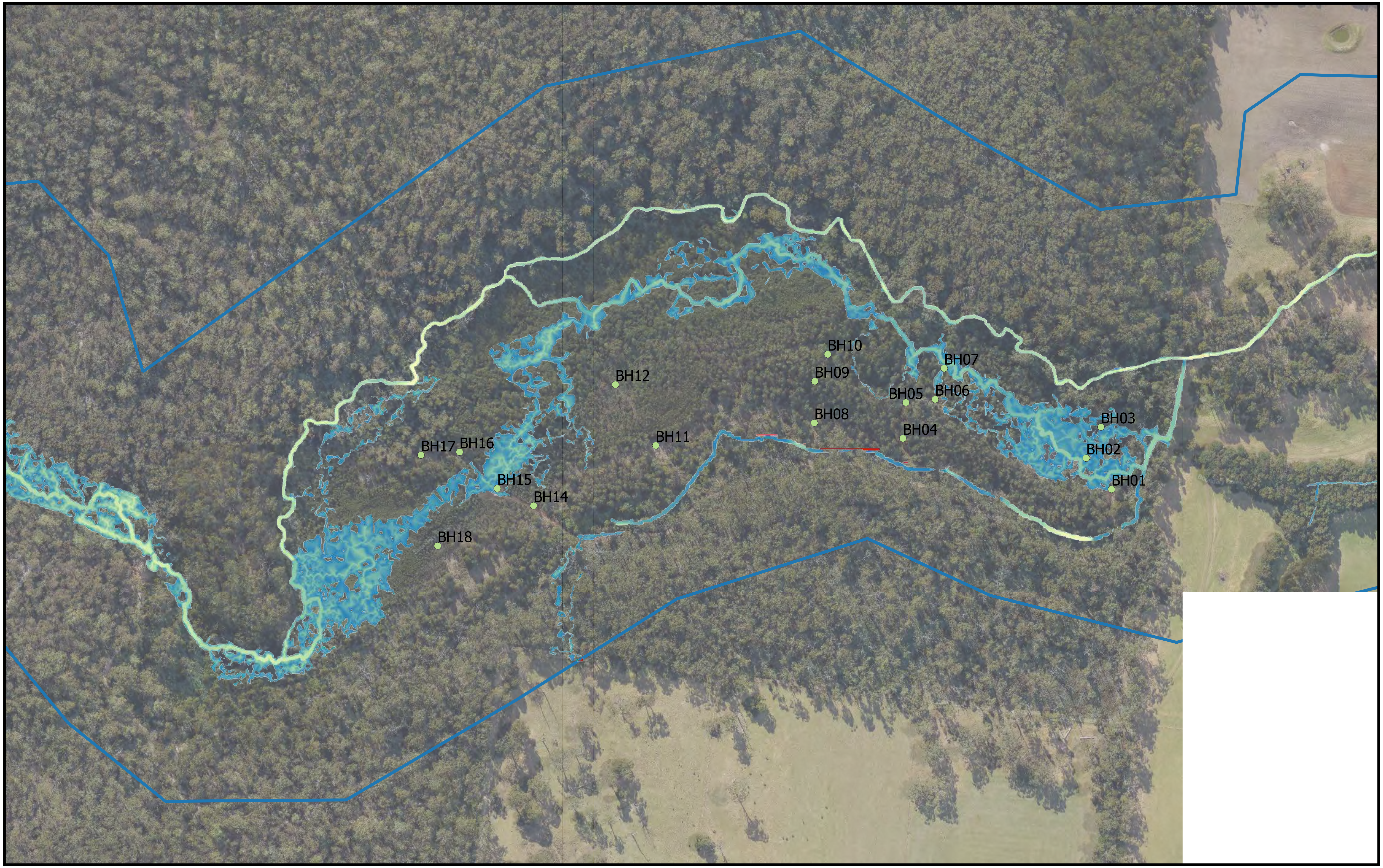
Appendices

Appendix A – Additional TUFLOW Outputs



Legend

Water Depth (m)

0	0.6
0.2	0.8
0.4	1
	1.2

Tufow model boundary

Borehole locations

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Existing conditions
Wet period water depths (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

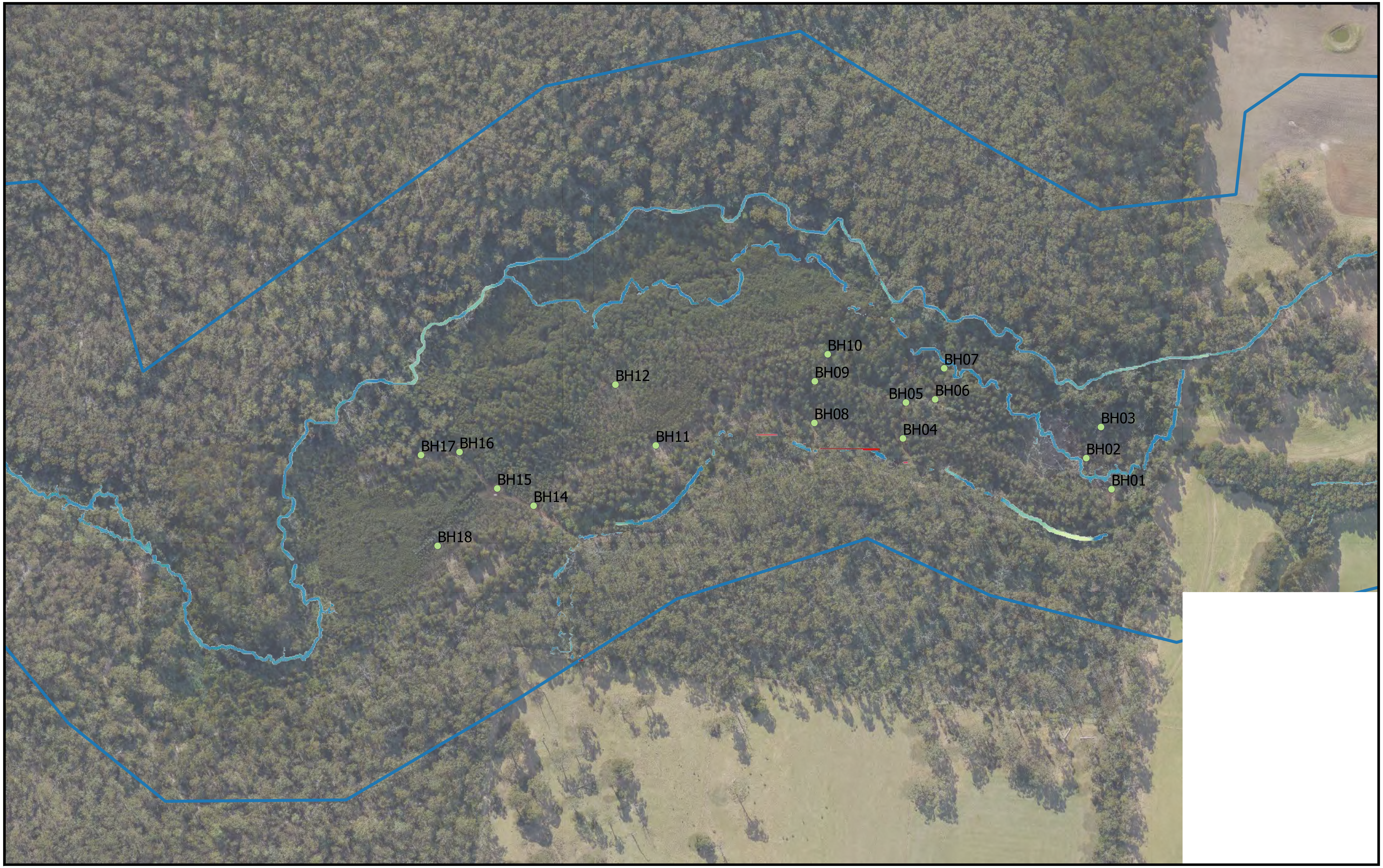
FIGURE SW-01

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2

Tufow model boundary

Borehole locations

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Existing conditions
Dry period water depths (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

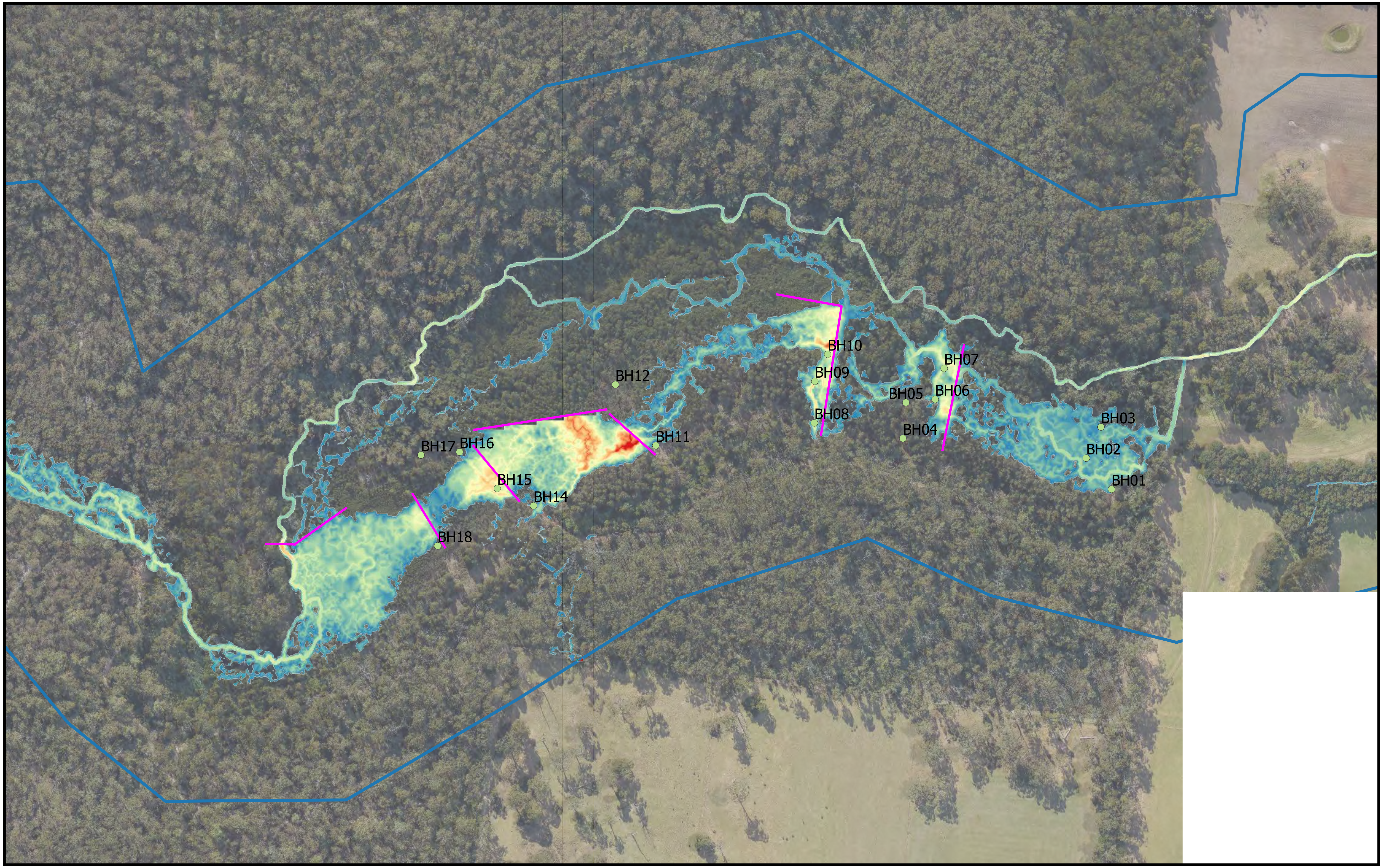
FIGURE SW-02

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2

Tufow model boundary

Borehole locations

Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Proposed Barrier Scenario (Group 12)
Wet period water depths (August 2019)

Project No. 12536659
Revision No. A
Date. 24/12/2020

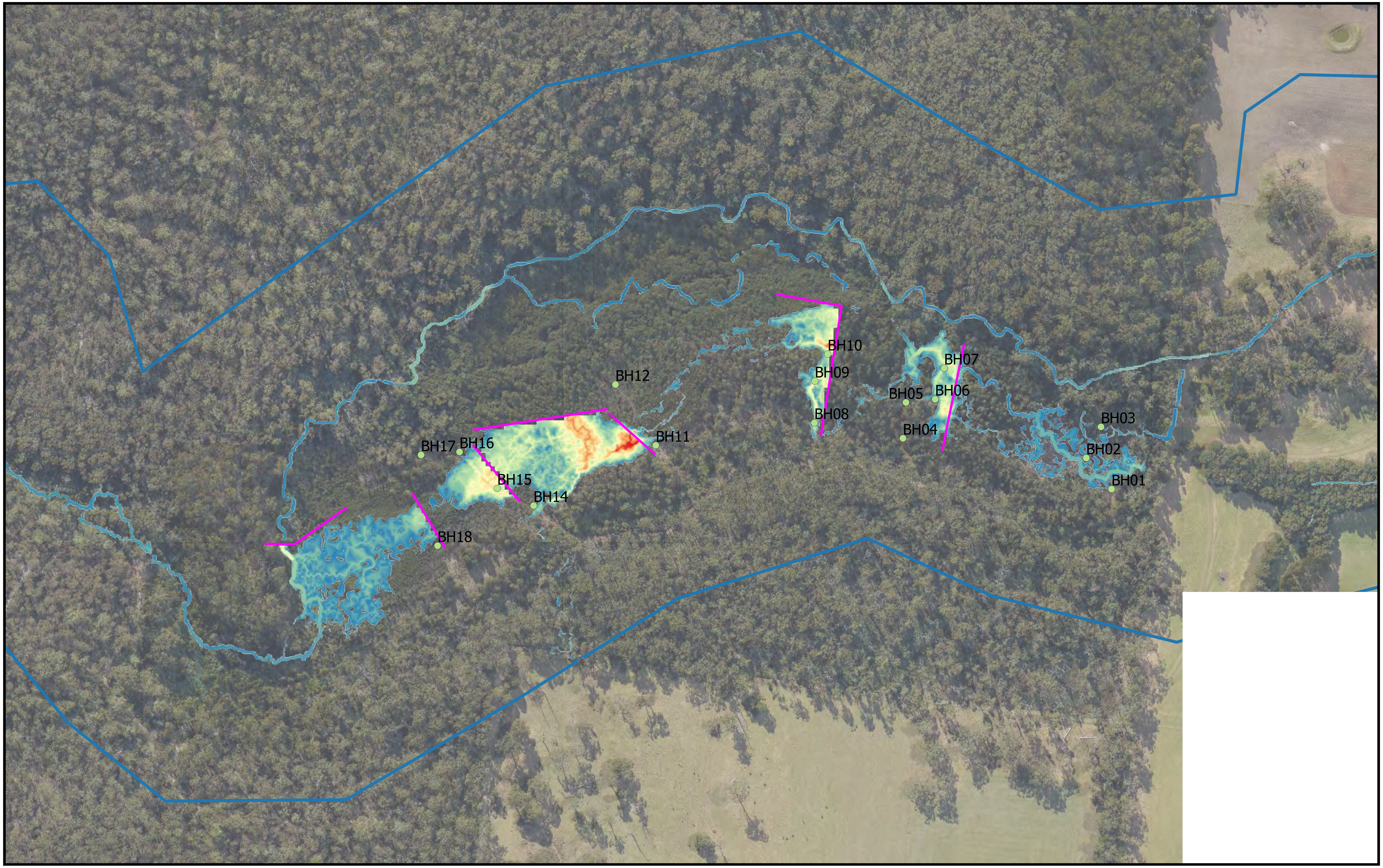
FIGURE SW-03

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)
- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- Tufow model boundary
- Borehole locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Proposed Barrier Scenario (Group 12)
Dry period water depths (March 2020)

Project No. 12536659
Revision No. A
Date. 24/12/2020

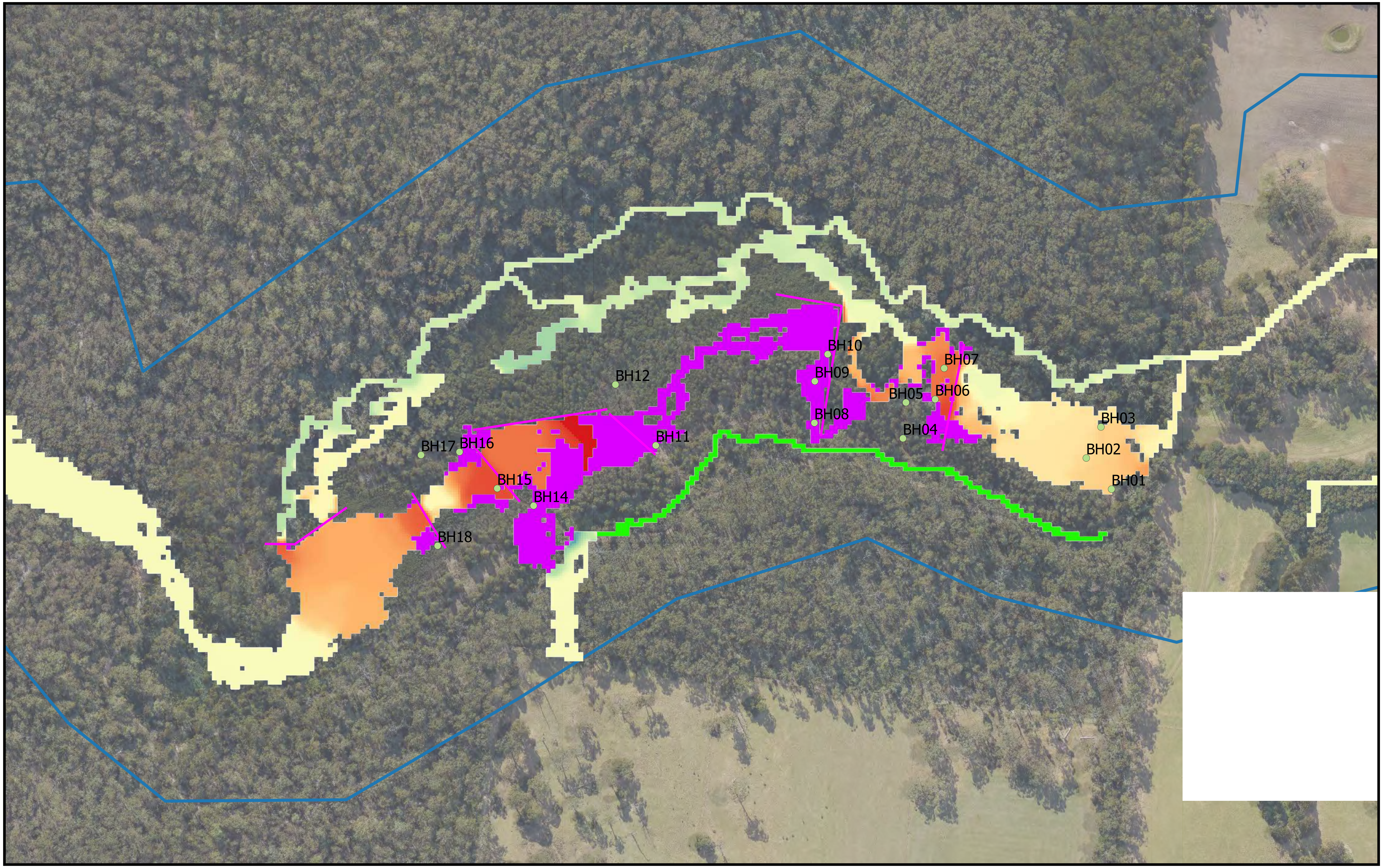
FIGURE SW-04

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)

-0.8	-0.05	0.5
-0.5	0	0.8
-0.3	0.05	> 0.8
-0.2	0.1	Was Wet Now Dry
-0.1	0.2	Was Dry Now Wet
	0.3	Tuflow Model Boundary

Borehole Locations
Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Proposed Barrier Scenario (Group 12)
Wet period depth afflux (August 2019)

Project No. 12536659
Revision No. A
Date. 24/12/2020

FIGURE SW-05

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

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Print Date:

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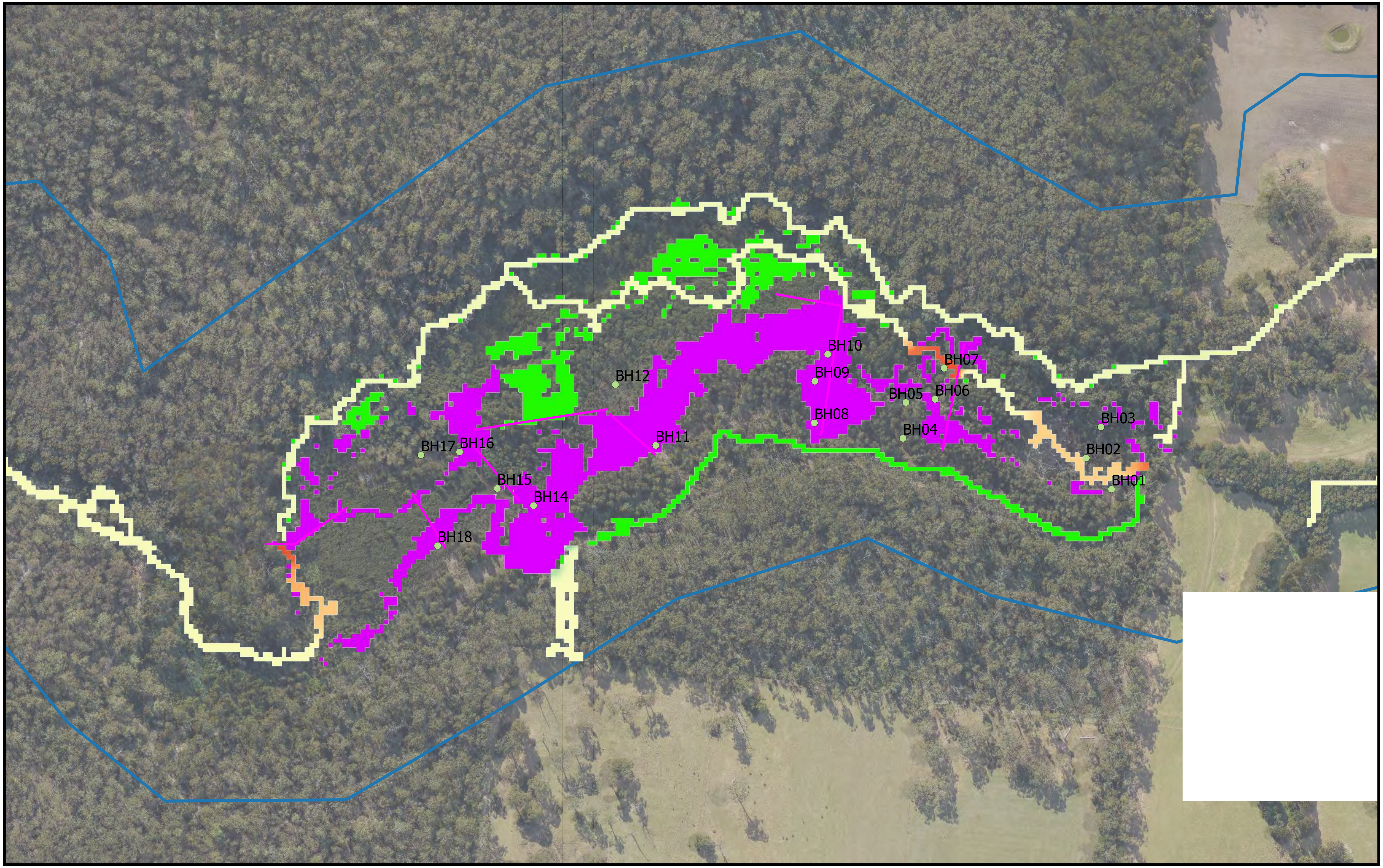

Legend

Depth afflux (m)
- -0.8
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- 0
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- 0.8
- > 0.8
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Proposed Barrier Scenario (Group 12)
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

FIGURE SW-06

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

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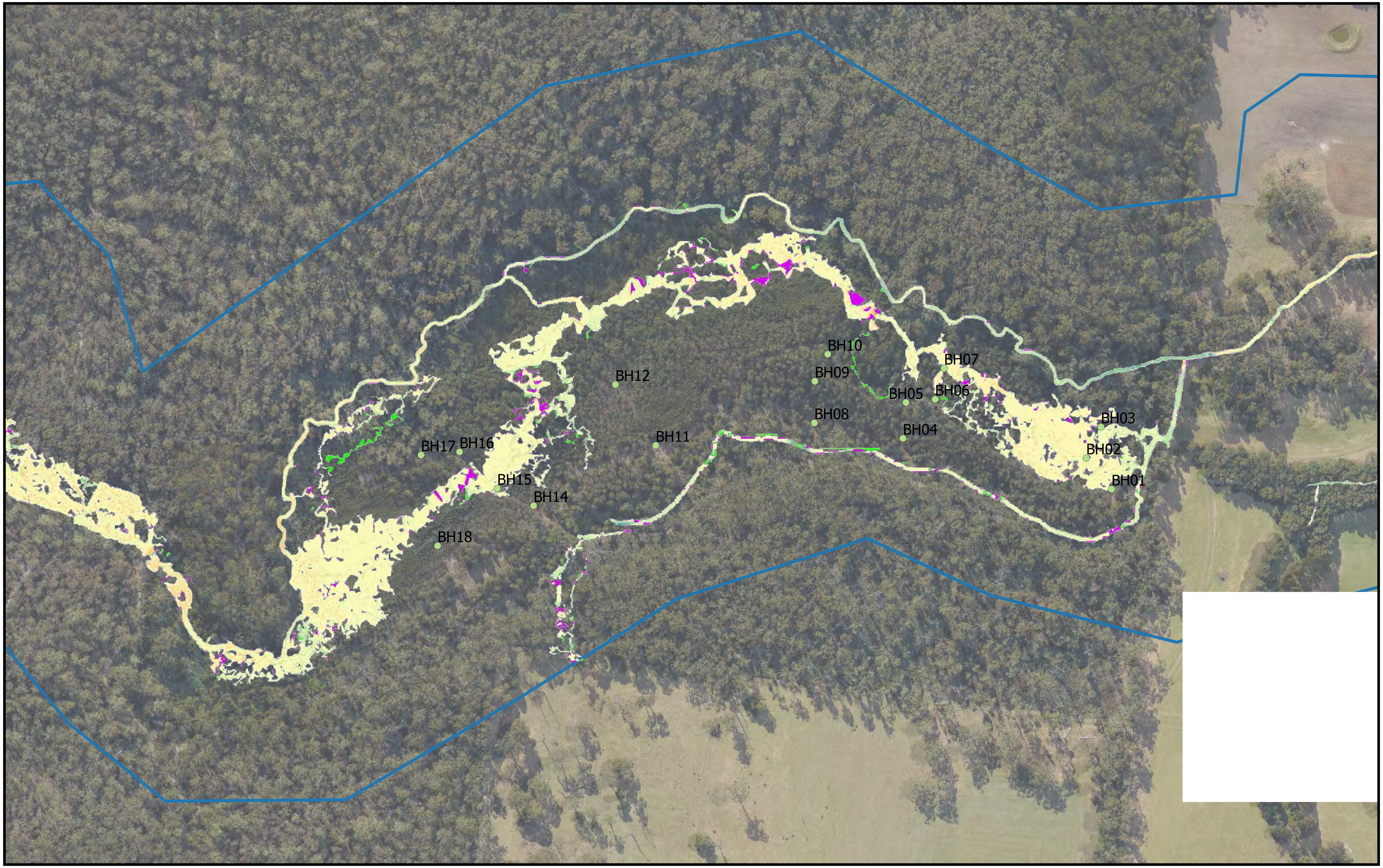

Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - 1 m grid cell size
Wet period depth afflux (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

FIGURE SW-07

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

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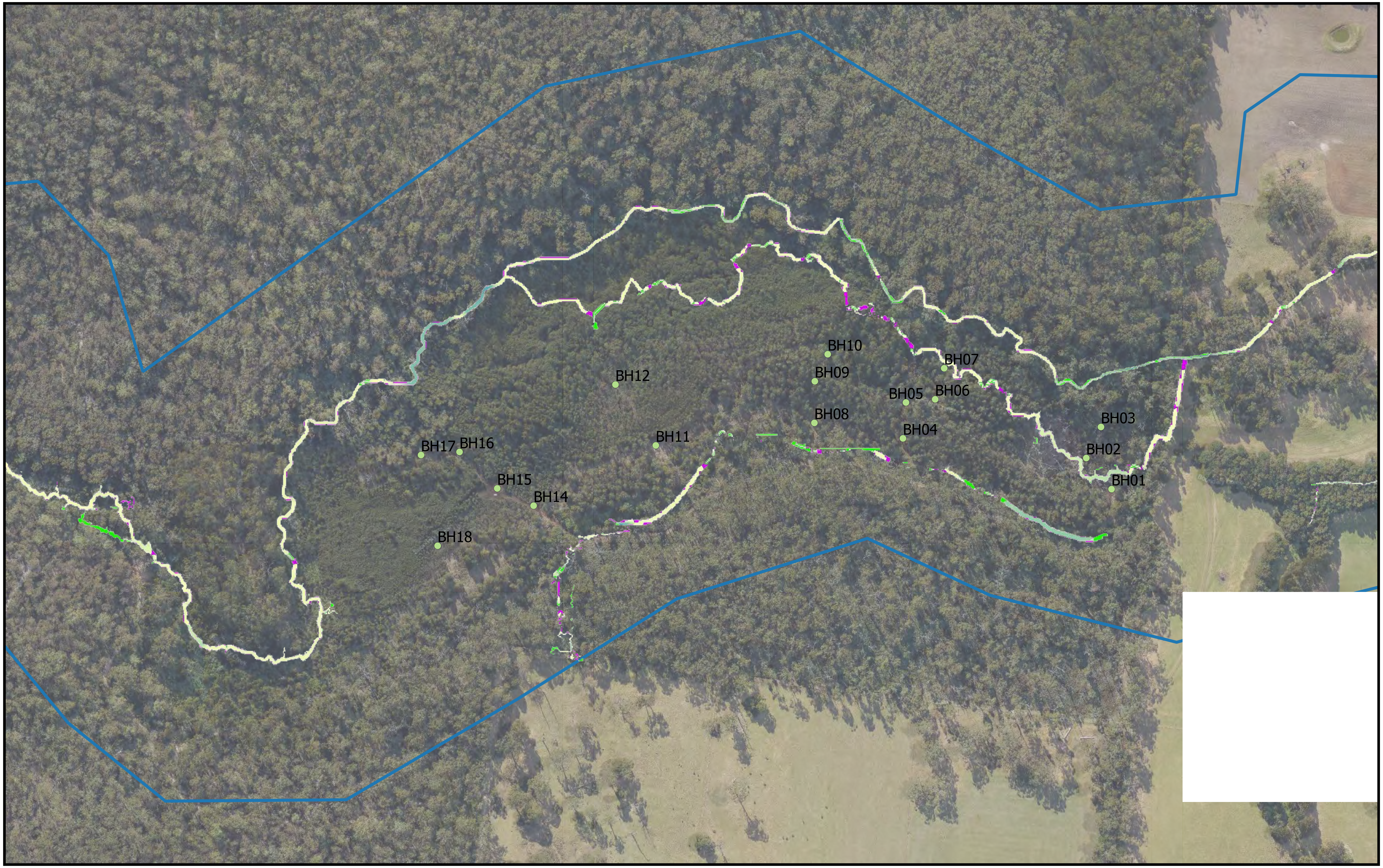

Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - 1 m grid cell size
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

FIGURE SW-08

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

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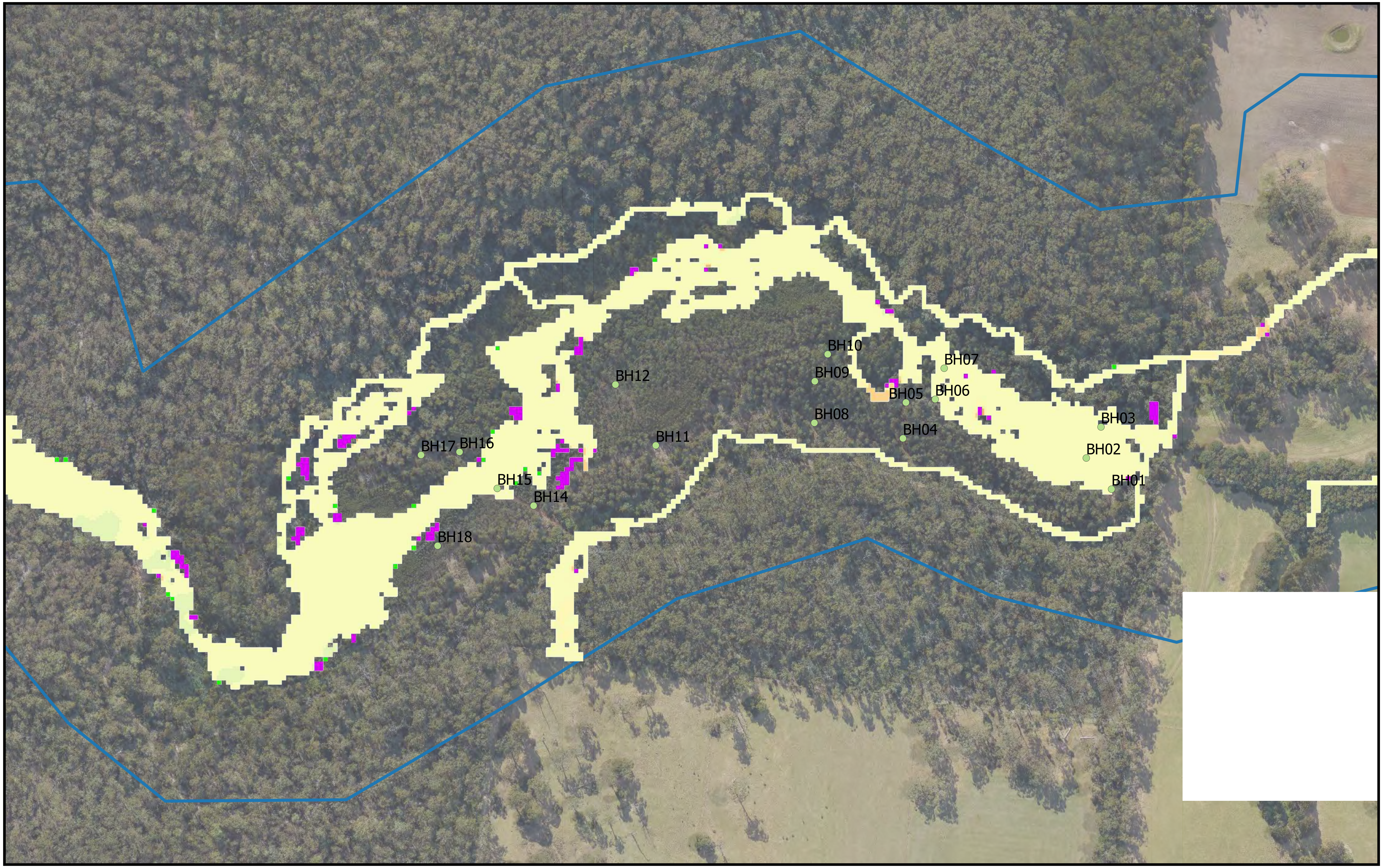
Created By: Ellie Denson



Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - 15 minute timestep on upstream inflow
Wet period depth afflux (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

FIGURE SW-09

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

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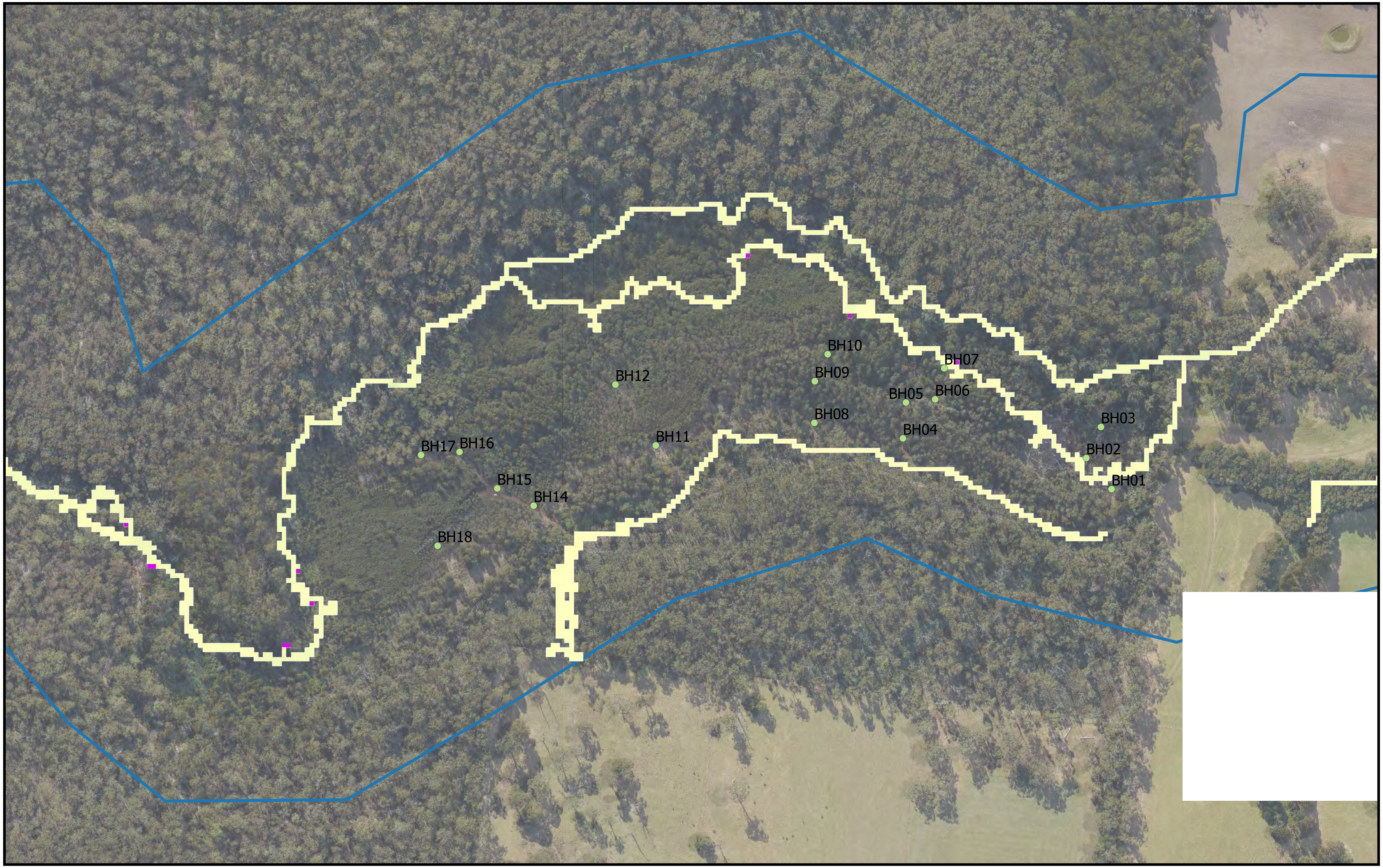


Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - 15 minute timestep on upstream inflow
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

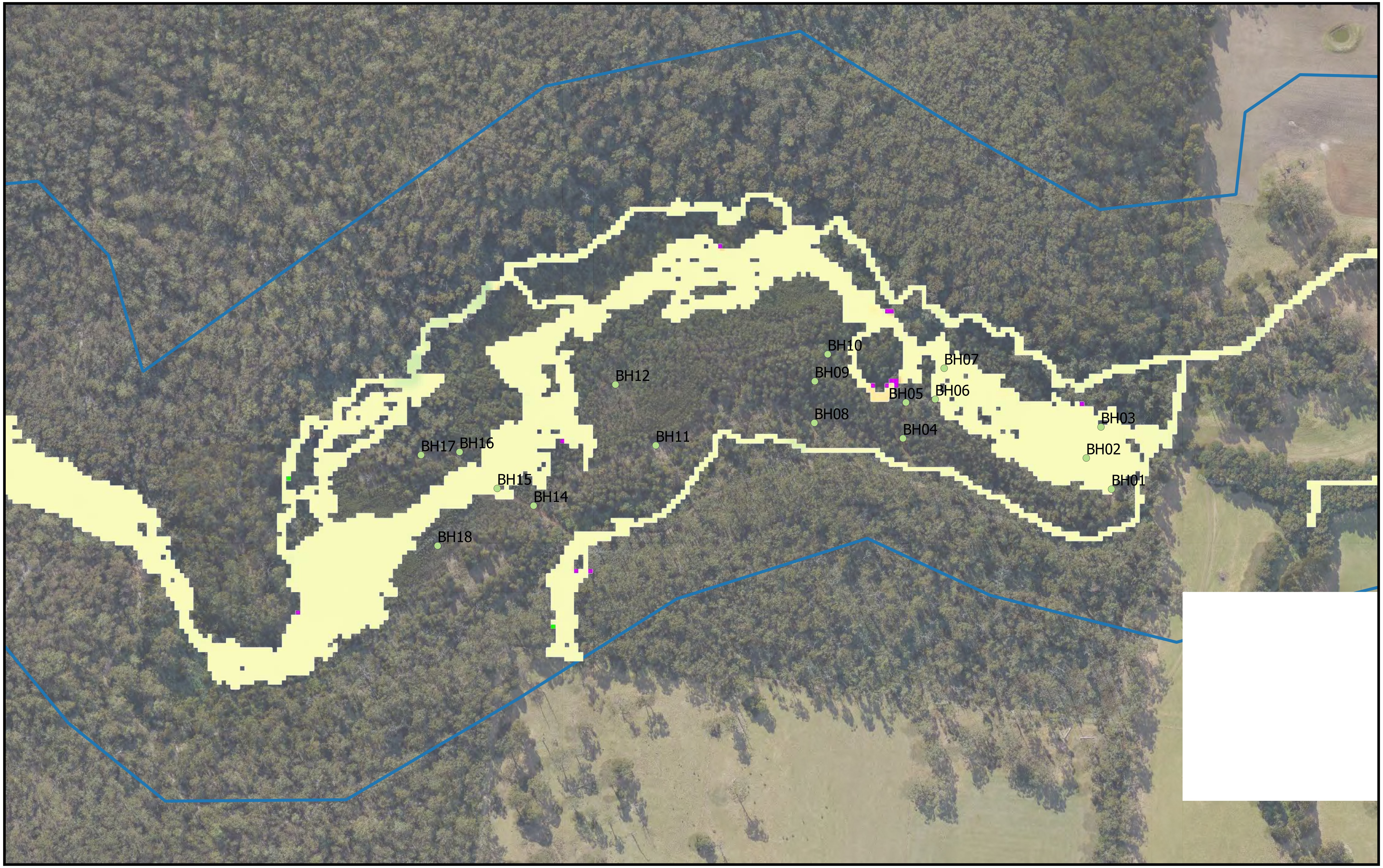
FIGURE SW-10

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - Double Precision
Wet period depth afflux (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

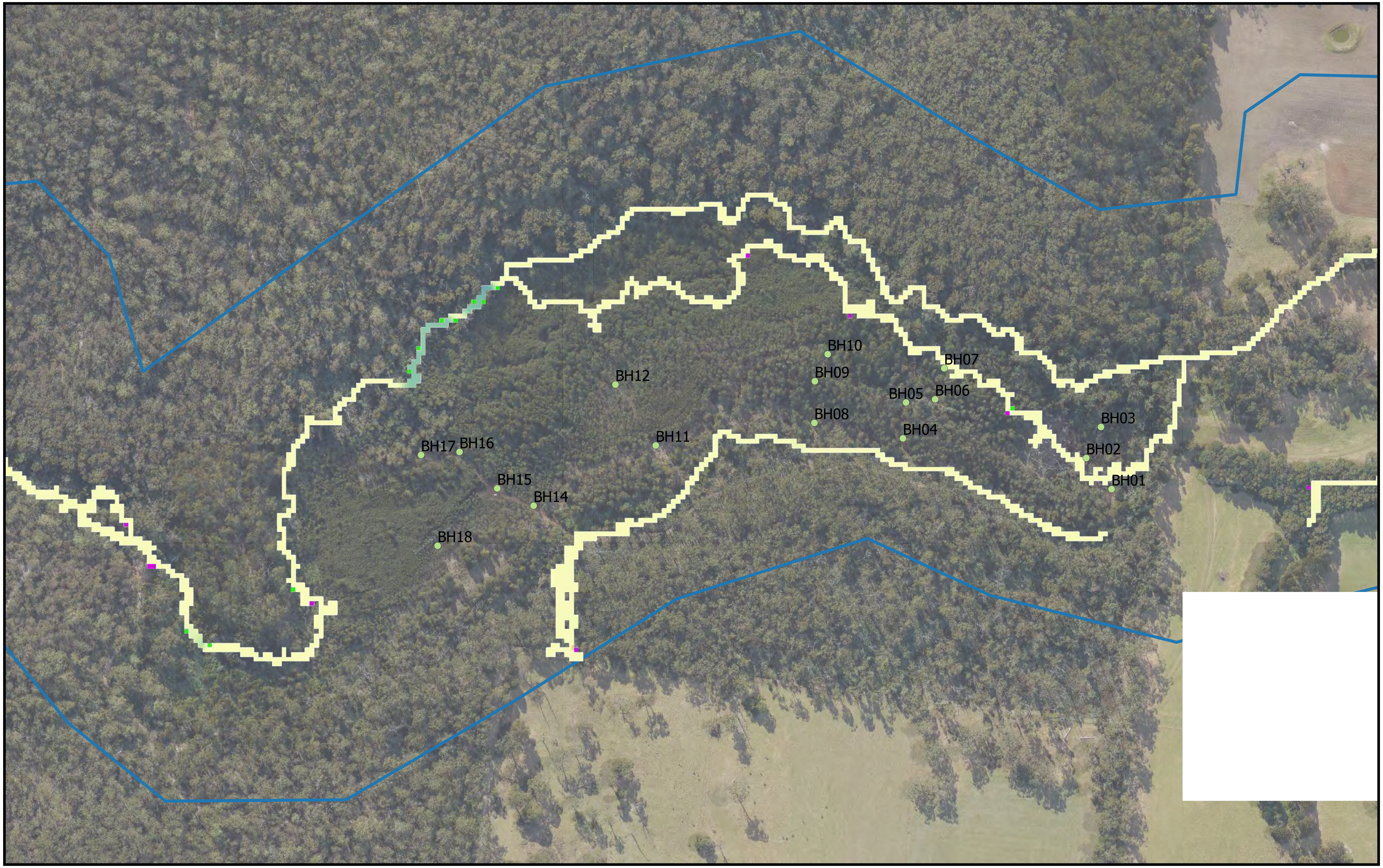
FIGURE SW-11

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)

-0.5	-0.02	0.3	Borehole Locations
-0.3	0	0.5	Barriers
-0.2	0.02	> 0.5	
-0.1	0.05	Was Wet Now Dry	
-0.05	0.1	Was Dry Now Wet	
	0.2	Tuflow Model Boundary	

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - Double Precision
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

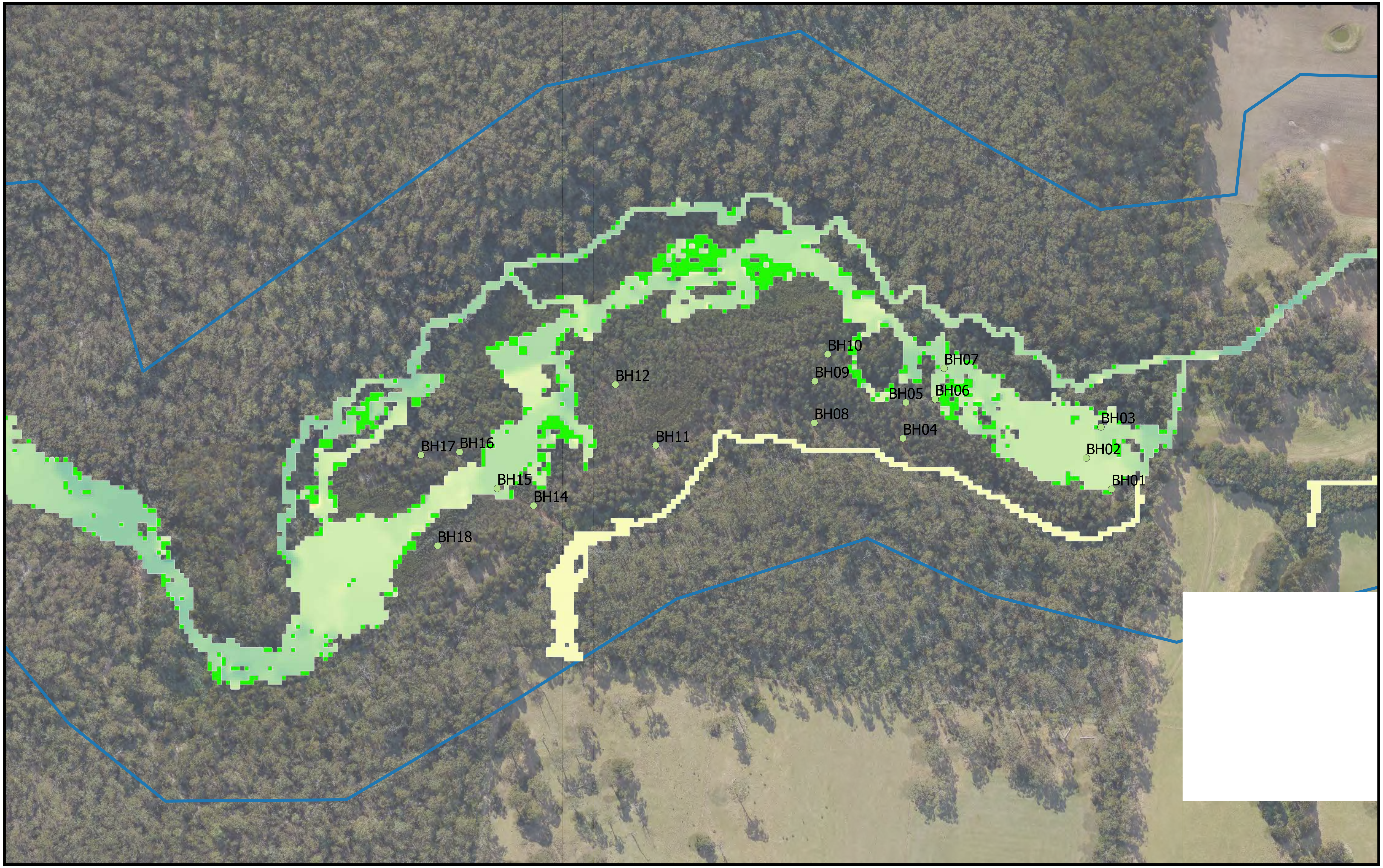
FIGURE SW-12

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - Inflow from GR4J
Wet period depth afflux (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

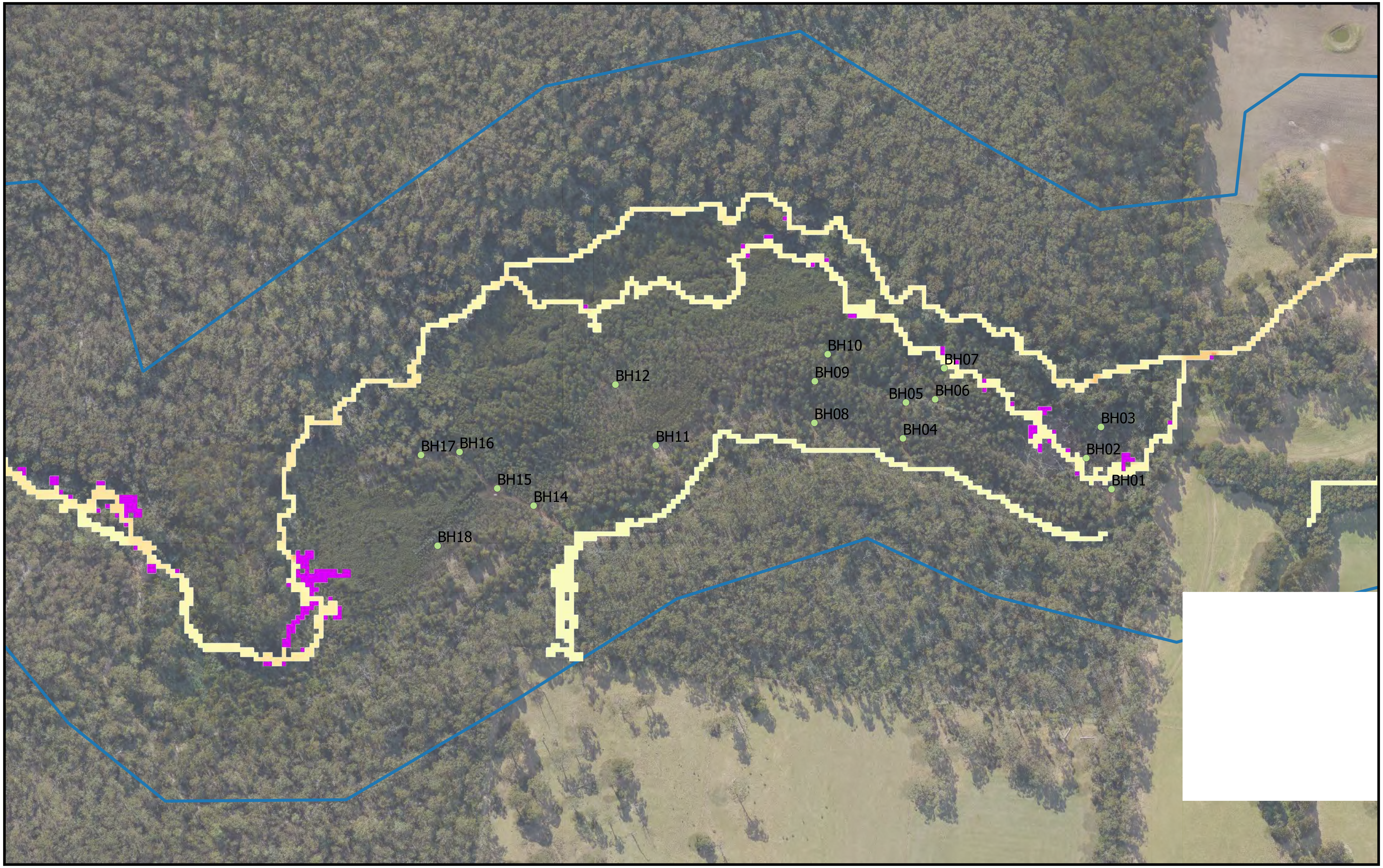
FIGURE SW-13

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - Inflow from GR4J
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

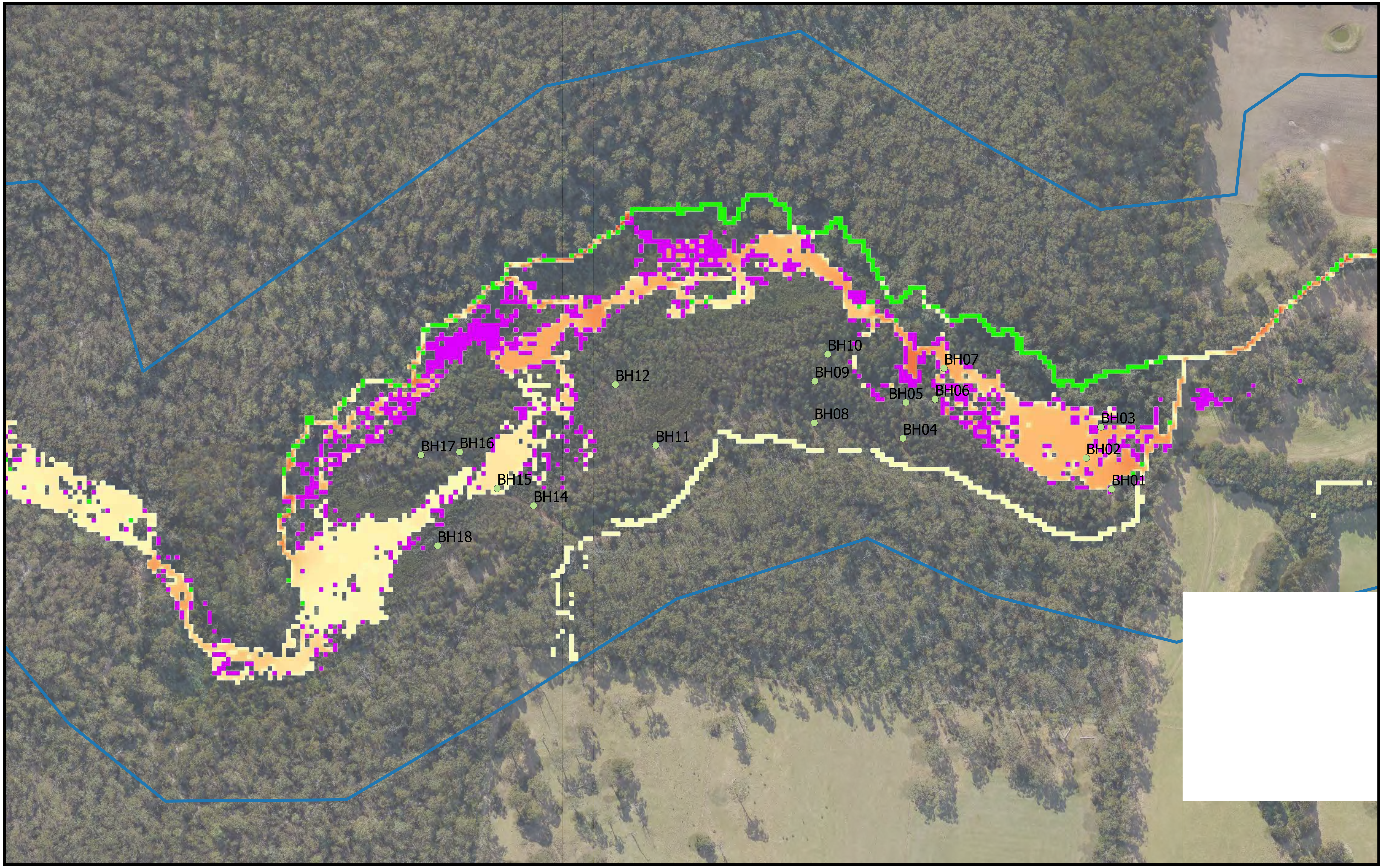
FIGURE SW-14

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)

- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - No stream gully shaping
Wet period depth afflux (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

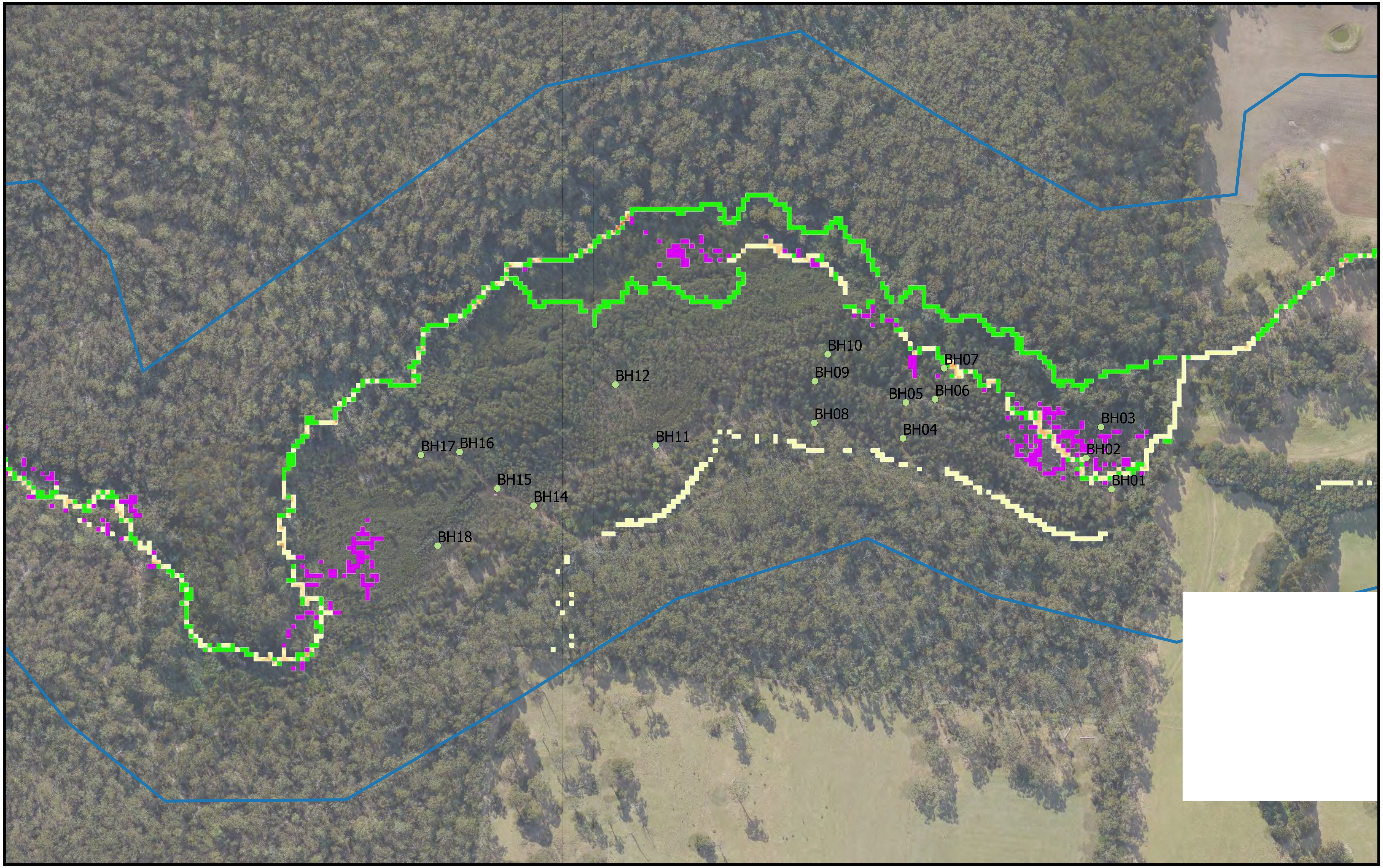
FIGURE SW-15

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)			
-0.5	-0.02	0.3	Borehole Locations
-0.3	0	0.5	Barriers
-0.2	0.02	> 0.5	
-0.1	0.05	Was Wet Now Dry	
-0.05	0.1	Was Dry Now Wet	
	0.2	Tuflow Model Boundary	

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - No stream gully shaping
Dry period depth afflux (March 2020)

Project No. 12536659
Revision No. A
Date. 24/12/2020

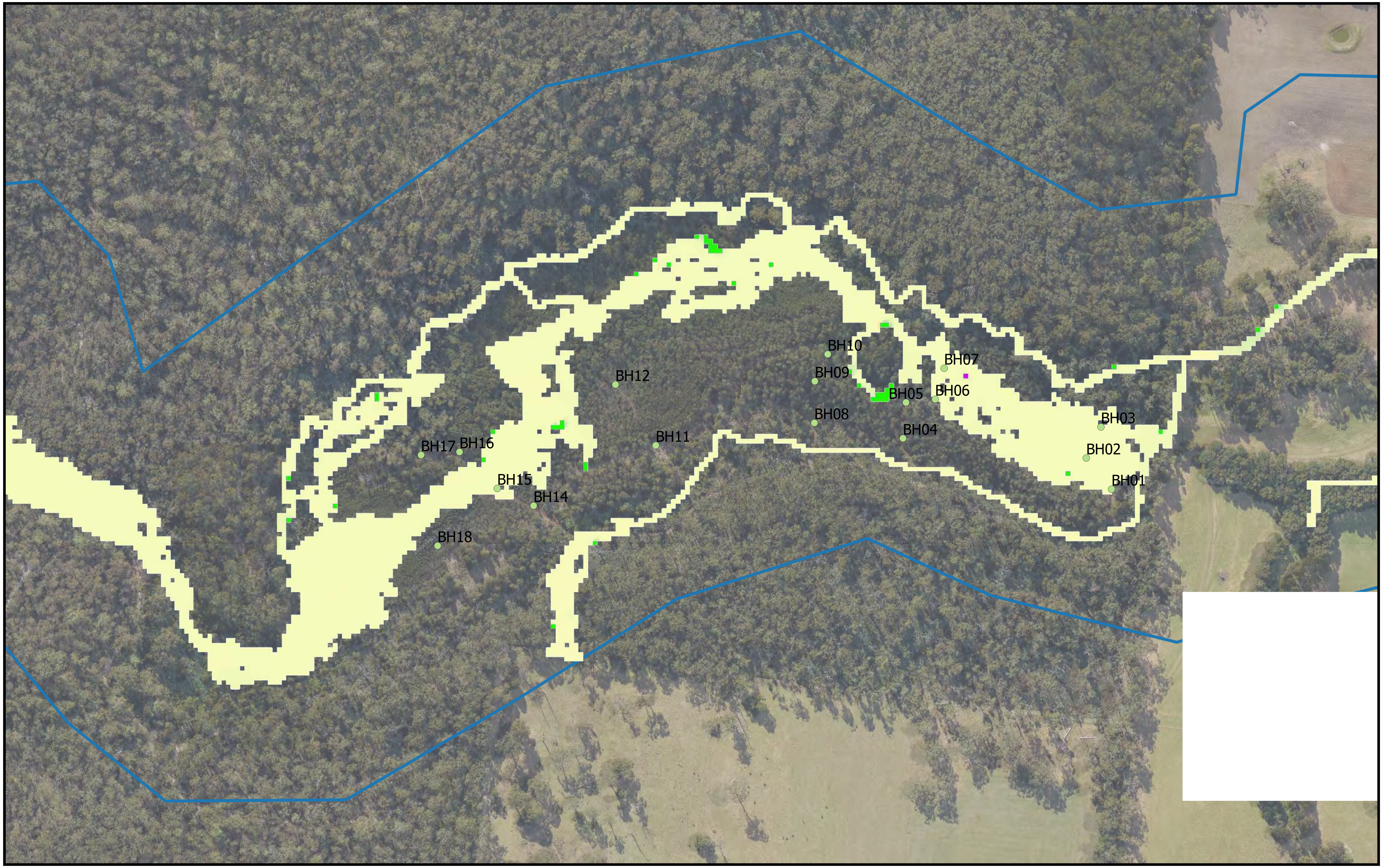
FIGURE SW-16

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)			
-0.5	-0.02	0.3	Borehole Locations
-0.3	0	0.5	Barriers
-0.2	0.02	> 0.5	
-0.1	0.05	Was Wet Now Dry	
-0.05	0.1	Was Dry Now Wet	
	0.2	Tuflow Model Boundary	

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - High infiltration
Wet period depth afflux (August 2019)

Project No. 12536659
Revision No. A
Date. 24/12/2020

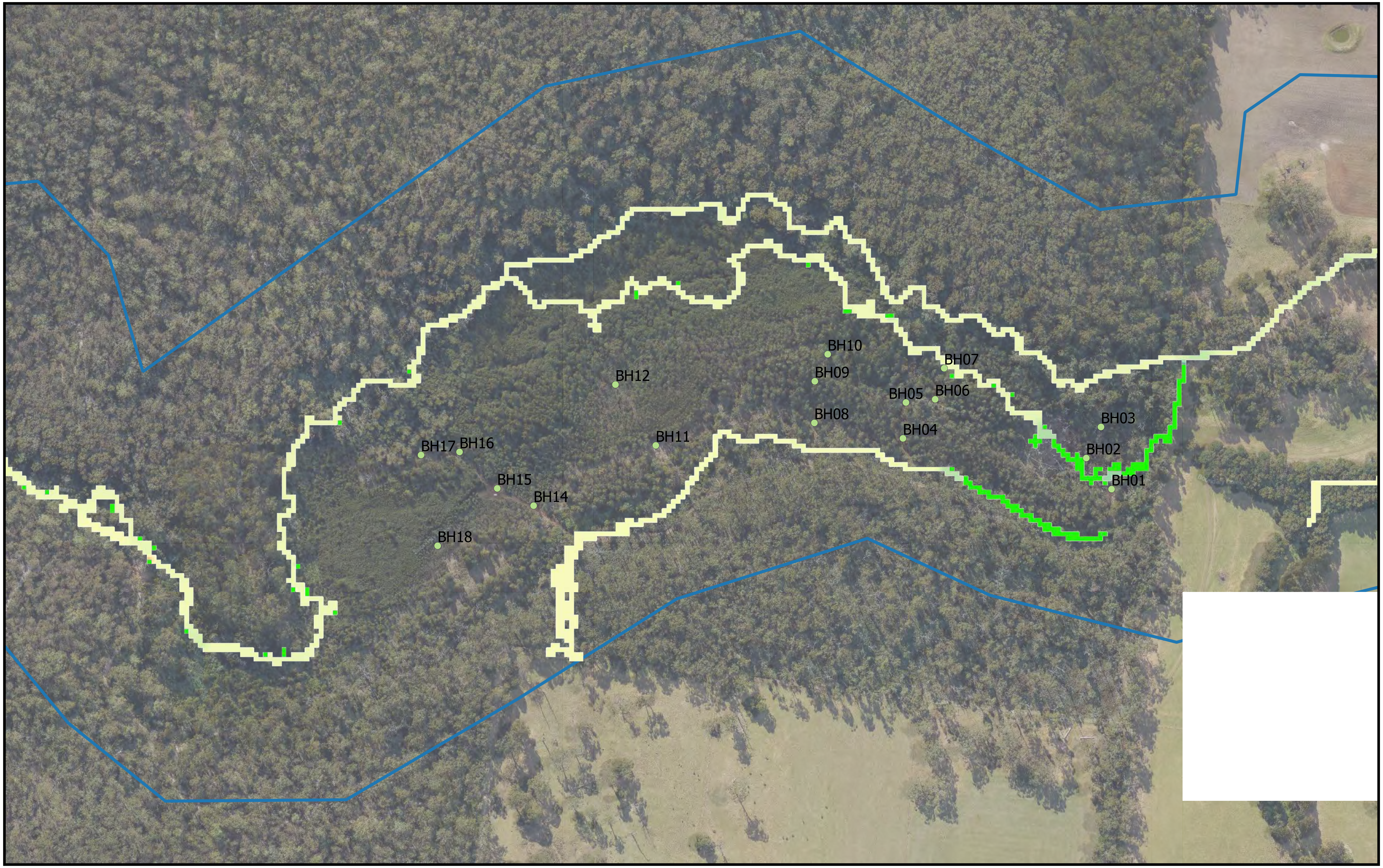
FIGURE SW-17

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)					
-0.5	-0.02	0.3	Borehole Locations
-0.3	0	0.5	Barriers
-0.2	0.02	> 0.5	
-0.1	0.05	Was Wet Now Dry	
-0.05	0.1	Was Dry Now Wet	
	0.2	Tuflow Model Boundary	

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Barwon Water
Big Swamp Modelling for Detailed Design

Sensitivity run - High infiltration
Dry period depth afflux (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

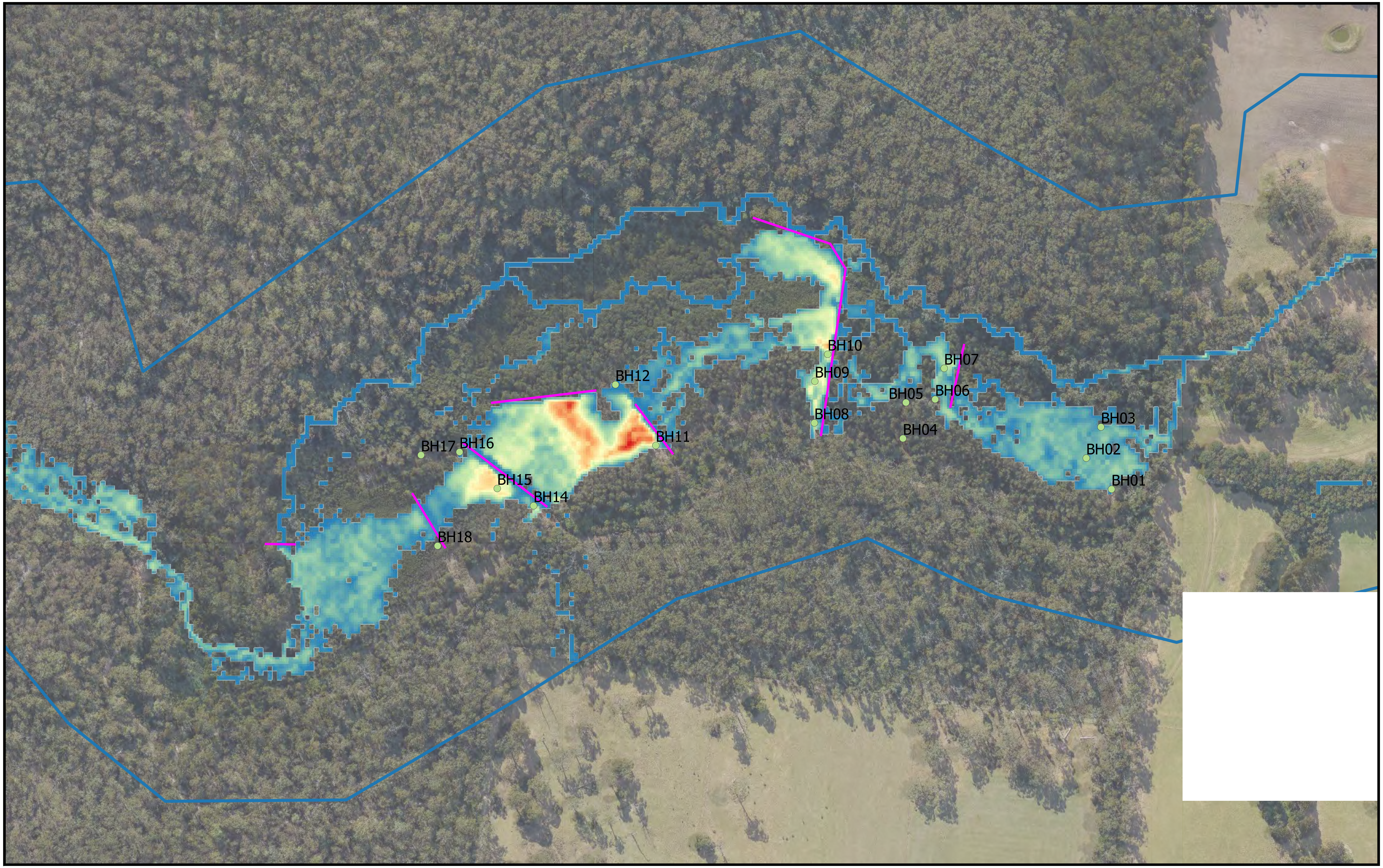
FIGURE SW-18

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- Tufow model boundary
- Borehole locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 3 version 2 results
Wet period water depths (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

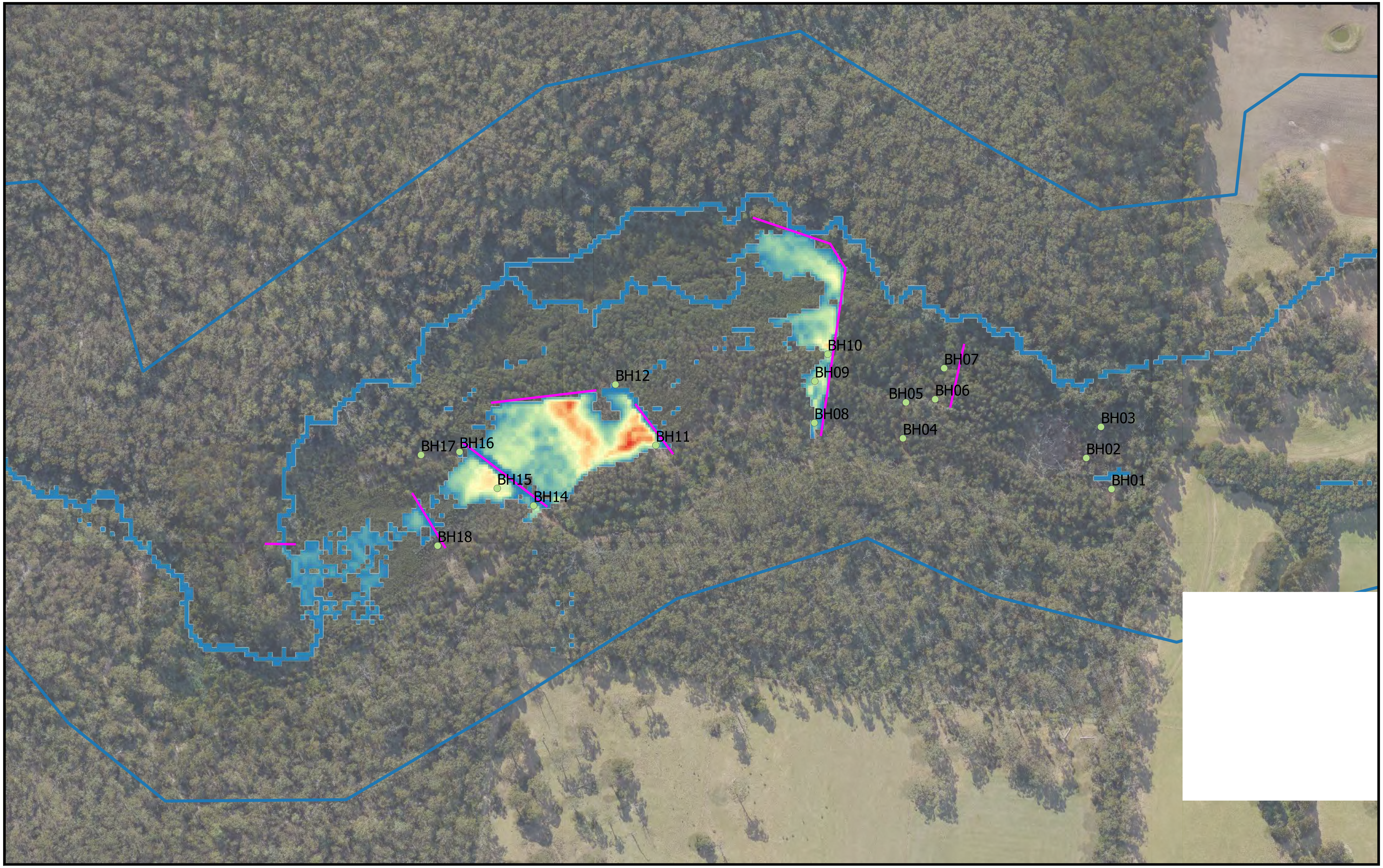
FIGURE SW-19

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)
- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- Tufow model boundary
- Borehole locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 3 version 2 results
Dry period water depths (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

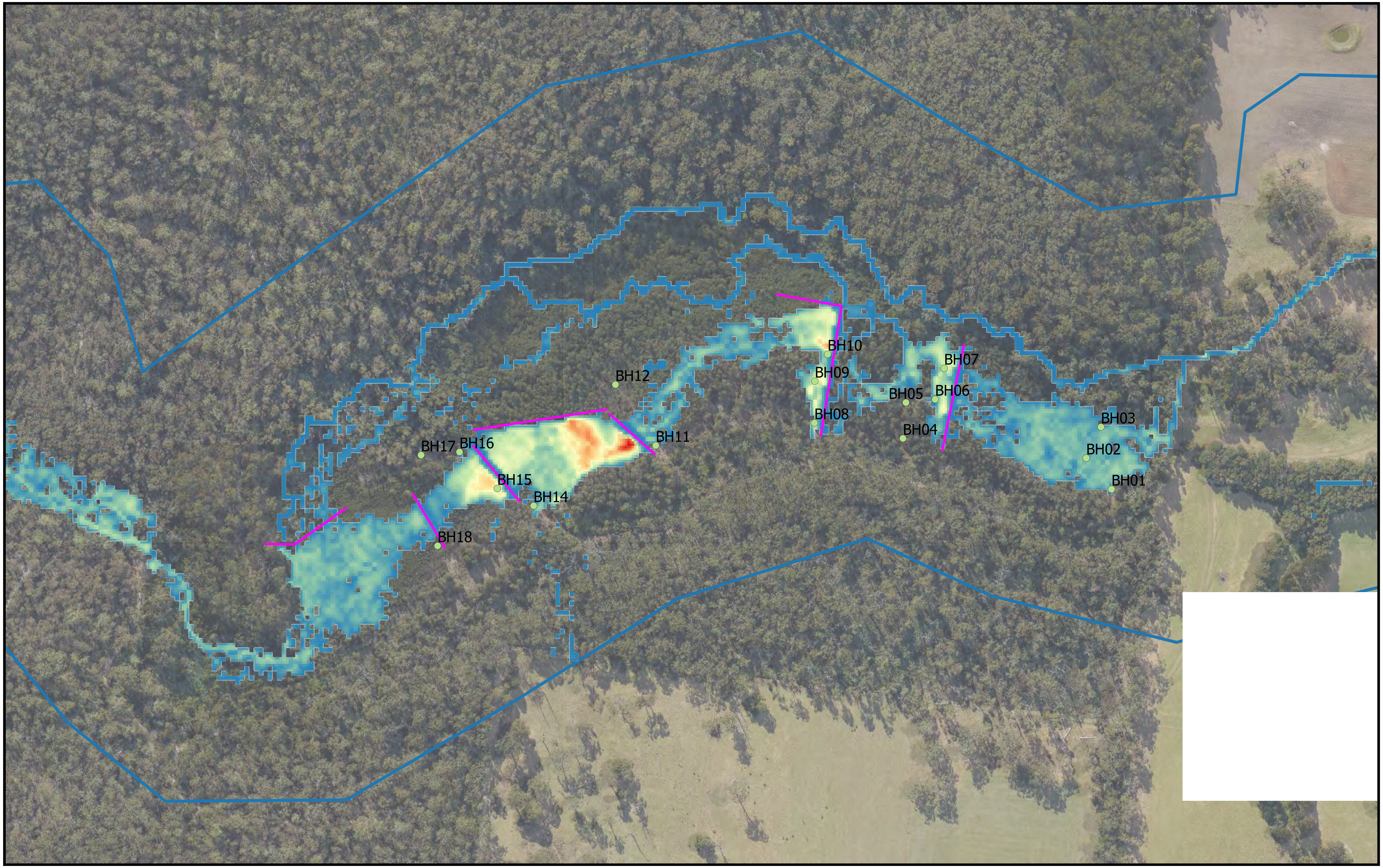
FIGURE SW-20

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- Tufow model boundary
- Borehole locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 5 results
Wet period water depths (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

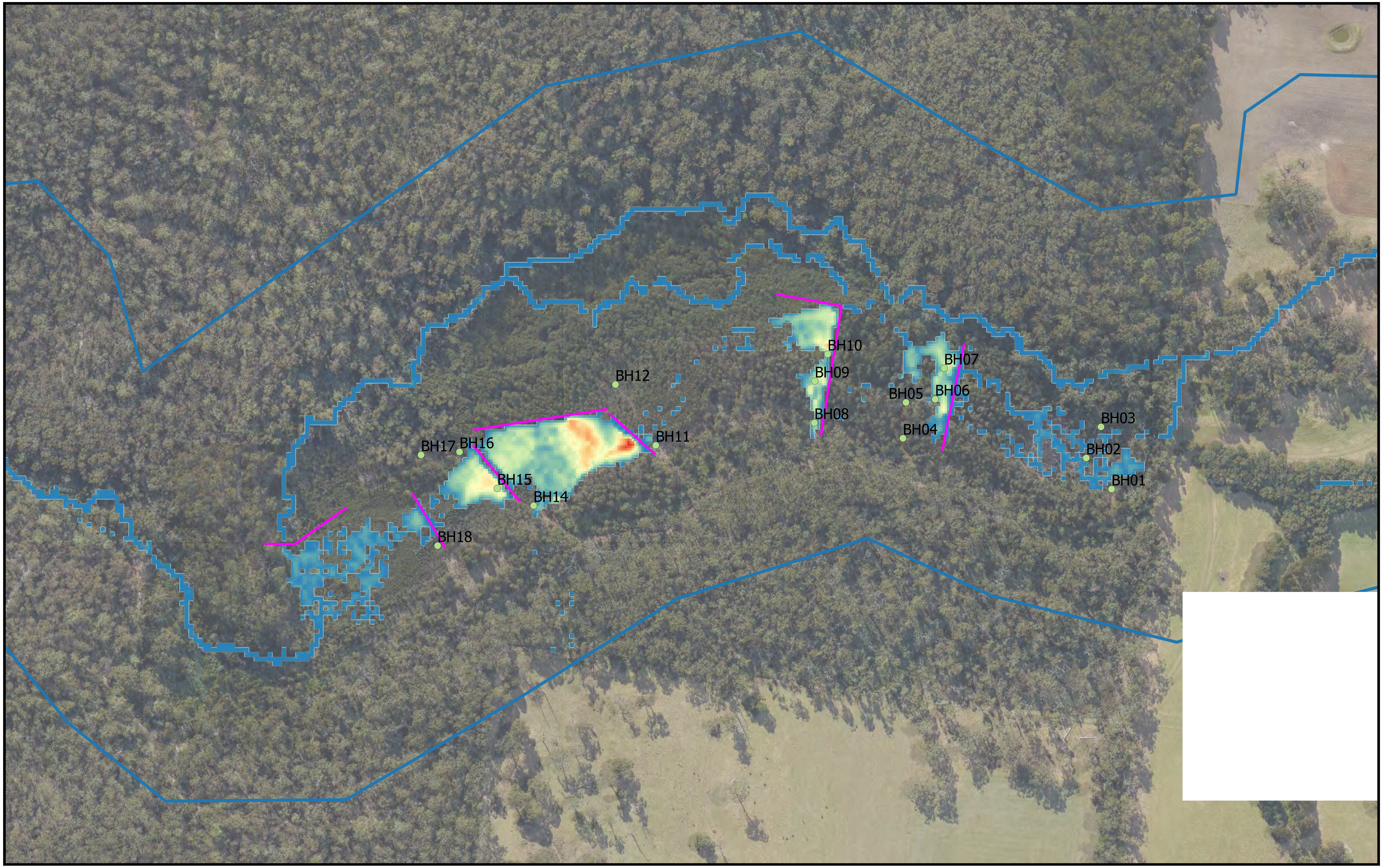
FIGURE SW-21

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- Tufow model boundary
- Borehole locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 5 results
Dry period water depths (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

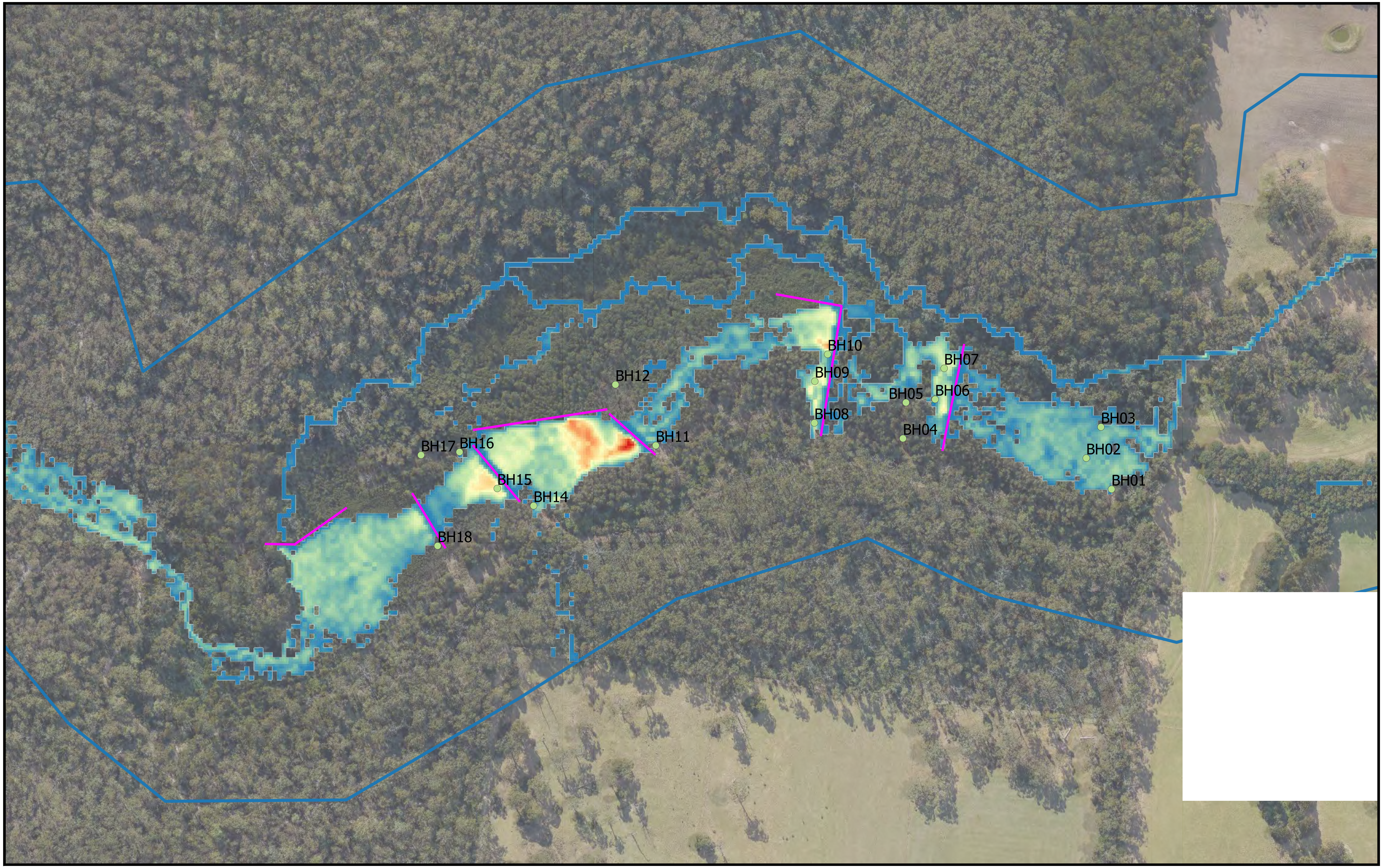
FIGURE SW-22

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2

Tufow model boundary

Borehole locations

Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 8 results
Wet period water depths (August 2019)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

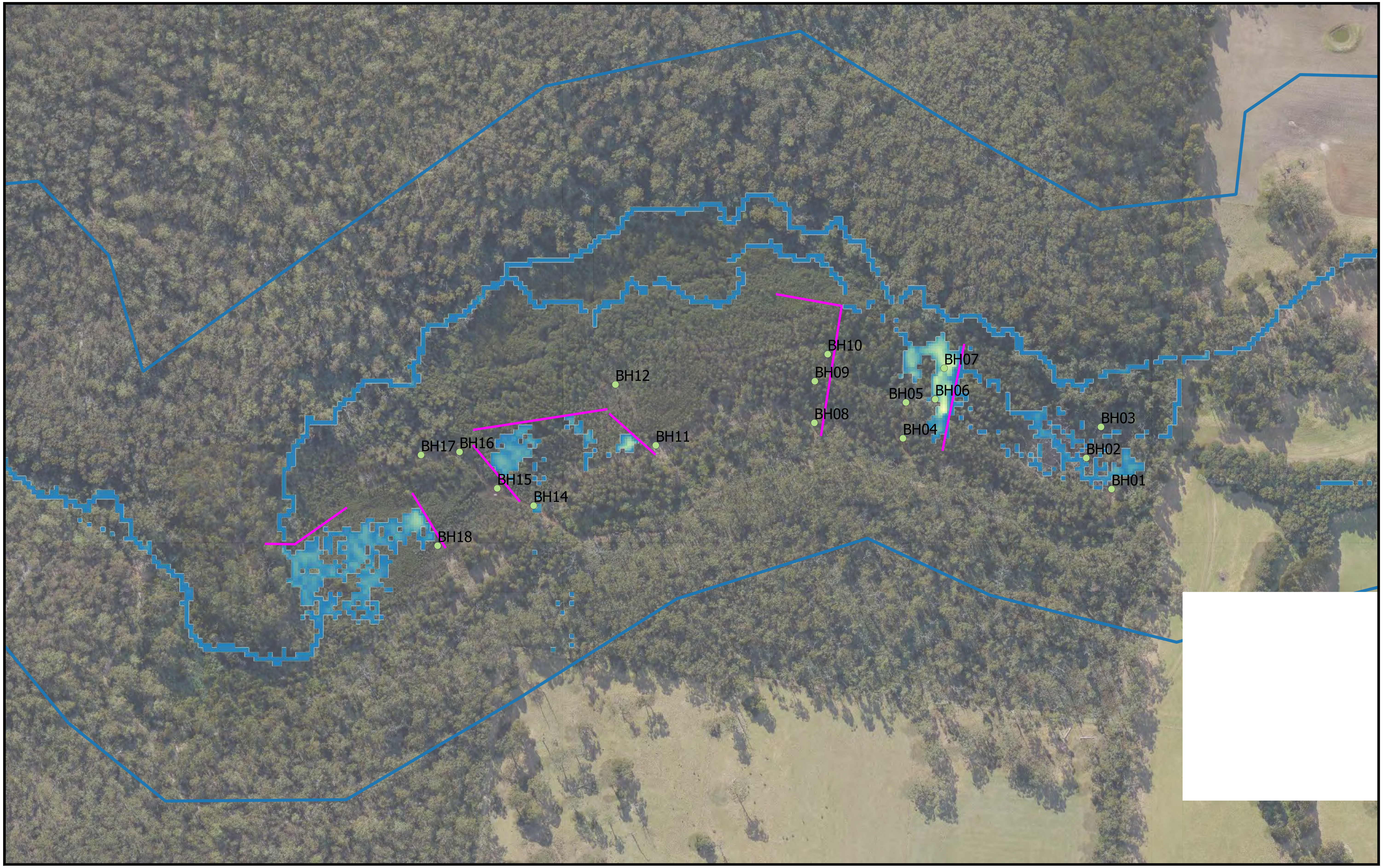
FIGURE SW-23

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Water Depth (m)
- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2

- Borehole locations
- Barriers
- Tufow model boundary

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design

Barrier group 8 results
Dry period water depths (March 2020)

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

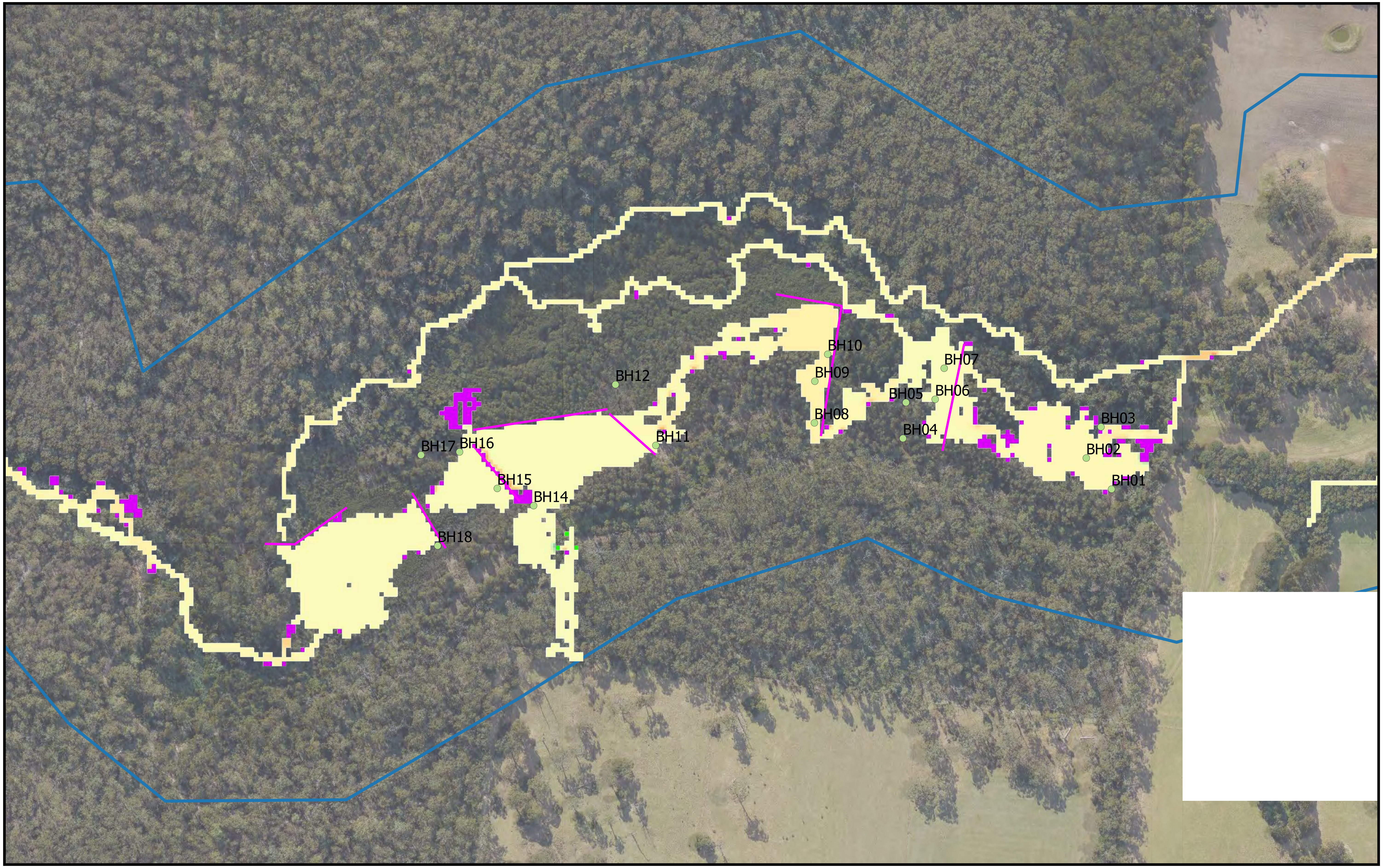
FIGURE SW-24

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)
- -0.5
- -0.3
- -0.2
- -0.1
- -0.05
- -0.02
- 0
- 0.02
- 0.05
- 0.1
- 0.2
- 0.3
- 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet
- Tuflow Model Boundary
- Borehole Locations
- Barriers

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water

Big Swamp Modelling for Detailed Design

Proposed barriers with 3ML/day supplimentary flow

Dry period depth afflux compared to 2ML/day

Project No. **12536659**
Revision No. **A**
Date. **24/12/2020**

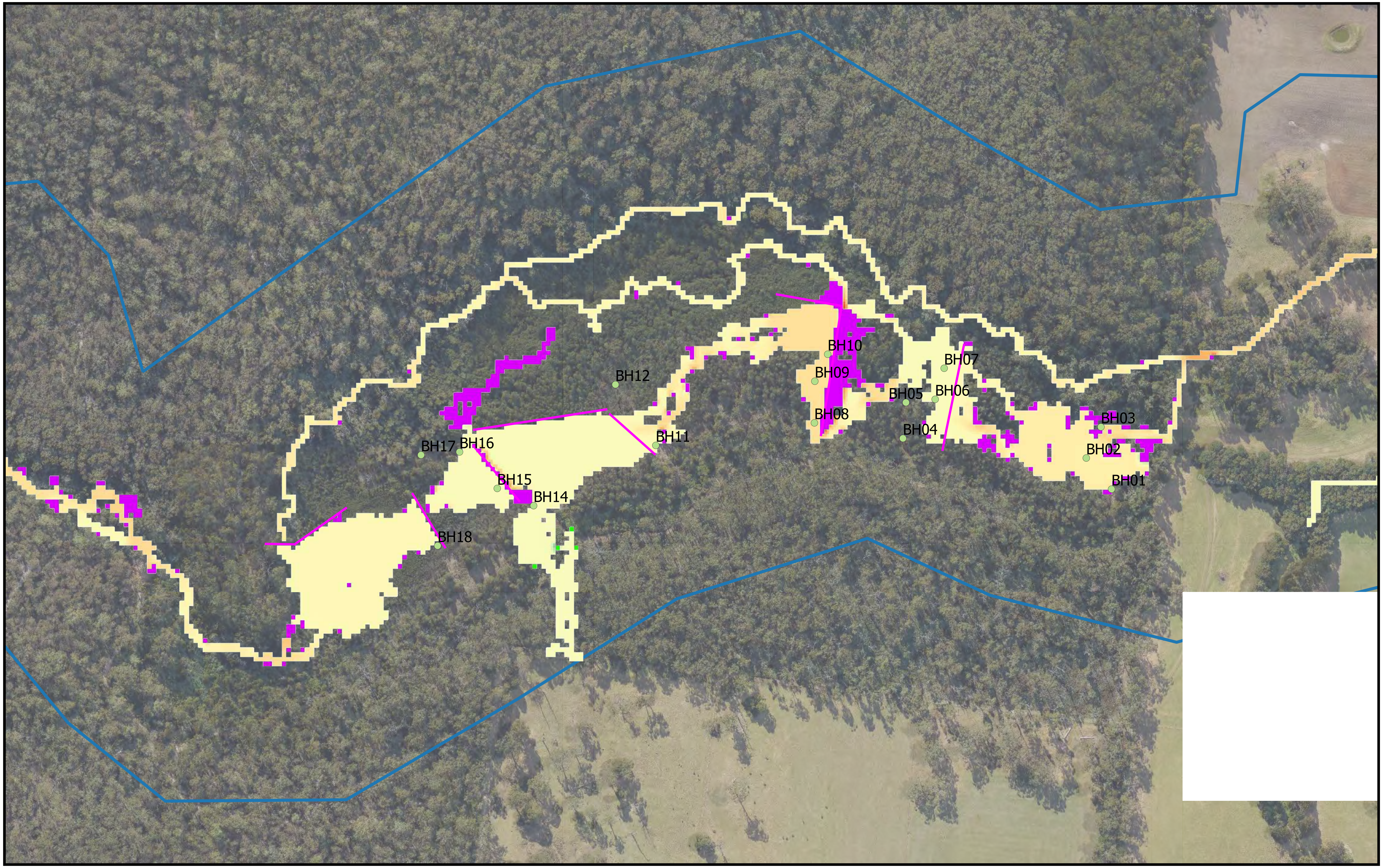
FIGURE SW-25

Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

Print Date:

Created By: Ellie Denson



Legend

Depth afflux (m)			
-0.5	-0.02	0.3	Borehole Locations
-0.3	0	0.5	Barriers
-0.2	0.02	> 0.5	
-0.1	0.05	Was Wet Now Dry	
-0.05	0.1	Was Dry Now Wet	
	0.2	Tuflow Model Boundary	

Paper Size ISO A3

0 50 100 m

Map Projection: Mercator Grid
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Barwon Water
Big Swamp Modelling for Detailed Design
Proposed barriers with 4ML/day supplimentary flow
Dry period depth afflux compared to 2ML/day

Project No. 12536659
Revision No. A
Date. 24/12/2020

FIGURE SW-26

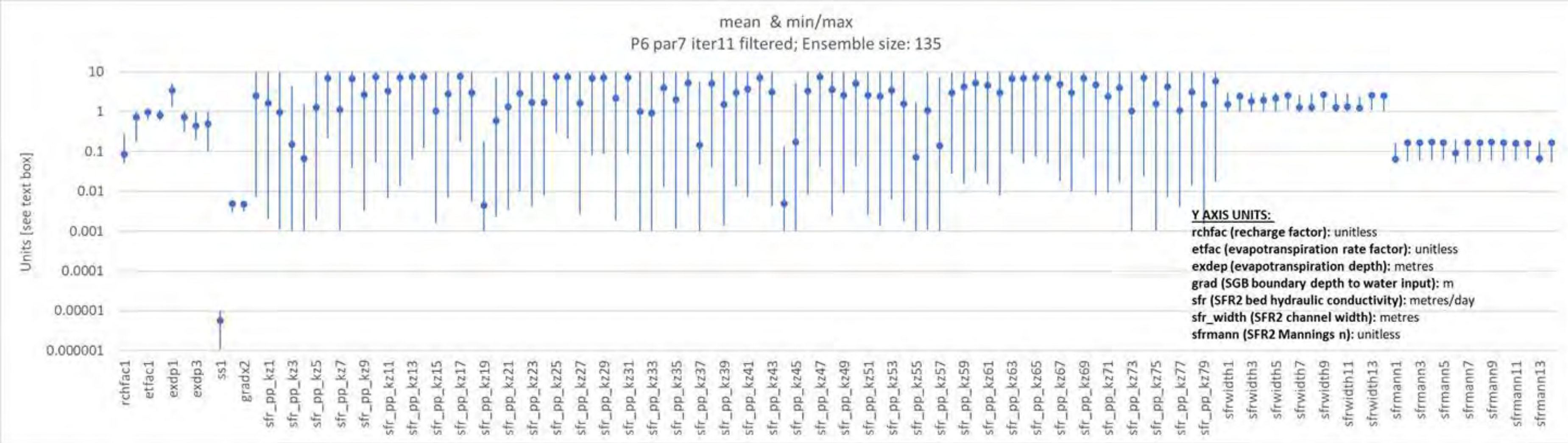
Document Path: \\ghdnet\ghd\AU\Melbourne\Projects\31\12536659\Tech\06_TUFLOW\TUFLOW\GIS workspaces\results_sensitivity.qgz

Data Source: Barwon Water, Imagery, 2019; Jacobs, Bore Locations, 2019; GHD, bore details, 2020;

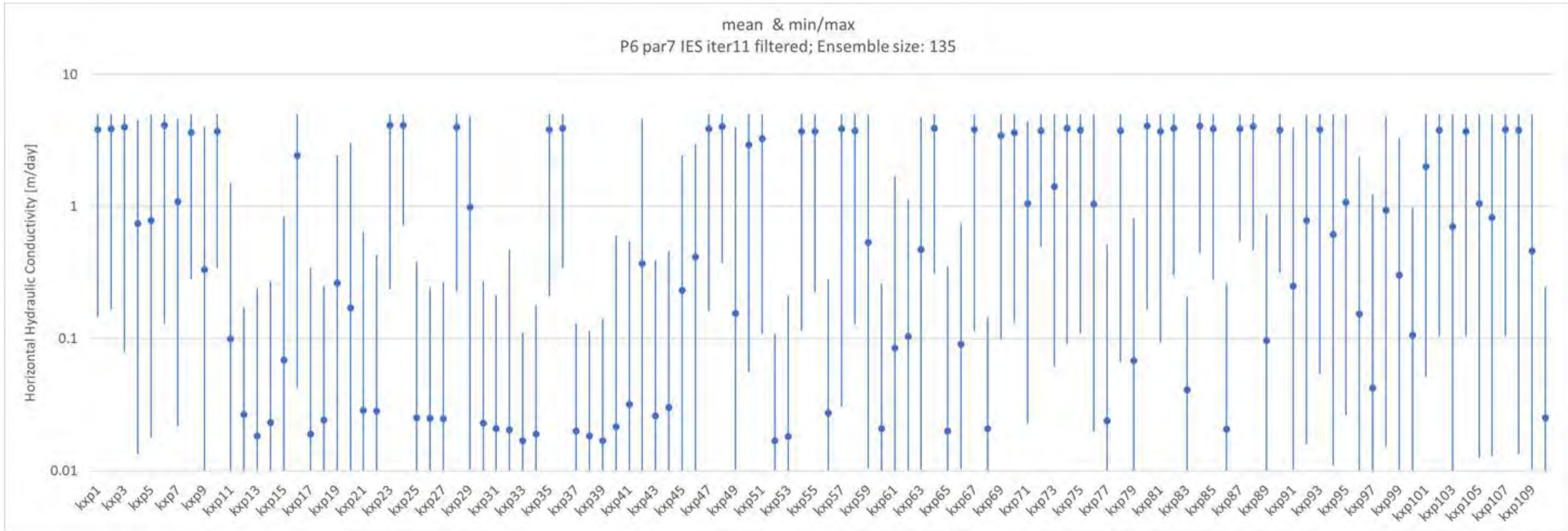
Print Date:

Created By: Ellie Denson

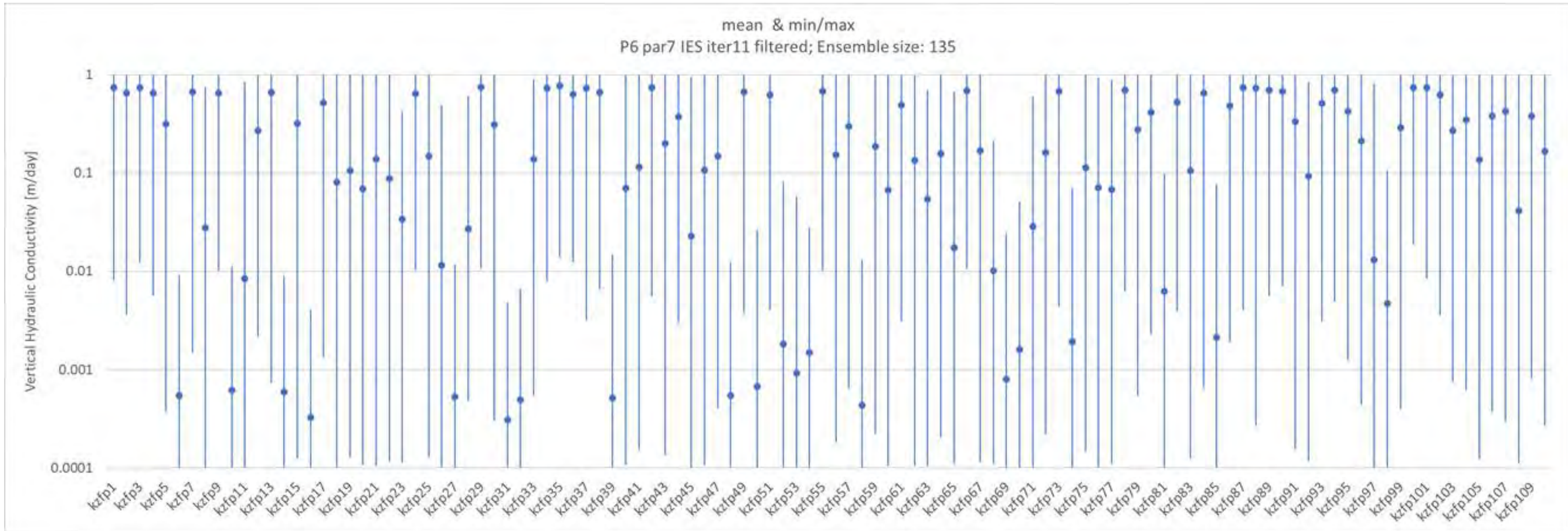
Appendix B – Stochastic history-matched parameter ranges

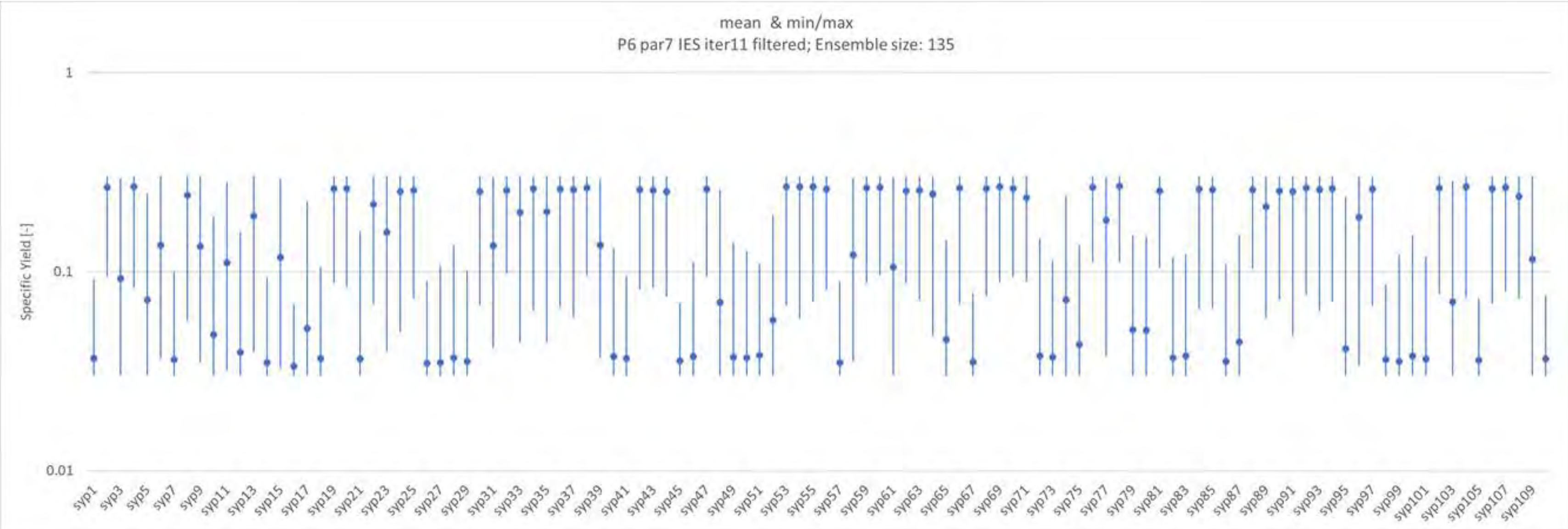


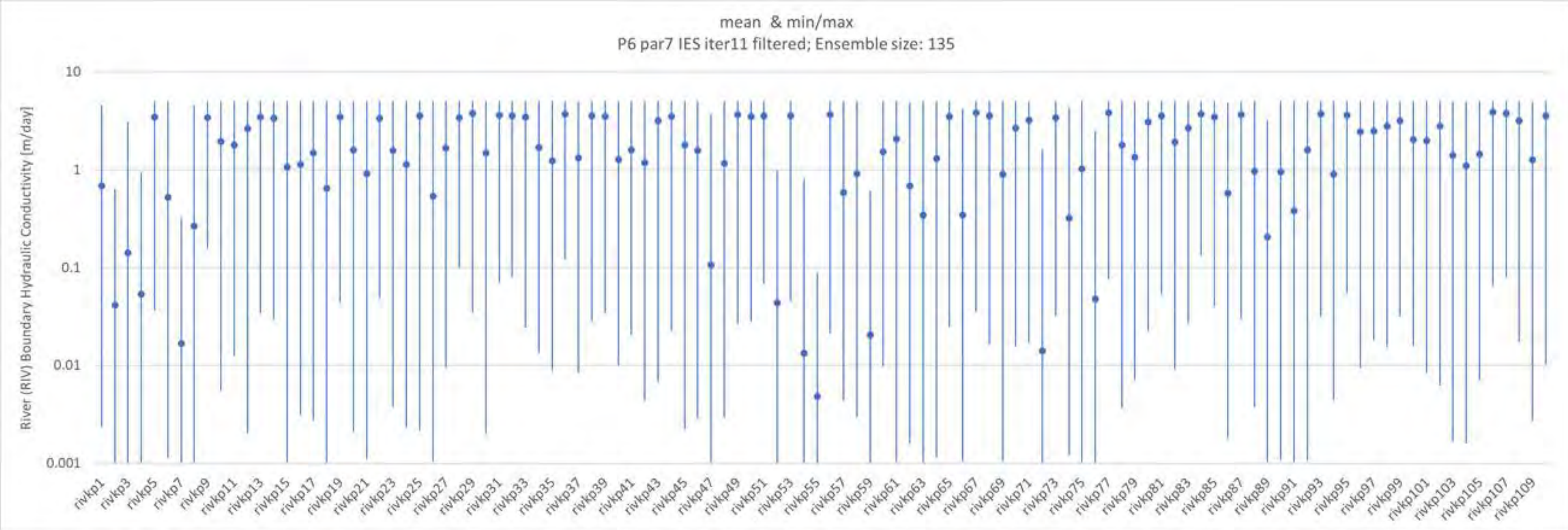
mean & min/max
P6 par7 iter11 filtered; Ensemble size: 135
Units [see text box]
Y AXIS UNITS:
rchfac (recharge factor): unitless
etfac (evapotranspiration rate factor): unitless
exdep (evapotranspiration depth): metres
grad (SGB boundary depth to water input): m
sfr (SFR2 bed hydraulic conductivity): metres/day
sfr_width (SFR2 channel width): metres
sfrmann (SFR2 Mannings n): unitless

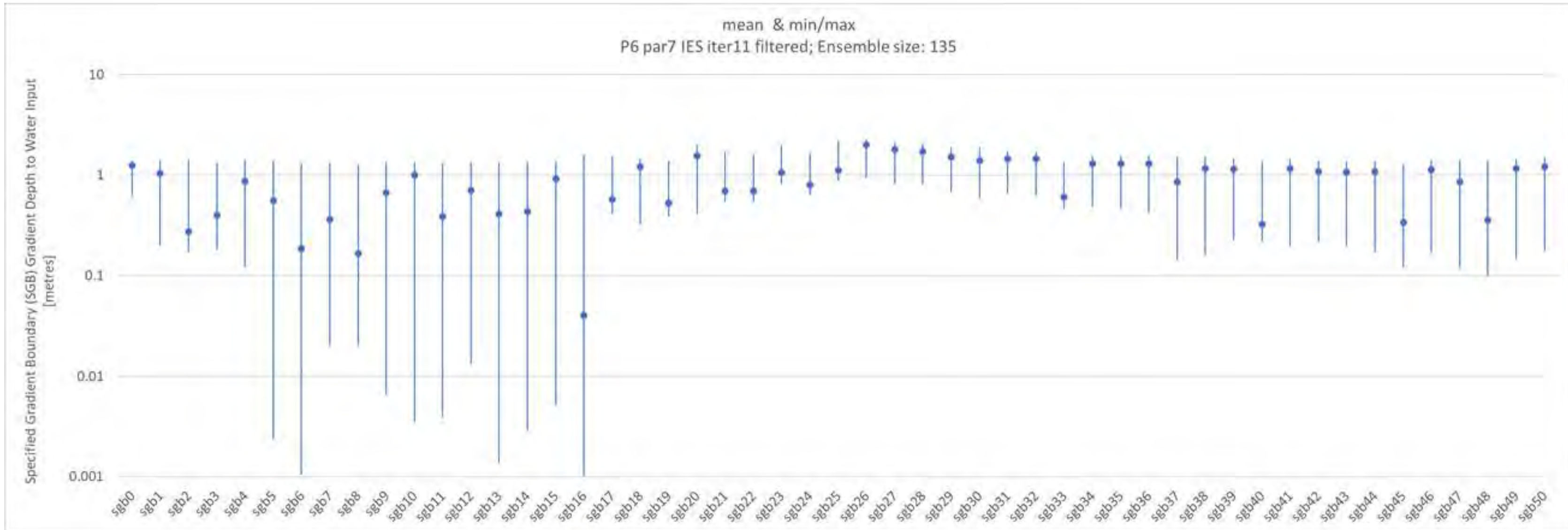


mean & min/max
P6 par7 IES iter11 filtered; Ensemble size: 135
Horizontal Hydraulic Conductivity [m/day]

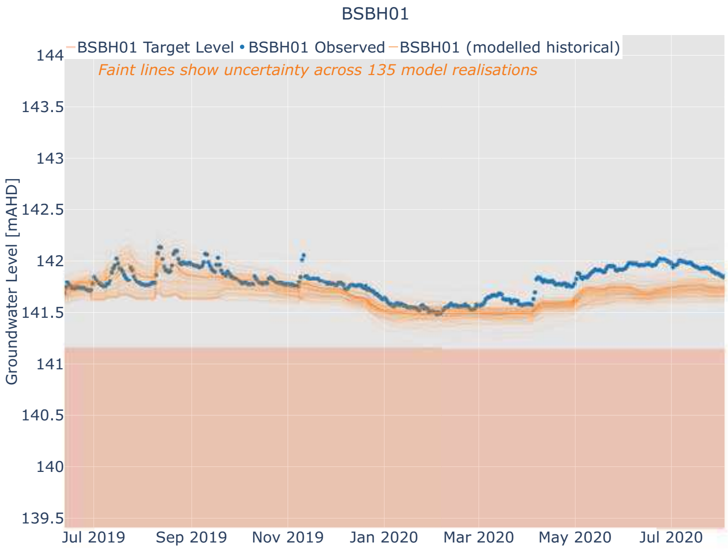

mean & min/max
P6 par7 IES iter11 filtered; Ensemble size: 135
Vertical Hydraulic Conductivity [m/day]
1
0.1
0.01
0.001
0.0001
kzfp1
kzfp109

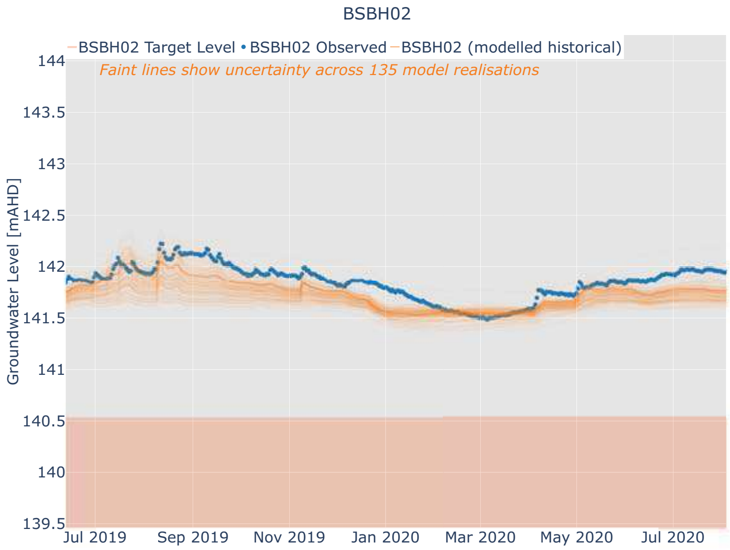

mean & min/max
P6 par7 IES iter11 filtered; Ensemble size: 135
Specific Yield [-]
1
0.1
0.01
syp1
syp109

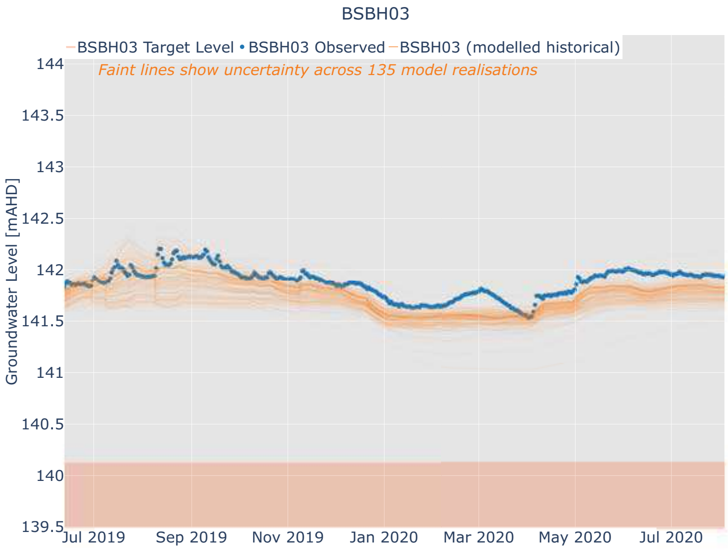

mean & min/max
P6 par7 IES iter11 filtered; Ensemble size: 135
River (RIV) Boundary Hydraulic Conductivity [m/day]
10
1
0.1
0.01
0.001

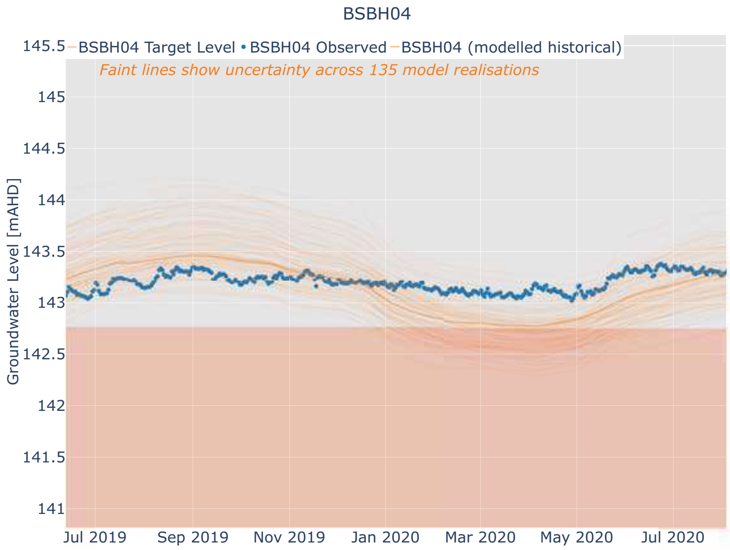

mean & min/max
P6 par7 IES iter11 filtered; Ensemble size: 135
Specified Gradient Boundary (SGB) Gradient Depth to Water Input [metres]
10
1
0.1
0.01
0.001

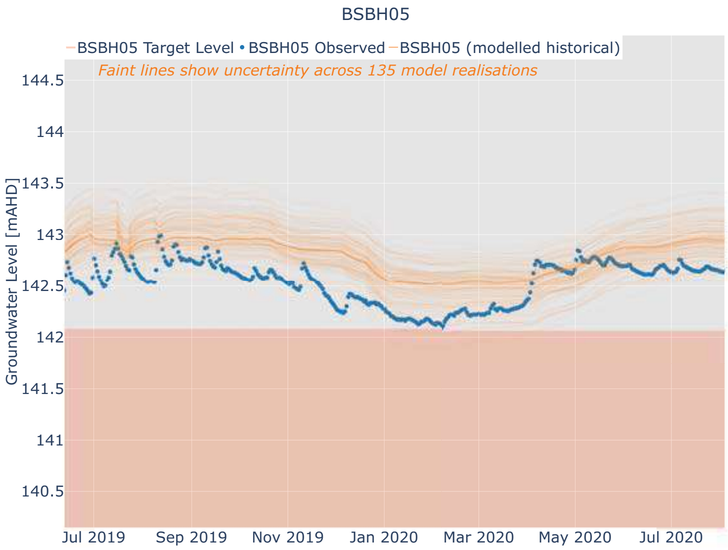
Appendix C – Stochastic history matching – groundwater level hydrographs

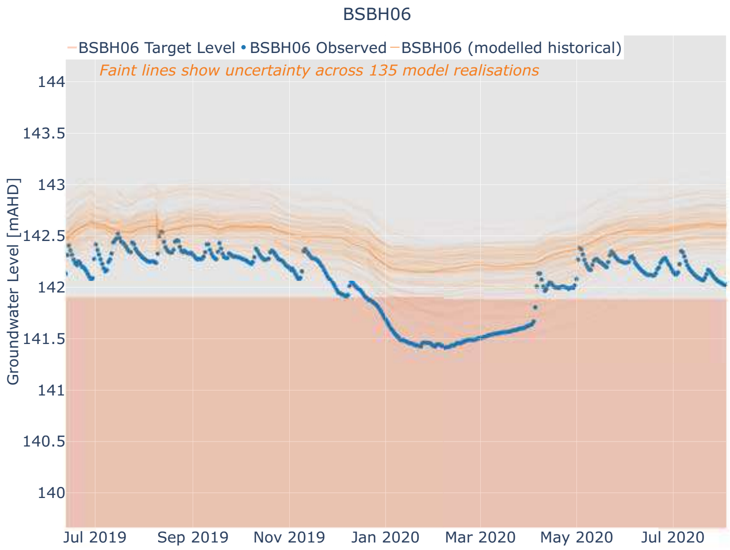

BSBH01
BSBH01 Target Level
BSBH01 Observed
BSBH01 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020

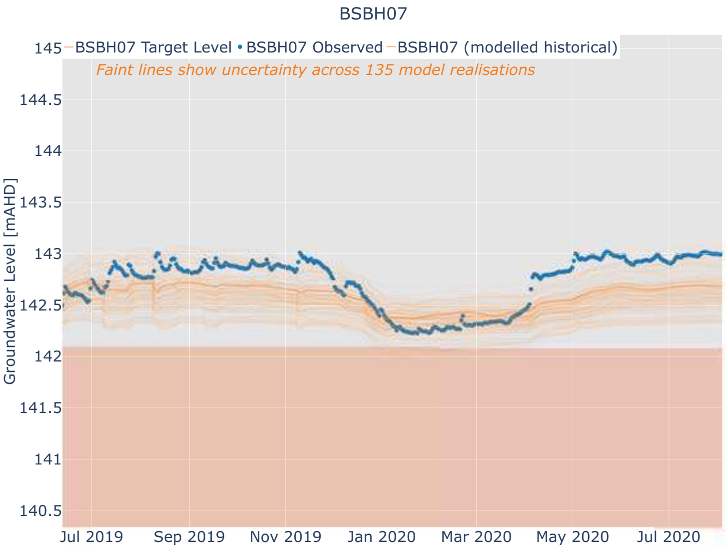

BSBH02
BSBH02 Target Level
BSBH02 Observed
BSBH02 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020

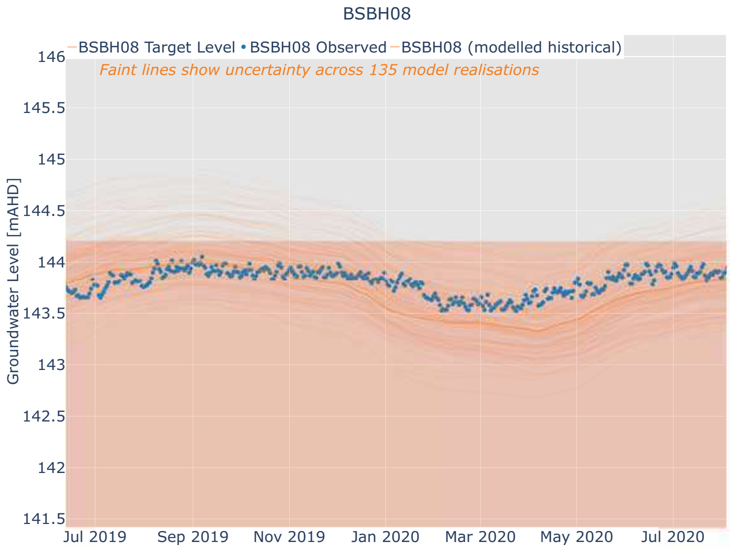

BSBH03
BSBH03 Target Level
BSBH03 Observed
BSBH03 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
144
143.5
143
142.5
142
141.5
141
140.5
140
139.5
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020

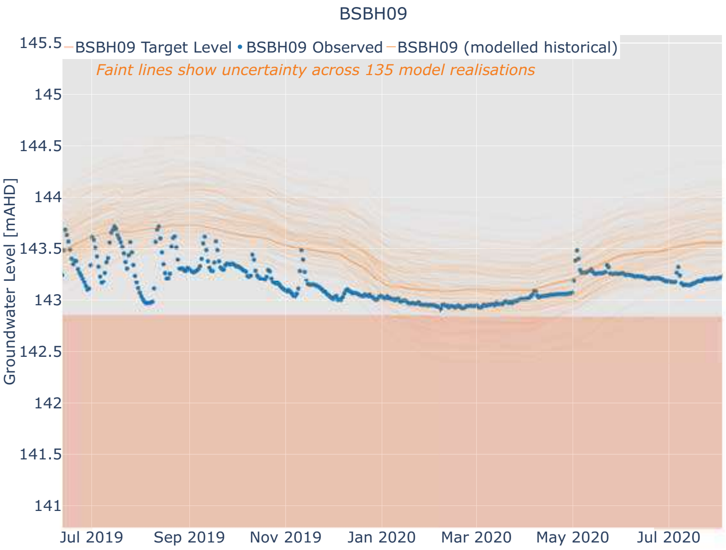

BSBH04
BSBH04 Target Level
BSBH04 Observed
BSBH04 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
145.5
145
144.5
144
143.5
143
142.5
142
141.5
141
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020

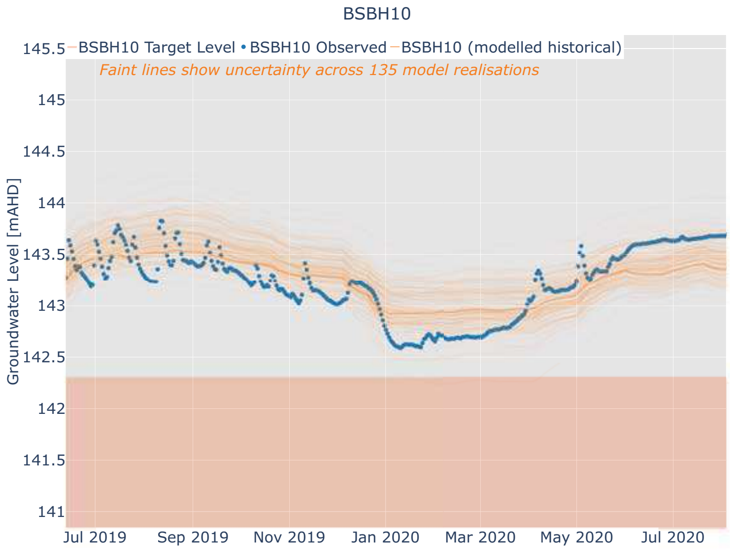

BSBH05
BSBH05 Target Level
BSBH05 Observed
BSBH05 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
144.5
144
143.5
143
142.5
142
141.5
141
140.5
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020

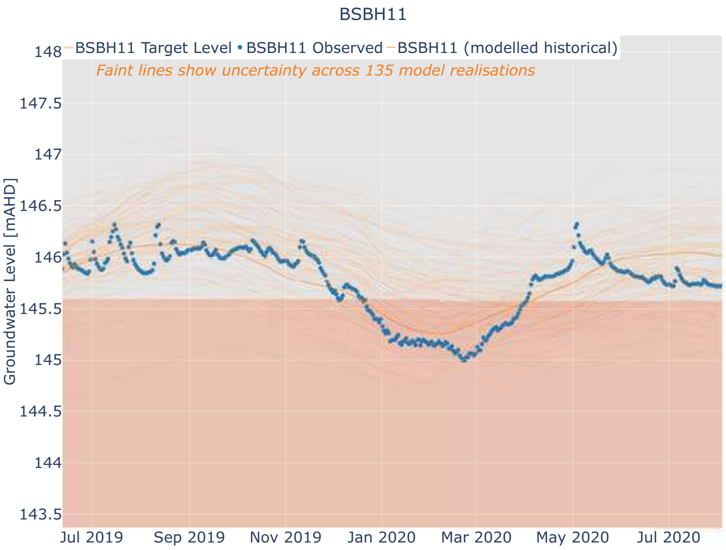

BSBH06
BSBH06 Target Level
BSBH06 Observed
BSBH06 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
144
143.5
143
142.5
142
141.5
141
140.5
140
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020


BSBH07
BSBH07 Target Level
BSBH07 Observed
BSBH07 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020


BSBH08
BSBH08 Target Level
BSBH08 Observed
BSBH08 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020


BSBH09
BSBH09 Target Level
BSBH09 Observed
BSBH09 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020


BSBH10
BSBH10 Target Level
BSBH10 Observed
BSBH10 (modelled historical)
Faint lines show uncertainty across 135 model realisations
Groundwater Level [mAHD]
Jul 2019
Sep 2019
Nov 2019
Jan 2020
Mar 2020
May 2020
Jul 2020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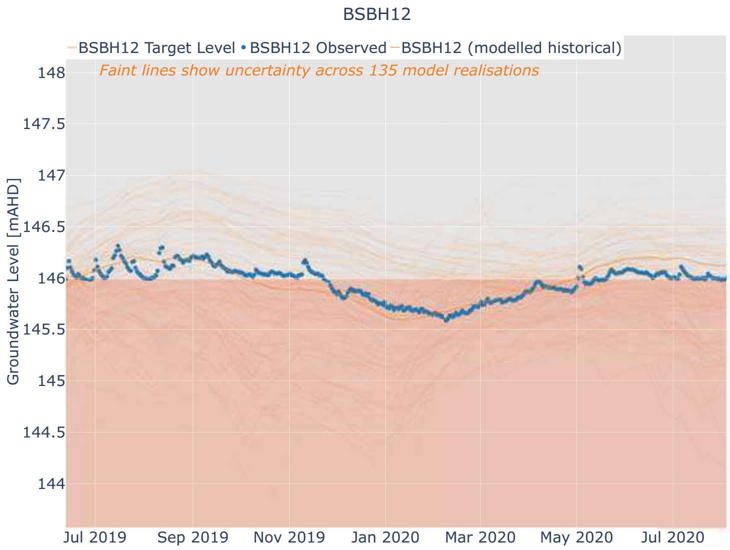
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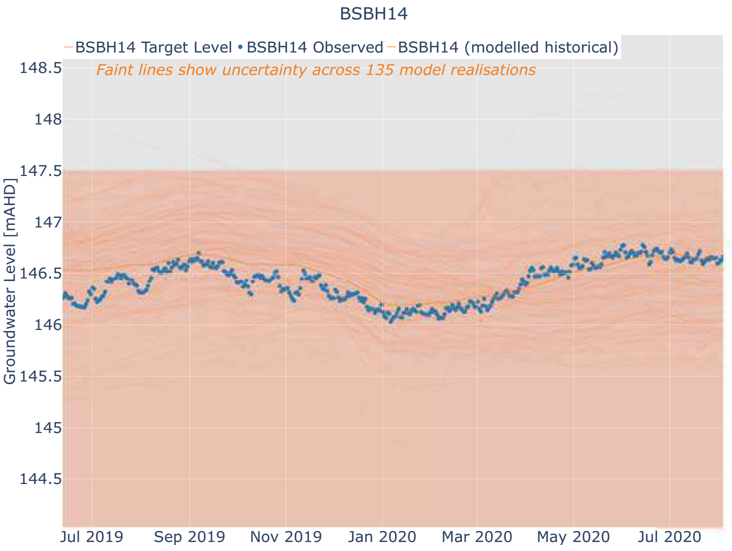
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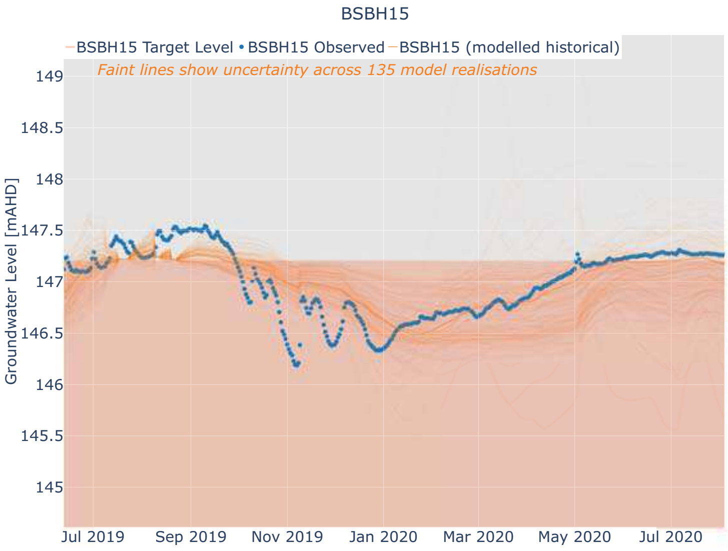
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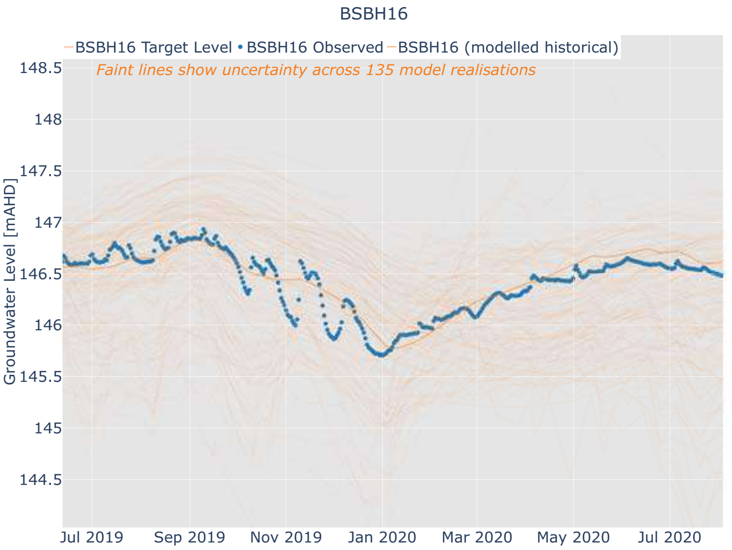
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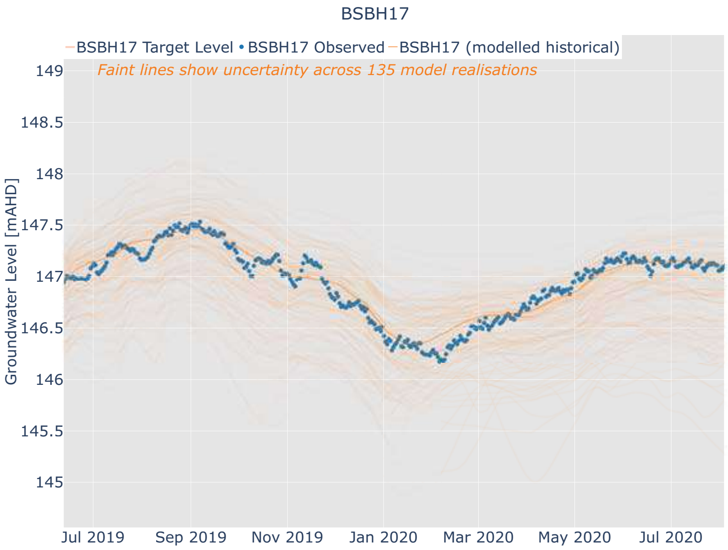
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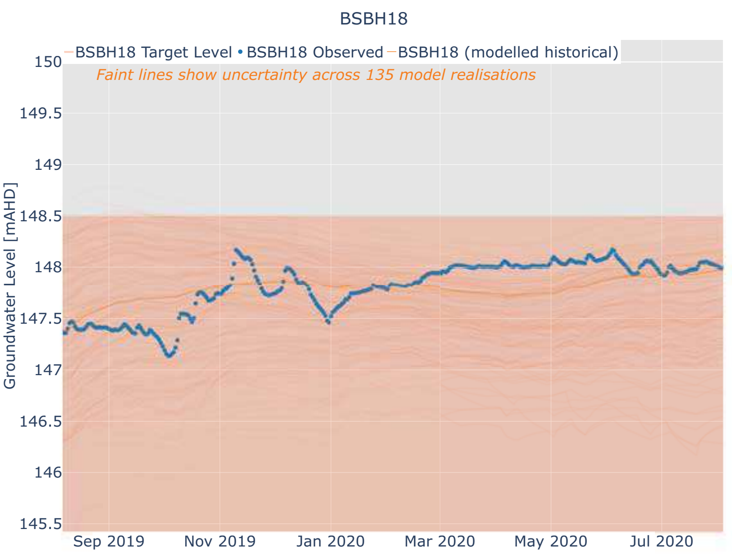
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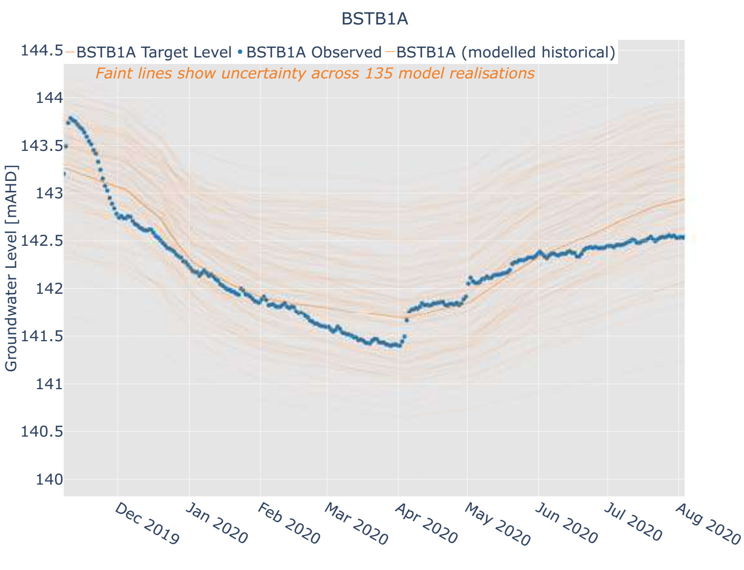
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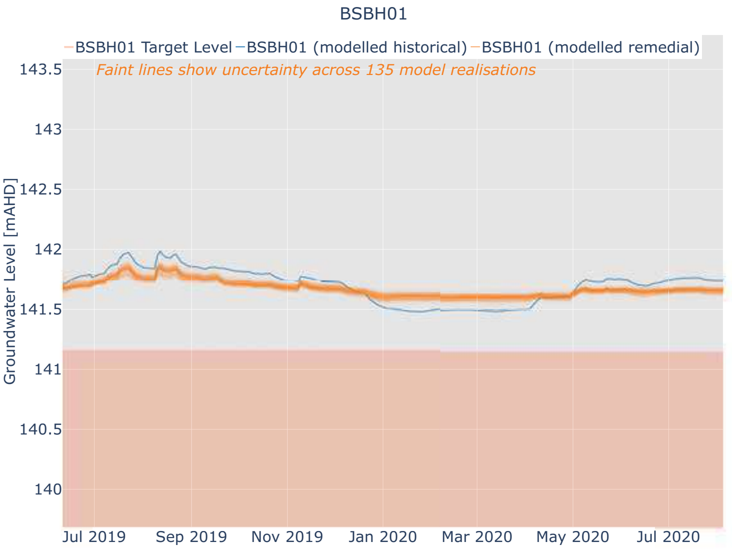
Appendix D – Stochastic remedial forecasting – groundwater level hydrographs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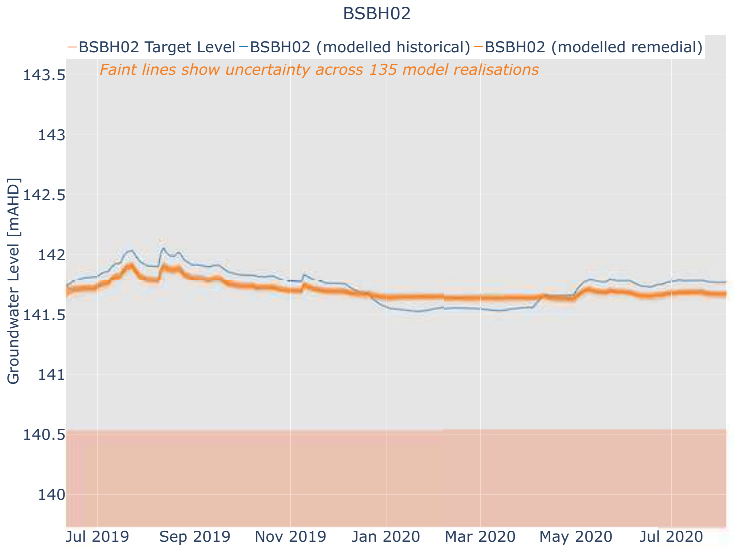
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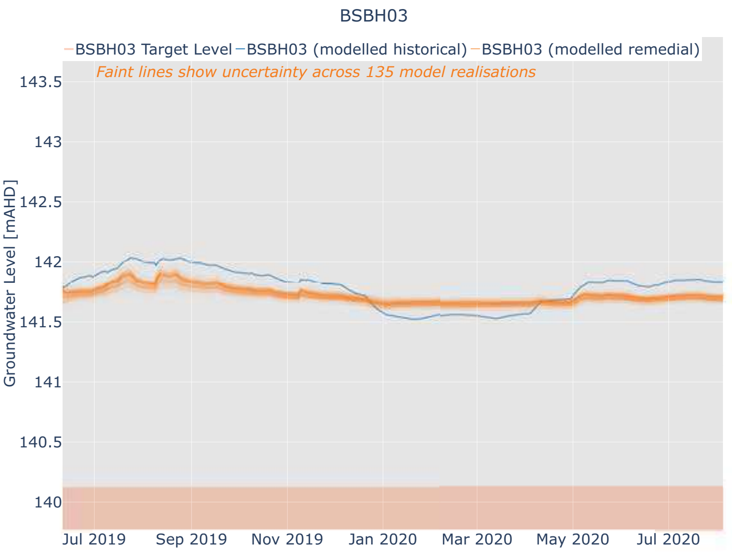
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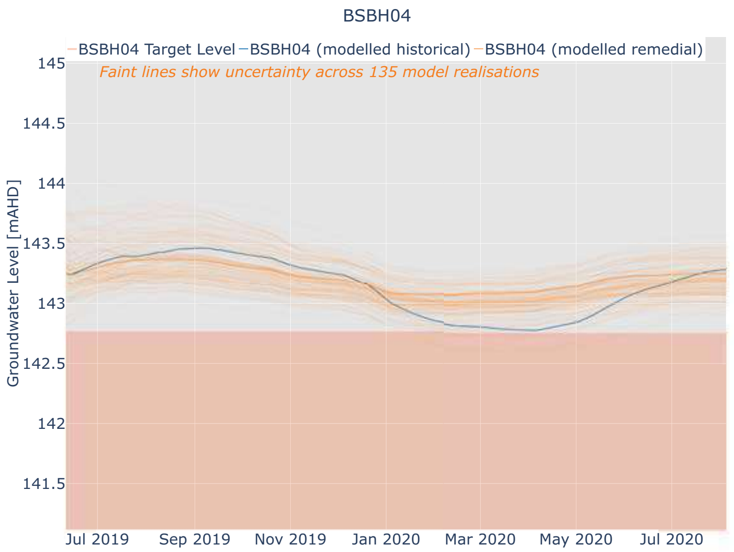
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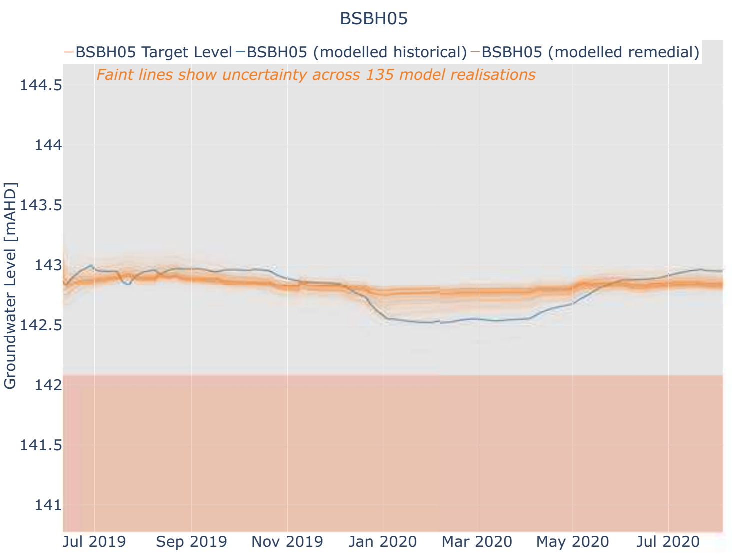
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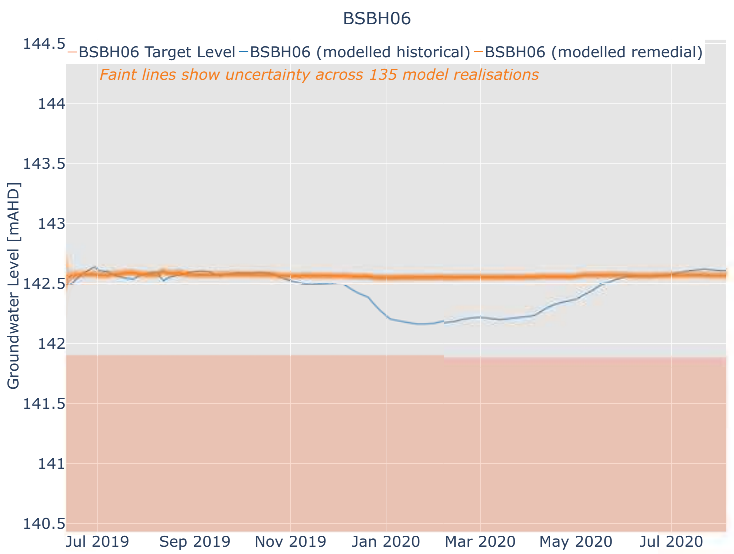
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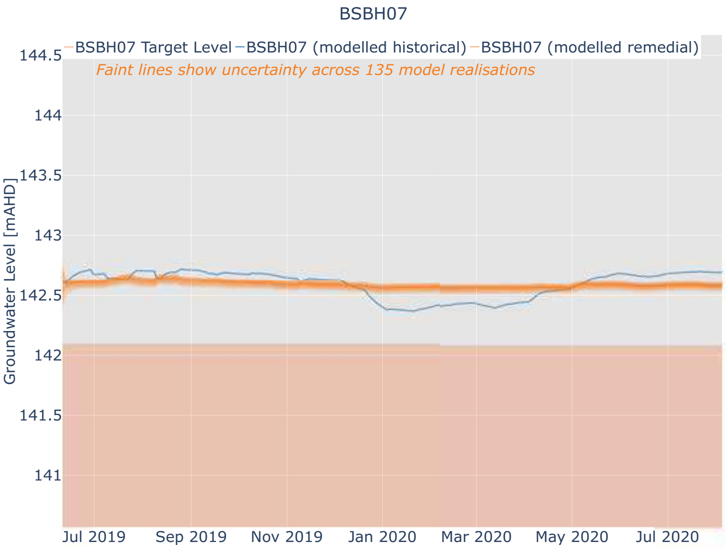
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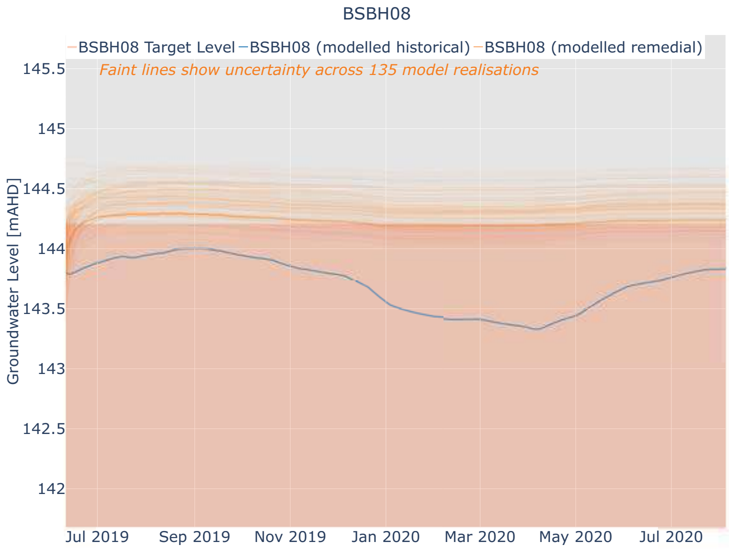
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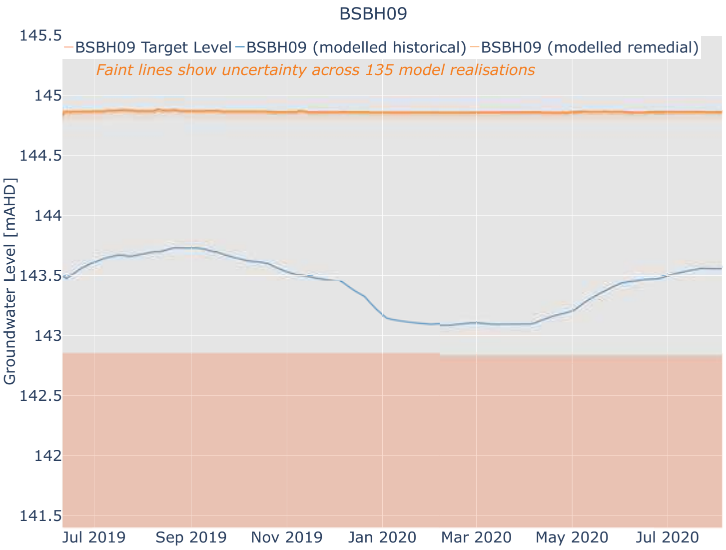
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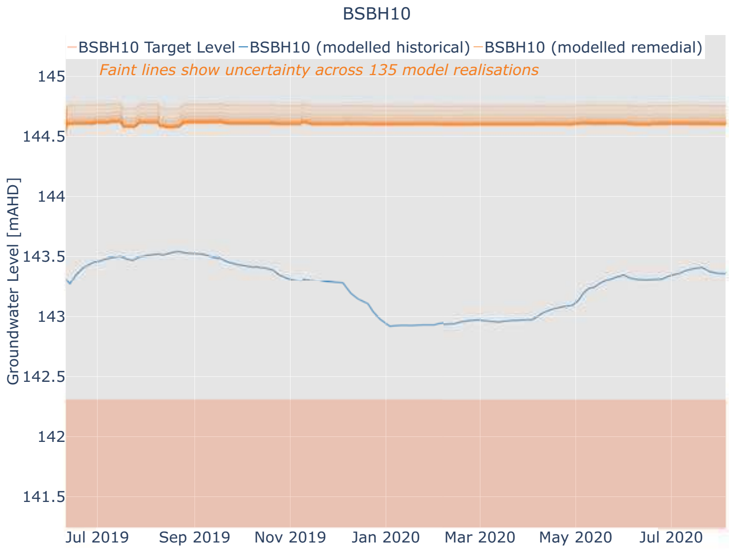
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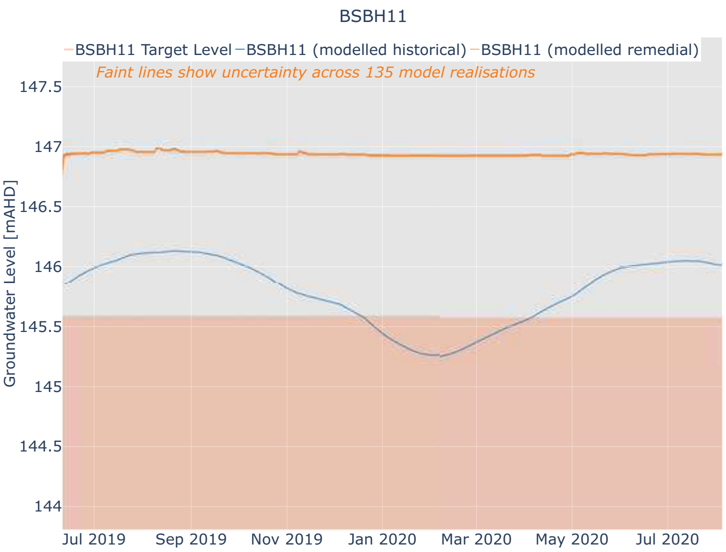
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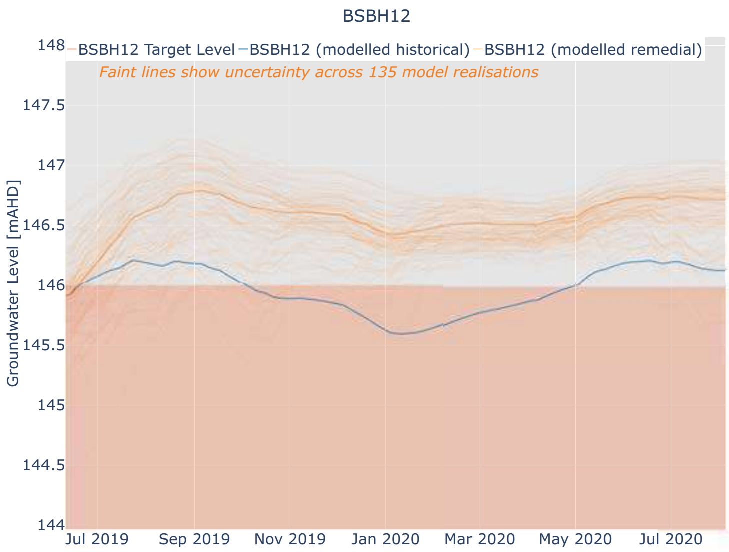
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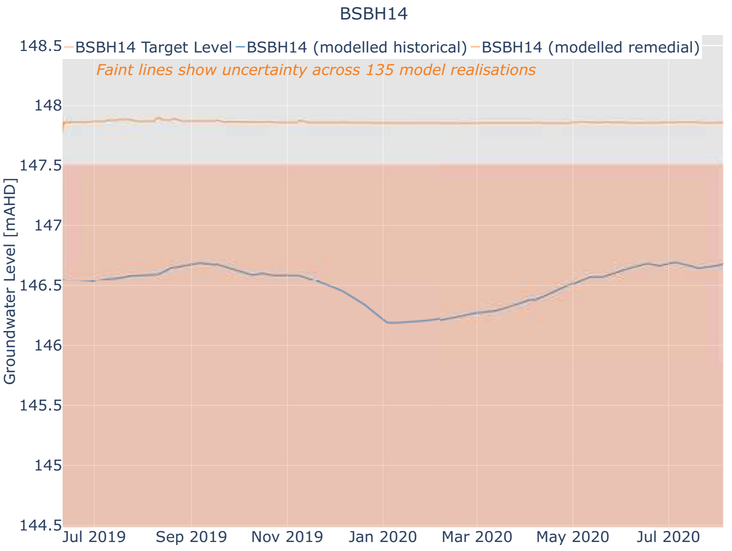
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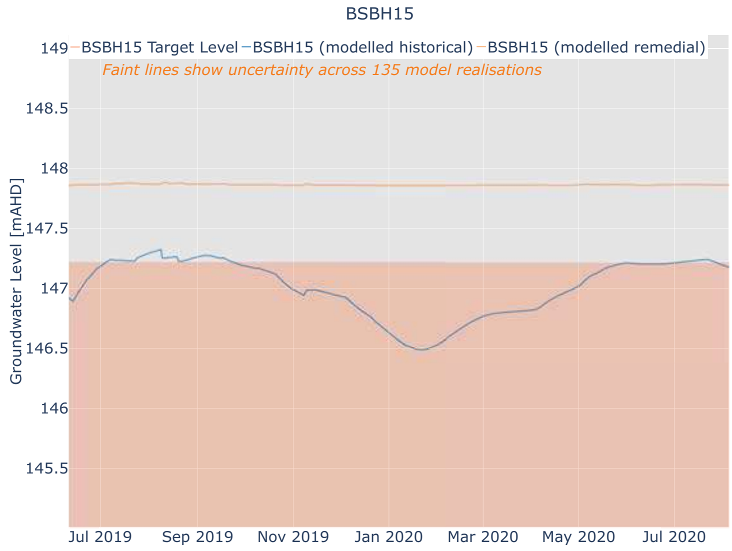
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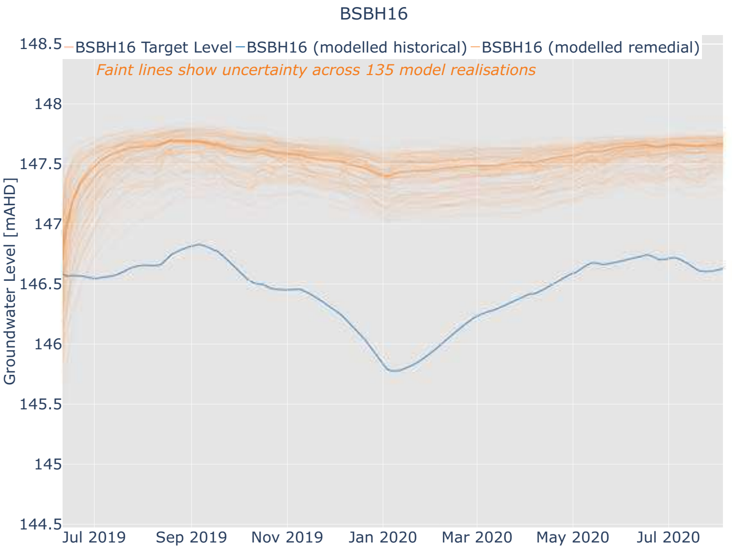
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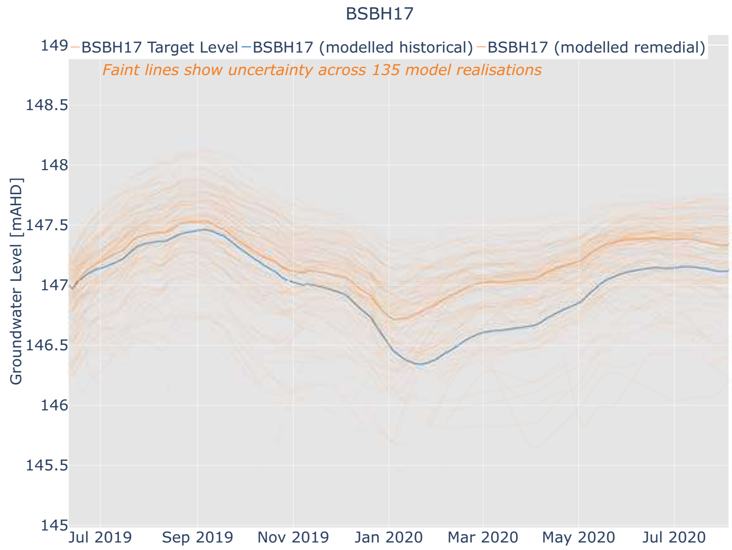
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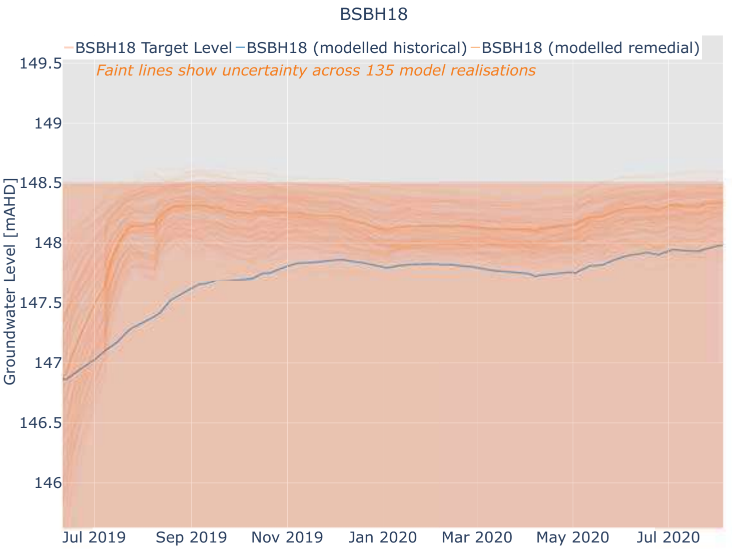
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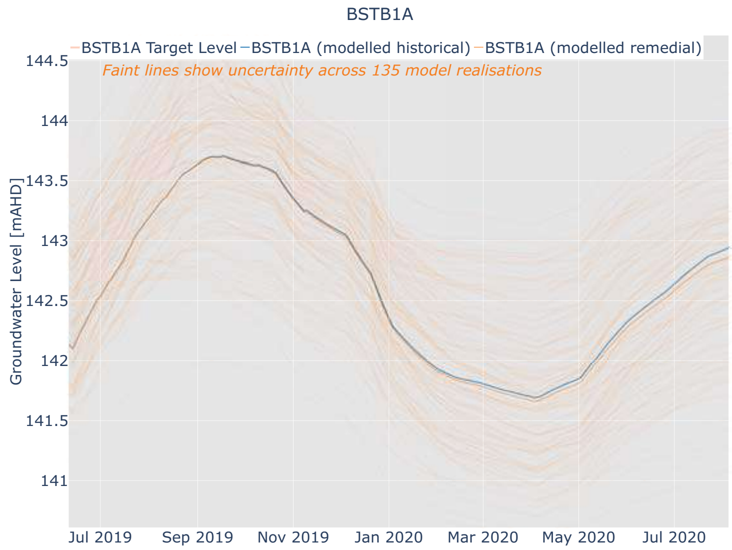
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Jul 2019 Sep 2019 Nov 2019 Jan 2020 Mar 2020 May 2020 Jul 2020

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12536659-15234-2/https://projectsportal.ghd.com/sites/pp17_01/bigswampgroundwaters/ProjectDocs/Completion_Report_Final/12536659-REP_BigSwamp_GW_SW_Model.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Final	R. Gresswell E. Denson M.Medwell-Squire C.Nicol	J. Morgan		J. Morgan		09/04/21

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PO Box 312, Lindfield NSW 2070 ■ Phone: 0427 004 2338
www.hgeo.com.au ■ stuart.brown@hgeo.com.au

To:	Jarred Scott (Barwon Water)	cc: Jeff Morgan (GHD)
From:	Stuart Brown	
Subject:	**Independent Peer Review: Groundwater-Surface Water Modelling of Big Swamp for Detailed Design. Final report**	
Date:	15 April 2021	**Ref:** D21136

Stuart Brown of HGEO Pty Ltd was engaged to provide independent peer review of numerical groundwater-surface water modelling being carried out by consultants GHD to inform detailed design of remediation strategies at Big Swamp. Big Swamp is a peat swamp located along Boundary Creek, which forms a tributary of Barwon River, Victoria. Reduced flow along Boundary Creek in recent years has resulted in lowering of the water table in Big Swamp and activation of acid sulfate soils. Remediation options being considered by Barwon Water include controlled release of supplementary flow and construction of a series of hydraulic barriers to increase net recharge and groundwater levels across the swamp. Modelling was carried out by GDH to assess hydraulic barrier designs under different rainfall and flow regimes.

This memo presents the findings of a peer review of a final draft of the modelling report by consultants GHD, entitled:

- Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design Technical Modelling Report. December 2020.

The report was supplied as a pdf file: 12536659-REP_BigSwamp_GW_SW_Model_DraftA.pdf. In keeping with best practice, regular milestone meetings were held (and attended by the reviewer) to discuss the modelling approach and progress. Model files were not inspected in full by the reviewer; however relevant excerpts of files were viewed through MS Teams.

The review was carried out with reference to principles and concepts outlined in the Australian Groundwater Modelling Guidelines (AGMG) (Barnett *et al.* 2012), and guidelines on uncertainty analysis and decision support modelling (Middlemis and Peeters 2018; Doherty and Moore 2019).

Summary: In my opinion, the adopted modelling approach is appropriate for assessment of groundwater levels and recharge processes within the swamp and the assessment of remediation options. The model is fit for the purpose of informing the remediation strategies to address groundwater quality in Big Swamp. The results address the project objectives and provide significant insights into the hydrogeology of Big Swamp. The confidence level classification of Class 2 (with some attributes of Class 3, as defined in the AGMG) is considered appropriate.

A number of minor comments and recommendations were communicated to the modellers via meetings and subsequent emails which were incorporated into the final report. I have no further significant recommendations in relation to the final draft.

The modelling report is presented to a high standard with clear explanations of the modelling approach and the report structure conforms to best practice as recommended in the AGMG. The modellers should be commended on the standard of work and the outcome.

1. Review

Table 1 below summarises the findings of this review with respect to the AGMG model compliance checklist. The model and modelling report were produced to a high standard and found to be compliant with the guideline and in line with best practice.

Table 1. Numerical model compliance checklist (AGMG 2012)

Item	Model aspect	Comments	Yes/No
1a	Model objectives clearly stated?	Modelling objectives are clearly stated in Section 1.2 of the report	Yes
1b	Model confidence level stated?	Model confidence level is assessed as Class 2 (with some attributes of Class 3, as defined in the AGMG) in Section 7.2, based on attributes summarised in Table 7.1. I agree with the classification.	Yes
2	Are objectives satisfied?	The model provides an effective tool for assessing remediation options. Results are clearly articulated and presented in the report, satisfying the model objectives.	Yes
3	Conceptualisation consistent with objectives and confidence level?	Section 2 of the report develops a detailed conceptual model for the swamp, including aquifer characteristics, groundwater-surface-water interactions, and interactions with underlying aquifers.	Yes
4	Conceptualisation clearly presented and reviewed?	The conceptual model is clearly presented in Section2; earlier drafts of the conceptual model were presented in progress meetings and reviewed by relevant specialists in Barwon Water and the peer reviewer (Stuart Brown)	Yes
5	Does model design conform to best practice?	The modelling approach is consistent with modelling best practice and in terms of effective decision support (e.g. Doherty & Moore, 2019 and the GMDSI)	Yes
6	Model calibration (history matching) satisfactory?	Yes. History matching of the groundwater model was carried out using PEST and PESTPP-IES. Calibration statistics are satisfactory.	Yes
7a	Parameter values and model fluxes plausible?	The initial (prior) parameter values (Table 5) are plausible based on the site conceptualisation and data, and relevant literature values. The calibrated parameters are also reasonable.	Yes
8	Predictions conform to best practice	The model assessed changes in surface water inundation and groundwater response for several barrier options for the same period as used for history matching. The predictive scenarios were similar to natural baseline in terms of aquifer stress. Predictions assessed against clear management thresholds and presented clearly.	Yes
9	Uncertainty associated with predictions reported?	Model uncertainty is rigorously explored through the application of PESTPP-EIS following model calibration. Section 6 of the report presents the results of a thorough uncertainty analysis which conforms with best practice.	Yes
10	Is the model fit for purpose?	The model is fit for the purpose of informing the remediation strategies to address groundwater quality in Big Swamp. The results address the project objectives and provide significant insights into the hydrogeology of Big Swamp.	Yes

2. General comments

Reporting: The modelling report is presented to a high standard with clear explanations of the modelling approach and results. Maps, graphics, and data plots are also of a high standard. The conceptual diagrams and modelling flow diagrams are particularly effective. The report structure conforms to that recommended in the AGMG.

Conceptualisation: A conceptual model for the swamp groundwater system is presented in Section 2 of the report. The conceptualisation and supporting data provide a sound basis for numerical model design and calibration.

The swamp is underlain by Quaternary alluvium valley fill (QA) which is itself underlain by Tertiary aquifers and aquitards. Groundwater levels within the swamp are sustained by aquifer though-flow (QA and Tertiary), surface water infiltration from Boundary Creek and periodic inundation of the swamp floodplain, as well as distributed rainfall recharge. Discharge is via aquifer throughflow, seepage loss to the Tertiary formations and evapotranspiration (EVT). The conceptualisation draws of

previous hydrogeological studies, including drilling, and is supported by high quality observational data including regional groundwater monitoring bores, a dense groundwater monitoring network within the swamp and several surface water gauging stations.

A key area of uncertainty that arises from the conceptual model is the groundwater level in the underlying Tertiary deposits and its role in maintaining groundwater levels within the swamp. However, this aspect is addressed in the model by allowing for a range of possible levels during model history matching and uncertainty analysis. This approach provided insights into the role of the Tertiary deposits in the groundwater level recovery within the swamp during the dry period.

Model approach and design: Model design and approach are presented in Section 3 of the report. The objectives of the project and conceptual model of the swamp require that the model needs to include a mechanism for flood inundation of the swamp, surface water groundwater exchanges and inter-aquifer exchanges. As the modellers point out in Section 3, this can be done in several ways, ranging from fully coupled surface-groundwater models to groundwater model (only) with simplifying assumptions. Fully coupled models present a considerable challenge due to the difference in time-scales between surface water and groundwater flow processes and events (hours versus weeks to months). They can be numerically unstable and have very long run times making them unsuitable for assessment of system behaviour over long periods (months to years). The modellers proposed a loosely coupled ("middle") approach whereby a surface water runoff model (TUFLOW) provides surface water flow and inundation areas as input to a 3D groundwater model (Modflow-USG). I agree that this is the most pragmatic approach and provides a good balance with respect to model runtime and stability, and realistic representation of the surface water inundation.

The modelling approach uses multiple models and pre- and post-processors, coupled together using a Microsoft Windows batch file. The architecture is clearly depicted in Figure 4-6. A surface runoff model (GR4J through eWater Source) is used to generate surface water flow and level data. Those flows and levels were calibrated against stream gauges. TUFLOW was used to simulate flood inundation. Groundwater recharge and evapotranspiration were estimated using the program LUMPREM, a 1D soil water balance model. Outputs from these "external" models were then used to generate input files for the MODFLOW-USG groundwater model using a number of pre-processing utilities. Importantly, the TUFLOW output provided flood extents and depths which were represented in the groundwater model as MODFLOW RIV boundaries.

The groundwater model uses the control-volume finite difference code MODFLOW-USG (Transport) and includes boundary conditions to simulate flood inundation (RIV), stream flow and leakage (SFR) and inter-aquifer exchange (SGB). The SFR (stream) boundary was used in addition to the RIV boundary so that the stream losses could be verified against stream gauges.

The groundwater model uses an unstructured mesh, refined near the stream channels and in the areas of frequent inundation The model mesh refinement is appropriate for the coupling of TUFLOW outputs with groundwater infiltration (through MODFLOW-USG RIV boundaries). The model consists of two layers, although the second layer was included simply to aid simulation of partially penetrating barriers, if required. The use of few layers is justified by the shallow depth of the water table, meaning that vertical infiltration time is negligible compared with the length of the stress periods. Groundwater exchange with the underlying Tertiary aquifer was simulated using Specified Gradient Boundaries (SGB). This allows direct control and assessment of lateral groundwater flow components while avoiding the need to simulate the regional aquifer. The relatively simple model structure results in relatively short runtimes and allows rigorous assessment of parameter sensitivities and prediction uncertainty.

In my opinion, the adopted modelling approach is appropriate for assessment of groundwater levels and recharge processes within the swamp and the assessment of remediation options. The use of a conceptual model to identify and represent the most important hydrological features and the proposed use of advanced tools to explore parameter and predictive uncertainty is in line with current best practice.

History matching: For the groundwater model, the modellers employed a combination of automated techniques to derive parameter values with the least error variance. PEST-HP was used with Singular Value Decomposition (SVD) for initial history matching and "fine-tuning" while PESTPP-IES was used to generate an ensemble of parameter values, all of which produce an acceptable fit with observation data. History matching used a combination of head, flow and gradient (bore head difference) targets which were grouped and weighted to assist in the automated procedure.

The surface water models (GR4J and TUFLOW) were calibrated separately against gauge data and observations of inundation. Due to the loosely coupled nature of the surface water and groundwater models, a certain amount of iteration was required to endure that infiltration rates were consistent. Figure 4-12 shows that there is a good agreement between modelled and observed heads and flow at the downstream gauge.

The methods of history matching are considered appropriate for a highly parameterised model, loosely coupled with the output from surface water models. The Scaled Root Mean Squared (SRMS) error is around 3% and the Root Mean Squared (SRMS) error is around 0.2 m. Hydrographs shown in Figures 4-8 and 4-9 indicate a close match between modelled and observed groundwater heads within the swamp. At most bores, the model closely simulates both the absolute head and range over wet and dry periods. As such, the model provides an excellent basis for predicting groundwater response to changed surface water inundation conditions. Small or localised variations between modelled and observed conditions are to be expected due to uncertainties in ground conditions across the site.

Table 5 summarises the key hydraulic parameters in the groundwater flow model. The initial values are reasonable based on the site conceptualisation, and the ranges provide appropriate bounds for history matching and uncertainty analysis. Similarly, calibrated values (Section 4.4.5) are reasonable, noting that some of the calibrated stream parameter values are at their max/min bounds. PESTPP tools are used to carry out a thorough sensitivity analysis (Section 4), which provide important insights into groundwater processes, particularly around the importance of exchange between the Tertiary and Quaternary aquifers.

Predictions: Model predictions are presented in Section 5, relating to the stated objectives. Results are presented to show the effect of barriers on surface flow inundation (and preferred option), flow diversion and the effect of various barrier options on groundwater levels within the swamp. The hydrographs, contour maps and difference maps are an effective way of presenting the results. Predictive runs were carried out over the same 14-month period as the history-matching baseline, with aquifer stress conditions that are of a similar order of magnitude to the baseline conditions. This approach reduces predictive uncertainty related to future climatic conditions and increases the level of confidence. It is noted that the predicted heads in monitoring bores BH09, BH10, BH11, BH14 and BH15 are significantly higher than the baseline (as was the objective) and display little seasonal variability. This is presumably because those bores are close to the proposed barriers where ponding is predicted to be nearly continuous.

Uncertainty analysis: Predictive uncertainty analysis was carried out using PESTPP-IES, a non-linear approach appropriate for highly parameterised models. An ensemble of 135 calibrated parameter sets was used to run the predictive scenarios (using PESTPP-SWP) such that multiple predicted hydrographs could be generated for each monitoring bore. This provided an estimate of the predictive uncertainty at each location. The sources of uncertainty are discussed. Results are presented in a manner that clearly shows the range of predictive uncertainty.

Because of the loosely coupled nature of the model, the uncertainty associated with estimated creek flows and flood inundation are not fully integrated in the PEST workflow. However, the sensitivities of those aspects are thoroughly explored in Section 6.1.2, with the gully shaping (topography) assumptions in TUFLOW found to be most sensitive. The model results are therefore contingent on the accuracy of topographical data (LiDAR).

I hope you find these comments useful. If you have any further questions, please contact me using the details above.

Regards

Stuart

Dr. Stuart Brown

Principal Hydrogeologist

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Appendix B

Big Swamp, Hydraulic Barriers Design Report and Drawings

Big Swamp

Hydraulic Barriers Design Report

IA258200-RPT-001 | 2

30 June 2021

Barwon Water

Big Swamp

Project No:	IA258200
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Revision	Date	Description	Author	Checked	Reviewed	Approved
1	4/6/2021	Draft Report for Client Review	NP	TF	NU	LL
2	30/6/2021	Report for Client Submission	NP	TF	NU	LL

Contents

Executive Summary

Jacobs has been engaged by Barwon Water to provide a design for the Big Swamp hydraulic barriers. The hydraulic barriers are one of several remedial actions recommended in the Remediation and Environmental Protection Plan (REPP) to improve the flows and water quality, as well as the vegetation and ecology in Boundary Creek and Big Swamp.

The location and height of the hydraulic barriers was investigated by GHD (2020). Multiple iterations of the coupled surface water-groundwater model arrived at a recommended barrier configuration to achieve the objective of maintaining a high watertable in the swamp through distribution of surface water flows. These were adopted, with minor refinements.

A range of options were considered for the hydraulic barrier system. This includes earth banks, sand filled geotextile bag or tubes, rock banks with geotextile barriers, concrete wall or cantilevered sheet pile barriers. Based on site inspections and geotechnical investigation results, considerations were used for the selection of the appropriate type of hydraulic barrier.

Ultimately, it was found that the rock bank with a PVC sheet pile cut off reduced the total depth of pile and this was adopted as the preferred approach. In the final design the pile acts as a hydraulic barrier, which is structurally supported by the bank. The bank provides a method for gaining access into the swamp to incrementally install the sheet piles and embankment and ultimately remove it.

A flow control regulator is to be installed in Boundary Creek at Barrier J1. The regulator is to be a Lay flat overshot gate designed for a 1.22 m wide opening and to be floor mounted. Its purpose to raise the water level to enable the manipulation of the flow distribution between the creek and the swamp. The intent is that a proportion of low flows and supplementary flows in the order of 2 ML/d which might otherwise remain in Boundary Creek will be pushed through the swamp whilst still retaining flow in the creek. The site is located immediately downstream of the first natural overflow.

The fire trench is to be filled over its entire length along the southern side of the swamp with clean fill material. At the eastern end, where it continues into the body of the swamp, it is to be filled up to the edge of the swamp, to a point it can be practically constructed without disturbing PASS soils or draining the swamp.

It is not proposed to infill the agricultural drain at the east boundary of the site, as part of these works. Whist this is listed as a recommendation in the REPP, the basis for doing so has not been properly established.

Important note about your report

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

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate, or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Barwon Water and available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations, and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures, and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Project specific limitations which should be considered are:

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

This report has been prepared on behalf of, and for the exclusive use of Barwon Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Barwon Water. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

Jacobs has been engaged by Barwon Water to provide a design for the Big Swamp hydraulic barriers.

The hydraulic barriers are one of several remedial actions recommended in the Remediation and Environmental Protection Plan (REPP) to improve the flows and water quality, as well as the vegetation and ecology in Boundary Creek and Big Swamp.

To assist in realising the project vision, the following six project objectives were developed and agreed with the Remediation Working Group and their nominated experts during development of the REPP:

1. Maintain groundwater levels above the top of the non-oxidised sediments in Big Swamp (to prevent oxidation of deeper sediments within the swamp).

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

3. Maintain at least minimum flows in Reach 3 of Boundary Creek all year round.

4. Manage potential formation of acidity downstream of Big Swamp, which may be triggered as a result of implementation of some remediation options (i.e. swamp inundation).

5. Preserve/improve the ecological values of Big Swamp and Boundary Creek. This objective is focused around addressing the changes to the vegetation assemblages within the swamp post the initial acidic event and fire. The result is a drying of the swamp, creating a more terrestrial soil environment that has enabled the encroachment of Swamp Ovata, reducing the density of existing Melaleuca communities.

6. Reduce the peat fire risk in Big Swamp.

1.1 Background

Historically, investigations to improve the understanding of the performance and impacts of the Barwon Downs borefield were conducted at a regional scale. Over the last 10 years, Barwon Water has been rolling out a staged works program to continually improve the knowledge and understanding of the impacts of historical management of groundwater pumping at Barwon Downs on groundwater levels in deep and shallow aquifers, streamflow, aquatic and terrestrial ecology, and potential acid sulfate soils (PASS). In response to ongoing community concern, investigations began to focus on Big Swamp in 2017, when Jacobs undertook the Yeodene Swamp study.

The Yeodene Swamp study focused on reviewing the catchment history in concert with a soil, groundwater, and surface water monitoring program to develop a conceptual model of the swamp, characterise its current hydrogeochemical state and assess the drivers of acidification in the swamp. The study found that the key processes contributing to flow reductions in Boundary Creek were low rainfall and groundwater extraction, which subsequently led to drying and acidification of the swamp. A range of remediation options were considered, and the most feasible option was found to be inundating the swamp via increased inflows and a hydraulic barrier at the eastern (downstream) end of the swamp.

The remediation of the swamp was subsequently enshrined in a section 78 notice, which resulted in the Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan (REPP). This led to a range of studies to refine the remediation strategy and provide more certainty in the remediation outcomes including:

- A comprehensive soil sampling program aimed at refining the soil geochemistry in the swamp (Jacobs, 2019a)
- Soil incubation tests which simulated the soils geochemical response to inundation (Monash University, 2019)
- A basic conceptual geochemical model of Big Swamp (GHD, 2019)
- Preliminary groundwater-surface water model of Boundary Creek and Big Swamp to assess the viability of maintaining inundation in the swamp as a remediation strategy (Jacobs, 2019b)
- Boundary Creek and Big Swamp Remediation Options Assessment (CDM Smith, 2019)
- Revised groundwater-surface water model of Boundary Creek and Big Swamp by GHD (GHD, 2021).

These studies provided a greater understanding of the spatial distribution and concentration of acid sulfate soils, which helped inform the target water levels for inundation. The preliminary groundwater-surface water model proved the modelling approach of coupling a surface water flood model with a numerical groundwater model and using hydraulic barriers to create inundation and achieve target groundwater levels (Jacobs 2019). The modelling suggested that a modest supplementary flow with multiple hydraulic barriers within the swamp would assist in limiting further acidification of soils within the swamp.

Additional modelling was undertaken by GHD (2021). This trialed and then refined multiple barrier layouts and arrived at a preferred configuration to achieve the objectives of elevated groundwater levels within the swamp and prevent further acidification. It recommended seven hydraulic barriers through the swamp to maintain groundwater levels at or above the target levels (see Figure 1.1). The two barriers at the entry to the swamp are also required to have some form of level or flow control to allow flexibility to optimise the flow regime to meet the required targets within the swamp and flow regime downstream of the swamp.

The geochemical studies undertaken in recent years have confirmed that inundation of the swamp is likely to be a successful long-term remediation option, however it may take several years for the chemistry to change in the swamp and achieve improved water quality objectives downstream of the swamp.. With this mind, Barwon Water are also considering active treatment as an interim contingency measure, such as lime dosing in the swamp or downstream of the swamp, in addition the hydraulic barriers to mitigate risks associated with the acidity loads entering Boundary Creek in the short term.

The objective of this study is to consider the barrier options available and generate design drawings of each barrier so that once approved, they can ultimately be constructed via a suitable contractor. The designs have considered the constraints associated with the site in terms of the geotechnical foundations, flow regime in the swamp and downstream, minimized vegetation removal, durability of the materials and the constructability of the barriers.

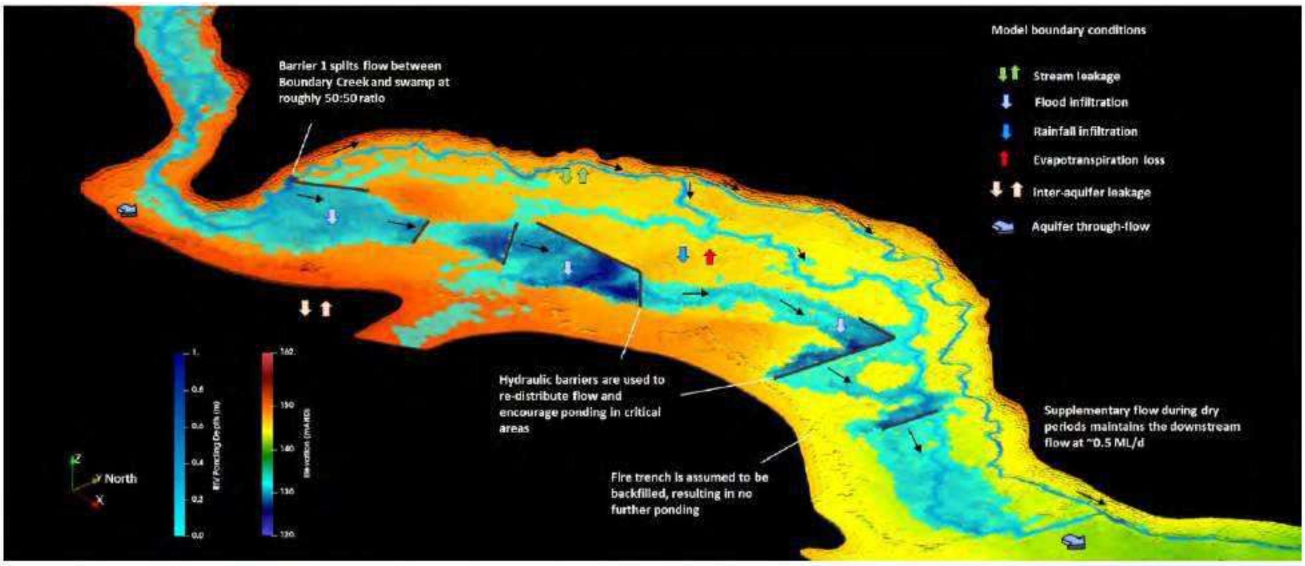

Figure 1.1: Location of hydraulic barriers (GHD, 2021)

1.2 Purpose of this report

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

- Submit the project for Southern Rural Water (SRW) review and endorsement.
- Undertake procurement of the proposed works to construct the hydraulic barriers.

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

- The consideration and design of contingency measures to actively treat acidity within Big Swamp or Boundary Creek (by Jacobs as part of this project)
- Relevant approvals including, but not limited to cultural heritage, flora and fauna, statutory planning, works on waterway and land access agreements.

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

2. Site Conditions

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

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

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

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

Figure 2.1 – Big Swamp location plan

3. Barrier Section - Basis of Design

This section defines the design criteria for the hydraulic barriers. It focuses on the cross-section geometry, materials, and construction method of the barrier and the hydraulic control structures.

Barrier cross section options are discussed and assessed against these criteria in section 4.

The functional requirements for the purpose of designing the barrier cross section are summarized in the following sections.

- Hydraulic
- Durability
- Potential Acid Sulfate Soil (PASS) disturbance
- Seepage
- Constructability
- Vegetation Disturbance
- Rehabilitation

3.1 Hydraulic Requirements

The purposes of the hydraulic barriers are to back up water behind each barrier and to distribute flow across the width of the swamp. There will be a tendency for water to channelize, and the barriers need to overflow evenly across the full width so that areas immediately downstream are wetted. The barriers do not form a series of overlapping ponds and the distribution of water over the swamp relies on how the overland flow is distributed.

It is unlikely that an earth or rock structure could be built and maintained at a tolerance to achieve a uniform flow distribution, particularly at the critical low flows (1 ML/d to 2 ML/d).

To illustrate this, calculations were performed for a perfectly horizontal knife edge weir (35 m long). The relationship between depth of water flowing over the crest of the weir (see Figure 3.1) produced the following results for typical design flows:

- 1 ML/d – head 3 mm
- 2 ML/d – head 5 mm
- 20 ML/d – head 28 mm

The implication is that a very small difference in crest level will cause the water to concentrate in one location. These tolerances would be extremely difficult to achieve on an earth structure and difficult for even a sheet pile weir. The estimated lengths of overflow sections on the barriers range from 35-120 m.

Achieving an even flow distribution at low flows would be more suited to a series of thin plate triangular weirs, evenly spread across the crest. A flow relationship for a series of ten "V" notch weirs (Figure 3.2) shows that at 1 ML/d the depth of flow at the weirs would be 0.06 m.

It is concluded that to ensure an even distribution of flow across the width of the swamp, a construction containing a series of V notch weirs would perform best.

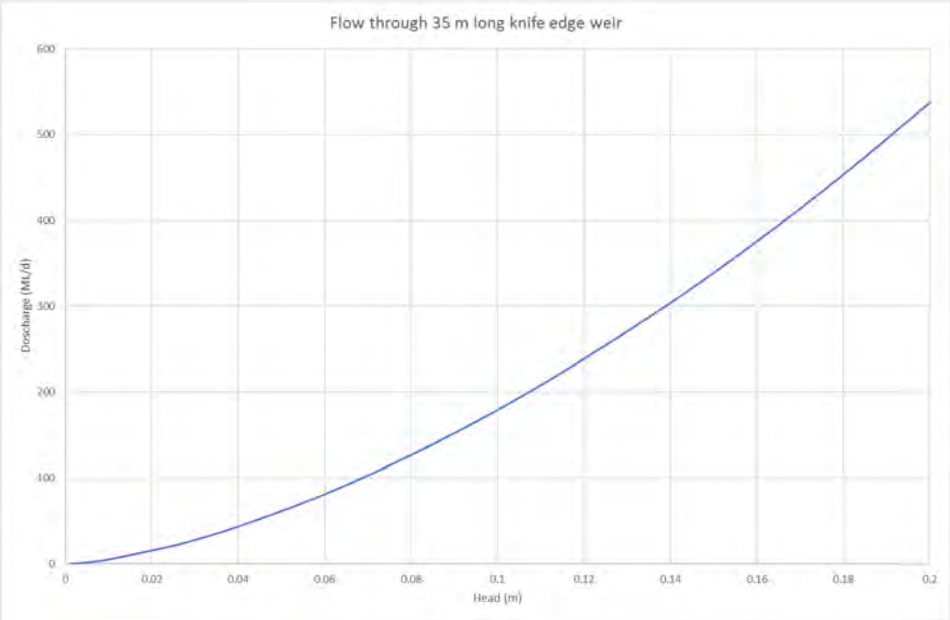

Figure 3.1: Discharge relationship for 35 m long knife edge weir

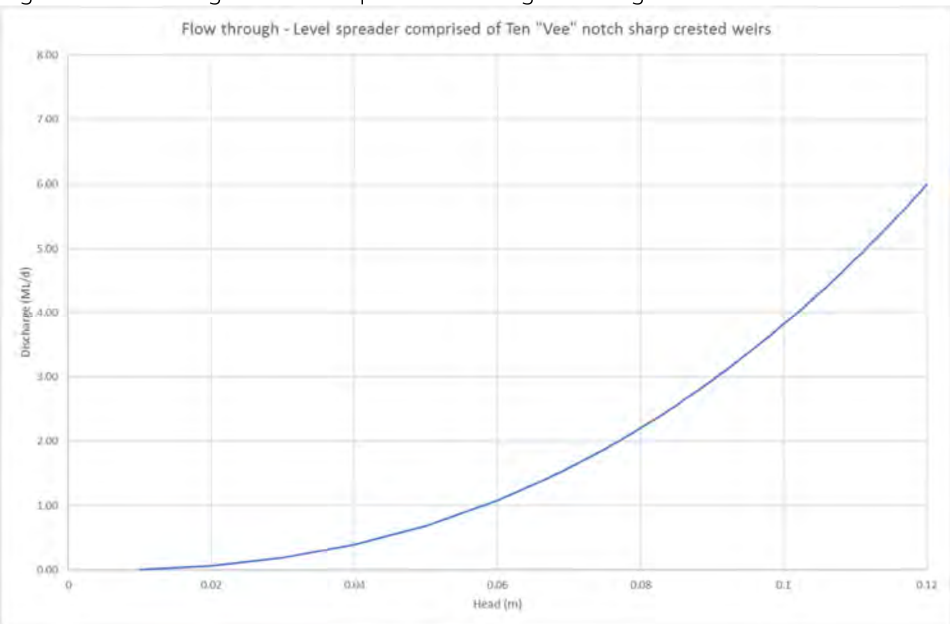

Figure 3.2: Head discharge relationship for series of V notch weirs.

3.2 Durability – Parameters for Design

The materials used in the barrier and regulator construction need to be durable for the conditions experienced. Values used for design are listed in Table 3.1.

Table 3.1: Soil and water parameters for design

Issue	Value	Source	Comment
Acidity of surface waters at outlet	Median pH 3.5 Range 3.2-4.5	Station 233276A. Field values	At outlet of swamp. Apply to all barriers in the swamp
Acidity of surface waters at inlet	Median pH 6.6 Minimum 5.3	Station 233275A. Field values	Consider only at the inlet regulator if a concession is required.
Sulfate as S04 – in surface waters	Up to 700 mg/L	Jacobs 2018	Sample D/S of swamp
Sulfate as S04 – in groundwater	Up to 4000 mg/L Up to 5100 mg/L	Jacobs 2018 Melbourne Uni (2020)	
Sulfate as S04 – in soil samples	380 to 680 ppm	Three tests in this project.	

For assessment of durability, the permeability of soil is also a consideration. Soils are typically divided into low permeability (clay) and high permeability (sands) for this purpose. The more permeable soils are the more adverse condition for material corrosion. The lithological logs (Jacobs 2019) indicate that while clays predominate the subsurface of the swamp below 1 m depth, more permeable soils (silts and sands) are present in the top meter of soil.

3.3 Concrete Durability

Concrete durability requirements have been assessed for a 50-year design life using AS 3600.

The conditions on site are highly aggressive to concrete, driven by the acidity and high sulfate concentrations. At this site, the acidity governs except at the inlet. However, the high sulfate content is also significant.

Assessment in accordance with AS 3600 gives:

- Exposure classification for surface soils, B2 based on sulfate
- Exposure classification for surface soils C2 based on pH at the outflow

These classifications result in concrete that would need to be carefully specified.

Recommendations in AS3600 for Exposure classification C2, combined with acid sulfate soil conditions are:

- Cement type SR
- 50MPa concrete
- 65mm cover to reinforcement when cast against formwork

- A protective coating over the concrete is recommended

It is concluded that the conditions are highly corrosive to concrete. Construction of concrete barriers is not recommended. Concrete might be considered at the inflow regulator, however alternative approaches are recommended if possible.

If concrete is used in the barriers, then it will need to be carefully specified; and with considerably more rigor than summarized above.

3.4 Durability of Metals

Acid soils are corrosive to unprotected steel. The Australian Standard for Pilings (AS 2159) specifies exposure classifications for steel piles in permeable soils as:

- pH <3 – Severe
- pH 2-3 Moderate (in permeable soil)
- sulfates > 1000 ppm, Moderate

The code specifies corrosion allowances of up to 0.04 mm/ year for moderate, and 0.1 mm per year for severe conditions.

RMS (Bridge technical direction BTD2007/13) give more specific information. They state that for pH less than or equal to 4.0 in acid sulfate soils, unprotected steel piles are not permitted. For range 4.0 ≤ pH ≤ 4.5, a minimum corrosion allowance of 4 mm on each surface is specified.

Whilst the above values give some guidance, the aggressiveness in acid sulfate soils is more complex. The piling code (AS 259) recommends specific durability design for these conditions. Where high concentrations of sulfate (>1000ppm) exist, sulfate-reducing bacteria may be active, leading to microbiologically induced corrosion.

In summary steel (such as steel sheet pile) is not recommended.

3.5 Disturbance of Potentially Acid Sulfate Soil (PASS)

The standard approach to construction in acid sulfate soils and PASS is to minimize disturbance and prevent bringing the sulfidic soils to the surface.

Soils that are excavated cannot be used in the construction and will need to be disposed of at an EPA facility, at significant cost. Previous similar activities required acid sulfate soils to be taken to Bulla land fill, with an estimate travel distance of 2 hours each way from Big Swamp. It is noted that Bulla land fill has since closed. This has implications for conventional embankment construction, which would normally require stripping of surface materials and excavation to a solid foundation.

Options that minimize disturbance for acid sulfate soils and PASS are preferred.

3.6 Seepage Cut off

The depth of the subsurface hydraulic cut off at each hydraulic barrier should be sufficient to elevate the water level and prevent piping failure, but not so deep as to cut off groundwater flow that could result in drying of sulfides on the downstream side of the barrier. The cut offs should be limited to the top few meters of soil, predominantly silts and clays; and not extend into the lower aquifer. The depth of cut off into the silts and clays should be the minimum necessary to pond water, and preferably not so deep as to prevent all groundwater movement through the silt/clay layer.

Prolonged periods of low flow; combined with vertical seepage mean that seepage through the above grade element of the hydraulic barriers needs to be limited.

The requirement should be to maintain some flow over the barriers at low flow, nominally 1.0 ML/day into the swamp, considering evapotranspiration and seepage. This assumes managed inflows are (2 ML/d) at station 233275.

3.7 Vegetation Disturbance

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

The alignment of barriers is for the most part set by the hydraulics. Section 6 of this report further refines the hydraulic barrier alignments and includes attempts to minimize vegetation disturbance.

Vegetation and ground disturbance are influenced by cross section design, and some considerations are highlighted below.

Earth (clay) water retaining structures need trees removed under the bank footprint, and a distance back from the water retaining bank. This includes removal of all roots under the bank and maintenance of a clear area at the toe of the bank. This is to prevent tree roots growing under the barrier. A minimum clear area of 3.0 m from toe of bank would need to be maintained free of trees for the life of the bank. For larger trees, it is usual to limit their drip line to the toe of bank.

Removal of vegetation under a water retaining bank requires grubbing out of roots, which in this case would inevitably disturb acid sulfate soils and PASS soils.

Alternative barriers (such as sheet pile) would not prevent all vegetation removal; however, the footprint would be reduced.

3.8 Rehabilitation Potential

It is desirable that, if required, barriers could be removed in the future with minimal disturbance. Assuming that the acid sulfate soils are remediated, barriers could potentially be allowed grow over or be removed. Design features that facilitate this are to be considered.

3.9 Constructability

The main construction issues can be summarized as poor access, contaminated soil, and wet conditions.

Access is through private property. The access tracks are narrow and unformed. The surface soils are fine sand and erodible. From a construction perspective, methods that limit the total number of vehicle (truck) movements through the site are preferred. This is directly related to the amount of material that must be brought in or removed.

Any acid sulfate soils or PASS that is brought to the surface will need to be removed to a licensed EPA facility for treatment.

Wet construction conditions, and soft soils increase the difficulty of construction. It is unlikely that a solid foundation will be found to compact soil against. Traffic movements, and compaction on the swamp material risks bringing acid sulfate soils and PASS to the surface.

4. Barrier Section - Options Assessment

The process for selection of the hydraulic barrier type consisted of an initial screening process followed by more detailed assessment of the remaining three options.

4.1 Initial Screening

A broad range of options were identified and considered as part of the initial option development. These were screened based on the functional requirements previously identified. Project time constraints to both complete the design and commence installation mean that the process was necessarily brief. This tends to favor conventional approaches with known outcomes ahead of more novel methods with uncertain outcomes.

The options considered are summarized in Table 4.1. The design elements refer to specific parts of the barrier in each design:

- Cut off referes to the element below the natural surface, which prevents seepage under the barrier
- The Barrier is the water retaining element in the structure, locaed above natural surface level
- The crest refers the the top of the barrier. Its design influences how the water can be accurately distributed across the width of the swamp
- Construction access refers to the minimum work needed to gain access across the swamp to build the works.

Table 4.1: Barrier Options

	Design Elements			
Option Description	Cut-off	Barrier	Crest	Construction Access
Earth bank	Clay core	Clay bank	Earth	Unresolved.
Sand filled geotextile bag	Buried membrane. Sewn to bag	Sand Bag	Sand Bag	Geogrid & 300mm rock
Sand filled geotextile tube	Buried membrane, sewn to bag	Sand Tube	Sand Tube	Geogrid & 300mm rock
Rock Bank with PVC Pile Barrier	PVC Pile	PVC pile	PVC pile	Geogrid & 300mm
Rock Bank with Geotextile Barrier and cut off	Buried membrane, wrapped into bank	Geotextile membrane	Geotextile over rock	Geogrid & 300mm rock
Water Filled Coffer Dam	Unresolved	Rubber dam	Rubber dam	Geogrid & 300mm rock
Precast concrete panels	Concrete	Concrete. Joints (unresolved)	Concrete	Geogrid & 300mm rock
Cast insitu concrete wall	Concrete	Concrete. Cast insitu joints	Concrete	Geogrid & 300mm rock
PVC Sheet pile barrier	PVC Pile	PVC pile	PVC pile	Geogrid & 300mm
Steel sheet pile	Steel Pile	Steel Pile	Steel Pile	Geogrid & 300mm rock
H pile wall with planks (plastic or timber)	Buried planks. Membrane	Planks. Geotextile. Earth	Planks	Geogrid & 300mm rock

The options were scored against the criteria outlined in section 3, using a numerical rating as listed below. A weighting was applied to each criterion, and the results multiplied to achieve a weighted score from 0 to 4. Any criteria that scored zero (fail), indicating that it is not feasible, resulted in a zero score for the option.

Grade	Description
4.0	Excellent
3.5	Very good
3.0	Good
2.5	Satisfactory
2.0	Fair
1.0	Poor
0	Fail

The assessment and results are given in Table 4.2.

Table 4.2: Initial Option Screening.

	Assessment Criterea									
Option Description	**Hydraulic**	**Durability**	**PASS distrubance**	**Certainty & Risk**	**Seepage**	**Constructability**	**Envronmental Disturbance**	**Rehabilitation**	**Weighted Score**	**Comment**
Weighting	15%	5%	20%	10%	10%	15%	20%	5%		
Earth bank	1	3	1	2.5	2.5	1	1	3	**1.5**	Conventional solution, as suggested at project innitiation
Sand filled geotextile bag	0	2.5	2	1	1	2.5	3	3	0.0	Fails because the individual bags would leak at the joints
Sand filled geotextile tube	1	2.5	2	1	1	2	3	3	1.9	Would require custom bags, difficult to build to tolerance to achieve hydraulic criterea.
Rock Bank with PVC Pile Barrier	3.5	3.5	3	3	3	3	2	3	**2.9**	
Rock Bank with Geotextile Barrier and cut off	1	3	2	2	2	2	2	3	2.0	
Water Filled Coffer Dam	1	2	2	1	2	3	3	3	2.2	Lacks a cut off. Not clear how this could be done. Sincle size tube would require a fine tolerence on the foundation.
Precast concrete panels	2	1	1	2	2	2	1	1	1.5	Extensive excavation and backfill. Unclear how the joints would be sealed
Cast insitu concrete wall	2	1	1	2	2	1	0	1	1.2	Need coffer dams to build it.
PVC Sheet pile barrier	3.5	3.5	3	3	3	3	2	3	**2.9**	
Steel sheet pile	3.5	1	3	3	3	3	2	3	**2.8**	Option more expensive than PVC pile, so not considered further
H pile wall with planks (plastic or timber)	2	3	2	2	2	2	3	3	2.3	

The assessment scored the options with a sheet pile wall the highest on the first four criteria. Most other options require a membrane barrier seepage cut-off; probably a material such as a Bentfix geomembrane. Irrespective of the form of membrane, the method of placement would cause difficulty, and would involve either a trenching/backfilling operation, or the development of an innovative means to press or plough the material into place.

An advantage with the sheet pile options is that the crest level can be set to a fine tolerance by cutting the pile after it has been placed. All other options are subject to difficulty in achieving tolerance during construction and would be subject to ground settlement after construction.

Of the options considered three were selected for further assessment:

- The conventional earthen bank. Whilst this scored poorly on most counts, it would superficially appear the most conventional approach, and is therefore discussed to highlight the issues involved.
- The PVC sheet pile barrier and rock bank
- The PVC sheet pile barrier

The steel sheet pile scored well, however offers no advantages over the PVC pile option, scores slightly lower and is more expensive. For these reasons, its previously identified poor durability, as well as it being in most other respects similar, it was removed.

4.2 Earth Bank – Clay cut off

This option is discussed because it is considered to be the most standard approach.

A typical design is shown in Figure 4.1. It consists of an earth bank with rock protection on the crest and downstream face. A typical bank height of 0.5 m is shown.

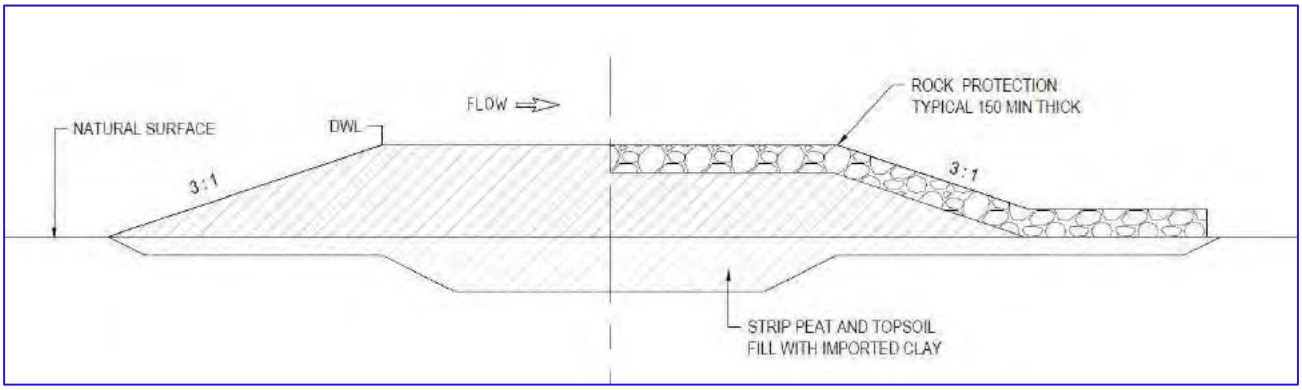

Figure 4.1: Typical Earth Bank Section

The key issues identified with this approach are:

1) Stripping. The foundation needs to be stripped to remove all topsoil, tree roots, peat through to an impermeable surface and the thickness is unknown. All the stripped material would need to be removed and treated off site, due to PASS.

2) Volume of material. All material that is removed would need to be replaced with imported fill. The base volume excluding the core trench would be 1400 to 1700 cum (the higher number assumes 0.1 m depth over the base area for losses, stripping and survey error). An additional 400 cum would be needed for an 0.3 m deep cut off trench over part of the base area.
3) Lack of solid base. For construction of an impermeable bank, a solid foundation is needed to compact against. The lithological logs show most of the foundation is soft and unsuitable to build off directly. The usual methods of dealing with this are to place geotextile and rock to create a base, however this not appropriate under a water retaining bank.
4) Acid sulfate soils and PASS disturbance. Acid sulfate soils can be brought to the surface by stripping, excavation, and traffic movement. This option has a high proportion of all these elements. Compaction on a soft foundation risks pushing up the adjoining soil.
5) Large footprint. The footprint consists of the area immediately under the bank plus a cleared area 3 m on each side, to protect the water retaining bank from tree roots.
6) Wet foundation. Difficult to build if there is water in the swamp, without building a second coffer dam or draining the swamp.
7) Water Retention. Difficult to build a water retaining bank from earth that also acts as a weir and requires rock protection. The rock protection is not water retaining, and the earth (clay) is susceptible to erosion. It can’t be built or maintained to the tolerance required to provide even distribution of flow over the crest and needs a hard crest to define the water level.

In summary an earth bank is not considered to be a viable solution.

4.3 Cantilever PVC Sheet Pile

This option assumes a lightweight Poly Vinyl Chloride (PVC) is used. It would be selected for its light weight, lower cost, and chemical resistance. Fiber reinforced Plastic (FRP) piles are also available however the sections are sized for heavier applications. The indicative design is shown in Figure 4.2. It consists of a simple cantilever wall. Rock erosion protection is shown at the base. This serves two purposes, a working platform for pile installation, and erosion protection when overflowing.

Key issues are:

1) Chemical resistance of piles. The PVC sheet piles are non-corrosive and resistant to acid except at high concentrations in excess of those at the site.
2) Structural strength. PVC piles have lower structural strength than steel. At the heights under consideration (conservatively up to say 1.5 m) the strength required is well within the capacity of available sections (in the order of 23 kN.m/m)
3) Deflection is greater than for steel. They need to deflect more to mobilize ultimate strength.
4) Geotechnical strength. The cantilever pile relies on the capacity of the supporting soil, which could be limiting given the soft substrate.
5) Seepage. PVC piles are frequently used for seepage cut off applications in levees and landfills. The interlocks can be sealed to reduce seepage; however, this will not be necessary. Calculation using a manufacturer estimate of seepage through the interlocks yielded very low quantities, less than 10 liters per day per 100 square meters of wall.

6) Constructability. It is anticipated that PVC piles can be pushed or driven into the site soils. The most likely obstruction would be submerged trees. Several placement options are available if conditions are more difficult including pre-ripping with an excavator ripping tyne or pre-driving a steel template.

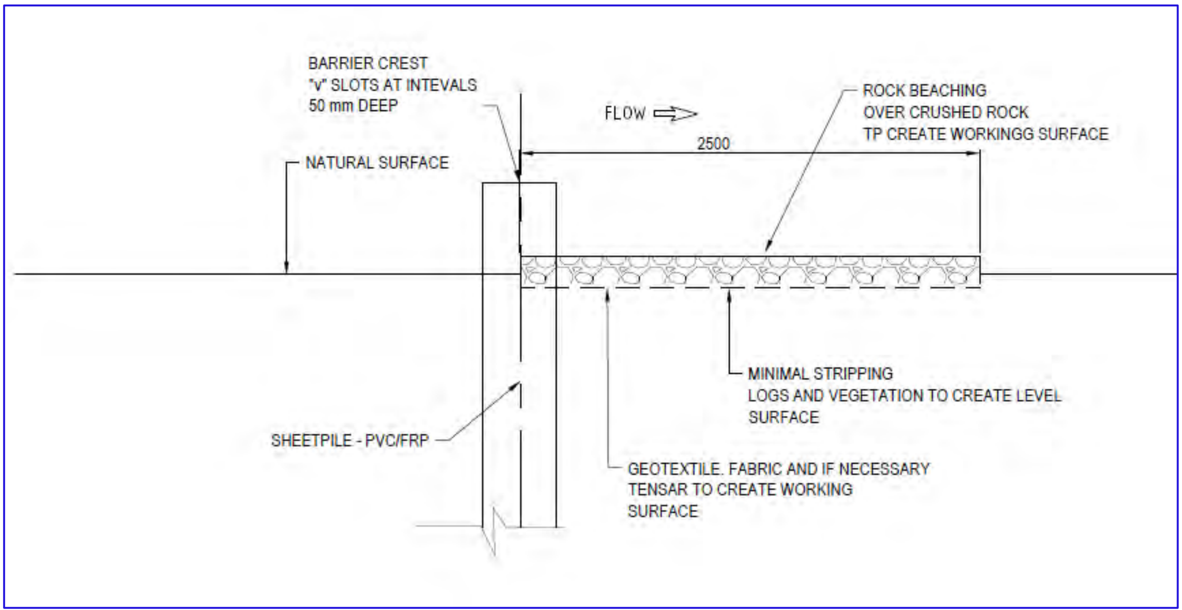

Figure 4.2: Cantilever - Sheet Pile Wall

Potential disadvantages of the design as shown are:

1) Lack of fire resistance. PVC piles are susceptible to fire damage, including small grass fires.

2) Possible damage by UV. As this design relies on the structural strength of the pile, UV damage is more critical than for other options. Manufactures can provide guarantees exceeding 50 years for UV exposure; however the material needs to be specified to achieve this.

3) Erosion protection may not be adequate for large drops, and the rock would need to be thicker

4) No access, or limited access in service, where the tailwater extends to the base of the wall

5) The platform does not provide good construction access in wet conditions, and it may be more difficult to place piles at the edge of the platform

6) The deflection of the sheet piles could be excessive and would increase the difficulty of maintaining the tolerance required for even flow over the crest.

4.4 Rock bank – sheet pile cut off

This option is similar to the cantilever wall and aims to rectify some of its deficiencies. The earth/rock bank is provided to just below crest level. This aims to provide fire protection, improve access, provide greater erosion protection, and reduce the sheet pile deflection.

The sheet piles would be used to provide a watertight barrier and seepage cut off. The embankment would provide structural support. The result is that the depth of pile can be reduced.

Compared to the Cantilever sheet pile it has the following advantages.

1) Construction access is improved, particularly if there is water in the swamp. This option may be the only approach that can be built with water in the swamp, and certainly the only option that avoids having machinery tracking in the water.
2) Operation and maintenance access would be better. It would allow pedestrian access across the structure when in operation, and depending on the length of pile protruding, may allow excavator or some vehicle access. Permanent access will be needed across one of the barriers to reach the regulator site.
3) Embankment provides fire protection to the piles
4) Less visual impact and potential for the embankment to grow over compared to the cantilever pile. Covering the rock with topsoil would help with this. This would be possible on all barriers except on those used for access.
5) Improved erosion control due to reduce drop
6) Sheet pile deflection is significantly reduced, making it easier to maintain the tolerance required
7) Relatively low site disturbance, compared to the earth bank, but slightly higher compared to the cantilever wall.

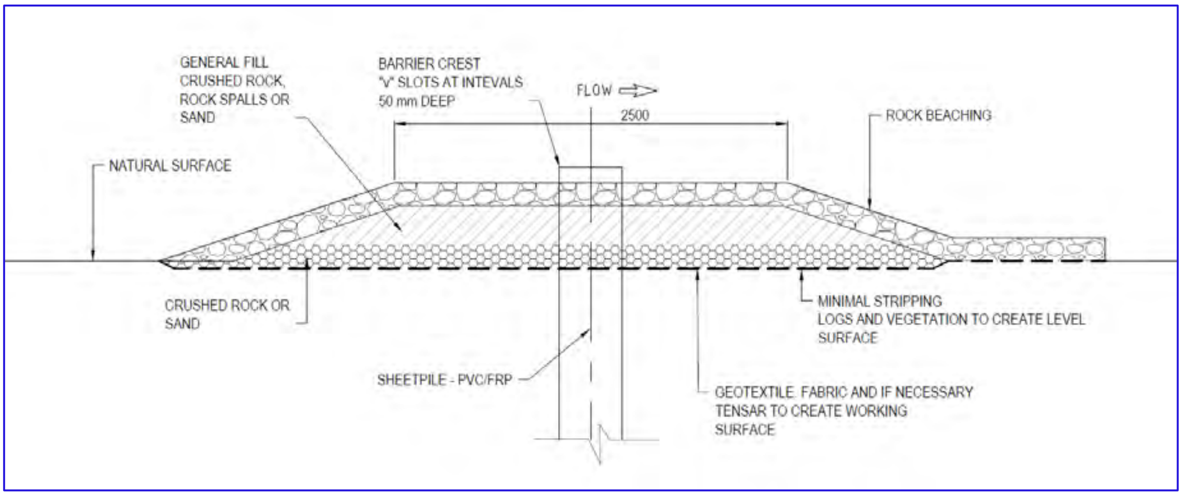

Figure 4.3: Rock Bank with sheet pile cut off

4.5 Discussion and Conclusion

A range of options were considered and ruled out in a screening process based on the criteria developed in the functional requirements. Some critical considerations are:

1) The swamp soil and water conditions are aggressive to many materials including mild steel and concrete, and their use in barriers and the regulating structure is not recommended
2) Methods to construct a watertight cutoff for the barrier whilst also minimizing the disturbance of acid and PASS soils are a challenge for most options

3) Implementation of an even distribution of surface flow across the swamp was considered important, and this led to a low score for options which could not be built and maintained with a crest to a fine tolerance to allow for even distribution of flow.

The conventional earth bank option was developed further and subsequently ruled out on the latter on points (2) and (3) above.

Structures based on a variation of PVC sheet pile are considered the most viable for meeting the functional requirements. Ultimately it was found that the rock bank with a PVC sheet pile cut off reduced the total depth of pile and this was adopted as the preferred approach. In the final design the pile acts as a hydraulic barrier, which is structurally supported by the bank. The bank provides a method for gaining access into the swamp to incrementally install the work and ultimately remove it.

5. Geotechnical Investigation, Interpretation and Analysis

The geotechnical work commissioned as part of this project comprised:

- Review of existing available geotechnical information
- Site investigation
- Interpretation of the current and previous investigation results
- Geotechnical calculation and design pertinent to the hydraulic barrier options

The investigation is provided as a technical memorandum in Appendix A.

5.1 Previous Investigations

Lithological logs are available from previous investigations within the swamp. The relevant projects are:

- Jacobs (August 2019). Boundary Creek and Big Swamp Remediation and Environmental Protection Plan, Soil sampling and well completion report.
- Jacobs (March 2017). Installation of additional monitoring assets. Bore Completion Report.
- SKM (2014). A hydrogeological investigation which comprised the drilling of three boreholes

The recorded coordinates for each bore, reproduced from Jacobs (2019) is listed in Table 5.1. The locations are shown and labelled on the design drawings.

Table 5.1: Previous Boreholes within Big Swamp

Bore ID	Date Drilled	Drilling Method	Coordinates[1]		Surface elevation (m AHD)	Borehole diameter (mm)	Termination depth	
			Easting	Northing			m bgl[3]	m AHD[4]
BH01	17/04/2019	GeoProbe	735858.9	5743834.9	141.9	203	6	135.9
BH02	7/05/2019	Hand	735838.9	5743863.1	141.8	60	3.6	138.1
BH03	7/05/2019	Hand	735853.3	5743889.0	141.7	60	3.6	137.7
BH04	23/04/2019	GeoProbe	735682.3	5743890.3	143.4	203	6	137.4
BH05	18/04/2019	GeoProbe	735686.9	5743921.0	143.1	203	6	137.1
BH06	18/04/2019	GeoProbe	735712.2	5743922.107	142.9	203	6	136.9
BH07	17/04/2019	GeoProbe	735721.7	5743948.325	142.5	203	6	136.5
BH08	25/04/2019	GeoProbe	735607.0	5743908.6	144.6	203	6	138.6
BH09	24/04/2019	GeoProbe	735609.7	5743944.4	144.4	203	6	138.4
BH10	24/04/2019	GeoProbe	735622.3	5743966.9	144.3	203	6	138.3
BH11	8/05/2019	GeoProbe	735469.3	5743898.1	147.1	203	6	141.1
BH12	9/05/2019	Hand	735438.0	5743952.7	147.2	60	3.4	143.8
BH14	25/04/2019	GeoProbe	735360.8	5743853.1	147.7	203	6	141.7
BH15	26/04/2019	GeoProbe	735330.5	5743870.0	147.4	203	6	141.4
BH16	7/05/2019	GeoProbe	735300.1	5743903.5	148.0	203	6	142.0

Bore ID	Date Drilled	Drilling Method	Coordinates[1]		Surface elevation (m AHD)	Borehole diameter (mm)	Termination depth	
			Easting	Northing			m bgl[3]	m AHD[4]
BH17	6/05/2019	GeoProbe	735266.8	5743903.0	148.1	203	5.9	142.2
BH18[2] (YS05)	23/03/2019	Hand	735276	5743824	148.7	60	3.6	145.1
YS01	21/03/2017	Hand auger	735733	5743850	142.9	100/65	3.0	
YS02	22/03/2017	Hand auger	735766	5743879	141.3	100/65	3.0	
YS03	22/03/2017	Hand auger	735821	5743910	142.3	100/65	3.0	
YS04	23/03/2017	Hand auger	735304	5743771	150.0	100/65	3.0	
YS05	23/03/2017	Hand auger	735276	5743824	148.7	100/65	3.0	
YS06	23/03/2017	Hand auger	735021	5743832	149.8	100/65	3.0	
TB01a	14/5/2014	Hollow Augur	735869	5743770	144	229	12	
TB01b	28/05/2015	Mud Rotary	735869	5743770		143	19	
TB01c	28/05/2015	Mud Rotary	735869	5743770		143	36.5	

Note:

1. Datum MGA94 zone 54 – BH01 to 018 survey to an accuracy of ±0.030 m. TB01a, TB01b, TB01c – Accuracy unknown, converted from Zone 55; recorded with the same coordinate, however located within 10 m of each other.
2. BH18 coordinates were taken via handled GPS and to an accuracy of ±3.0 m
3. m bgl – metres below ground level
4. AHD – Australian Height Datum

5.2 April 2021 Investigation

The geotechnical field investigation commissioned as part of the current project was carried out in April and May 2021. It comprised of three hand auger holes and seven cone penetrometer tests (CPT) at the locations along the proposed hydraulic barriers. The CPT's are located adjacent to pre-existing bores and adopt the same numeral as the adjacent boreholes. They collect additional soil parameters for engineering design.

The recorded coordinates for each CPT are listed in Table 5.2, and the locations are shown on the design drawings.

Table 5.2: 2021 Site Investigation Locations

CPT ID	Easting	Northing
CPT-01	735870.00	5743774.50
CPT-02	735857.00	5743807.10
CPT-05	735688.20	5743920.40
CPT-08	735609.90	5743908.60
CPT-10	735622.00	5743965.10
CPT-11	735472.00	5743898.30
CPT-15	735338.50	5743865.40

Datum: MGA94 Zone 54 Date: 26-27/04/2021 Please note that handheld GPS device used for location of sites has limited accuracy and is not to be used unless confirmed by filed survey.

The hand augur holes were located adjacent to the existing bores, BH01, BH06, and BH10, and were used for sample collection and classification testing.

5.3 Geotechnical Analysis

Conclusions from the geotechnical analysis are summarized below.

The cantilever sheet pile wall option was found to have excessive pile deflection, and the depth of pile necessary to achieve geotechnical stability was excessive. This finding led to the option being ruled out. A combined sheet pile and rock embankment option was subsequently assessed and adopted as the hydraulic barrier design solution.

The assessment of the combined sheet pile and rock embankment option was undertaken using Plaxis 2D (2021) software. Plaxis analyses were performed to design the sheet piles for both strength and serviceability in lateral and axial directions, as well as factor of safety checks for both the long term case and a temporary excavation in front of the sheet pile case. Structural properties for the vinyl sheet pile (Tidewall TW50) were determined from information provided in publicly available product manuals. The ground profile and soil parameters adopted in the Plaxis models for each bank are shown in Appendix A.

To minimise the risk of cutting off groundwater flow under each bank, a staggered sequence was used, with a short 2.0 m sheet pile alternating between the sheet pile design embedment depths.

Seepage analysis to determine the rate of groundwater flow underneath the sheet piles, as well as the hydraulic gradient (i) for piping failure was checked separately in Geostudio Seep/W software. Conservative permeability (k) values ranging between 1×10^{-5} to 1×10^{-7} m/sec were adopted for the silty sand and silty clay layers.

The long term and temporary Plaxis results are summarised in Tables 5.3 and 5.4, and the Seep/W results are shown in Table 5.5 below.

Table 5.3. Summary of Plaxis 2D output for construction of hydraulic barrier and rising of water.

Location	Embankment height (mm)	Max. Sheet pile cantilever (mm)	Sheet pile embedment (mm)	Max. Total sheet pile length (m)	Max. lateral deflection (mm)	Max. settlement (mm)	Max. bending moment (kN/m/m)	Factor of safety (FOS)	Clay depth (mbgl) & S_u (kPa)
Bank J3	500	250	3000	3.75	4.5	3.1	0.420	6.86	0.0-3.0 m
	1000			4.25	7.1	6.4	0.780	2.18	Su = 16kPa
Bank J4	500	250	3000	3.75	1.6	3.4	0.120	16.44	0.0-5.0 m
	1000			4.25	2.6	7.7	0.266	6.95	Su = 48kPa
Bank J5*	500	250	4000	4.75	5.9	4.8	0.395	6.91	0.0-6.0 m*
	1000			5.25	9.4	10.1	0.792	2.29	Su = 15kPa
Bank J6	500	250	4000	4.75	8.9	10.0	0.491	5.08	0.0-6.0 m
	1000			5.25	13.5	21.2	0.555	2.81	Su = 11kPa

*Bank J5 – southern extent of bank clay is 0.0 - 3.8 mbgl (S_u = 19kPa), underlain by sand.

Table 5.4. Summary of Plaxis 2D output for hydraulic barrier maintenance (i.e. 0.5 m temporary excavation).

Location	Embankment height (mm)	Sheet pile cantilever (mm)	Sheet pile embedment (mm)	Total sheet pile length (m)	Max. lateral deflection (mm)	Max. settlement (mm)	Max. bending moment (kN/m/m)	Factor of safety (FOS)	Clay depth (mbgl) & S_u (kPa)
Bank J3	500	250	3000	3.75	13.7	0.4	0.923	5.41	0.0-3.0 m
	1000			4.25	12.2	1.8	1.424	1.10	Su = 16kPa
Bank J4	500	250	3000	3.75	3.8	1.0	0.873	13.72	0.0-5.0 m
	1000			4.25	6.2	0.6	1.411	4.72	Su = 48kPa
Bank J5*	500	250	4000	4.75	14.4	0.5	0.957	2.62	0.0-6.0 m*
	1000			5.25	13.5	1.7	1.422	1.12	Su = 15kPa
Bank J6	500	250	4000	4.75	15.7	1.6	0.931	2.82	0.0-6.0 m
	1000			5.25	16.3	9.1	1.421	1.07	Su = 11kPa

*Bank J5 – southern extent of bank clay is 0.0 - 3.8 m bgl (S_u = 19kPa), underlain by sand.

Table 5.5. Summary of Seep/W output for seepage analysis.

Location	Sheet pile embedment (mm)	Max. flow rate per m length beneath sheet pile (m^3/sec)	Hydraulic exit gradient (i)	Factor of safety (FOS)
Bank J3[1]	2000[2]	1.3×10^{-7}	0.07 – 0.20	> 5.0
	3000		0.07 – 0.17	> 5.8
Bank J4	2000[2]	7.8×10^{-9}	0.10 – 0.19	> 5.2
	3000		0.10 – 0.14	> 7.1
Bank J5	2000[2]	4.5×10^{-9}	0.10 – 0.19	> 5.2
	4000		0.10 – 0.11	> 9.1
Bank J6	2000[2]	1.8×10^{-9}	0.01 – 0.18	> 5.5
	4000		0.01 – 0.08	> 12.0

Notes:

1. Seep/W design profile and results adopted for Banks J1 and J2.
2. 'Short' pile depth in 'staggered' sequence for hydraulic barrier.
3. A water level of 1.2 m above natural ground surface was modelled on the upstream side of the wall, with a maximum embankment and cantilever height of 1.0 m and 0.2 m respectively.

The sheet pile wall design has satisfied the sheet pile strength requirements. Factors of Safety for stability and hydraulic exit gradient are satisfactory. Deflection and settlement have been minimized whilst also minimising the sheet pile embedment depth to reduce the risk of cutting off groundwater flow.

Due to the very soft nature of the soil, establishing a suitable working platform for the construction of the embankment requires a layer of Combigrid 40/40 (or equivalent) composite geogrid and geotextile, followed by a 300mm minimum thick layer of free drainingrock aggregate. An opening should be left for the installation of the sheet piles. The opening is to be closed upon installation of the sheet piles. The sheet piles will be stepped for design and cost optimization, as well as to address concerns of cutting off groundwater aquifer flows.

The bank is to be constructed with rock aggregate in lifts no greater than 300 mm, alternating between both sides until the design height of the bank is achieved. Immediate settlement should be allowed to occur prior to trimming the sheet piles to design level.

Surcharge loads from construction equipment should be limited to no greater than 10 kPa (approximately equivalent to a 20 tonne excavator) to limit sheet pile movement and settlement of the bank.

The extraction of the sheet piles after use should generally be achievable. The longer the sheet piles remain in the ground, the greater will be the resistance to pulling.

6. Hydraulic Barrier Design

6.1 Introduction

The location and height of the hydraulic barriers was investigated by GHD (2020). Multiple iterations of the coupled surface water-groundwater model arrived at a recommended barrier configuration to achieve the objective of re-wetting the swamp through distribution of surface water flows. This comprised seven hydraulic barriers, at the locations and heights summarised in section 6.3.

This section documents the basis of design for blocking bank alignments and vertical geometry. The alignments and pond levels match the hydraulic design provided. Refinements are made to the alignments for constructability.

The design is documented in the drawing set (Appendix B), showing embankment alignments and longitudinal sections. The footprints shown assume a standard rock bank with 3.5 m crest and batter slopes at 3:1. The footprint allows for the width of an excavator up to 20 tonne. The design states this as a maximum, and allows the contractor to reduce this, which is to provide the contractor with an incentive to construct the works with smaller machinery and a smaller footprint if it proves feasible.

6.2 Survey Ground Model

Time constraints in this project did not allow for the procurement of feature survey along the bank alignments.

The design is based on a ground model built from the available LIDAR data. The dataset was used in the development of the TuFlow model (Jacobs 2019), Yeodene (Big) Swamp Groundwater and Surface water modelling. This was used in subsequent surface water modelling in the concept design. The data is 1 m resolution grid.

In the current project the data has been manipulated for use in AutoCad Civil 3D:

- Thinned to reduce file size to produce a TIN model ground model
- Transposed from the supplied coordinate system, GDA94 Zone 55, to Zone 54.

A number of survey spot levels have been acquired in previous projects, at boreholes, in the fire trench and as spot levels in the swamp. It is understood these were used previously to check the accuracy of the ground model. Review in this project showed a good match between ground survey and LIDAR in open areas as would be expected, and slightly more variability in the base of fire trenches and forested areas.

It is concluded that the Lidar based ground model is adequate for conceptual design. It appears to provide a reasonable estimate in the body of the swamp, noting that the areas surveyed are on relatively open cleared ground. It is not considered ideal for detailed design. In particular, caution is recommended in the following instances:

- Where the tie in of banks to higher ground is not definitive
- Creek and ditch crossings
- Use of outputs for material volume estimates
- Where there is limited relief and the natural ground is assumed to form a hydraulic barrier which is relied on

It should also be noted that the bank alignments are for the most part in forested areas, slightly off the cleared paths. The ground slopes significantly up from east to west, and the few surveyed points cannot be taken as indicative of the ground level along the alignments.

It is required that ground survey along and each side of the proposed alignments be acquired as part of the implementation, and that this be used to confirm the barrier design extents and material quantities.

6.3 Bank Alignments and Elevations

6.3.1 Concept Design

The conceptual bank alignments are provided in GHD December 2020 and are reproduced in **Figure 6.1** below. This work is referred to as the Concept Design in the following discussion.

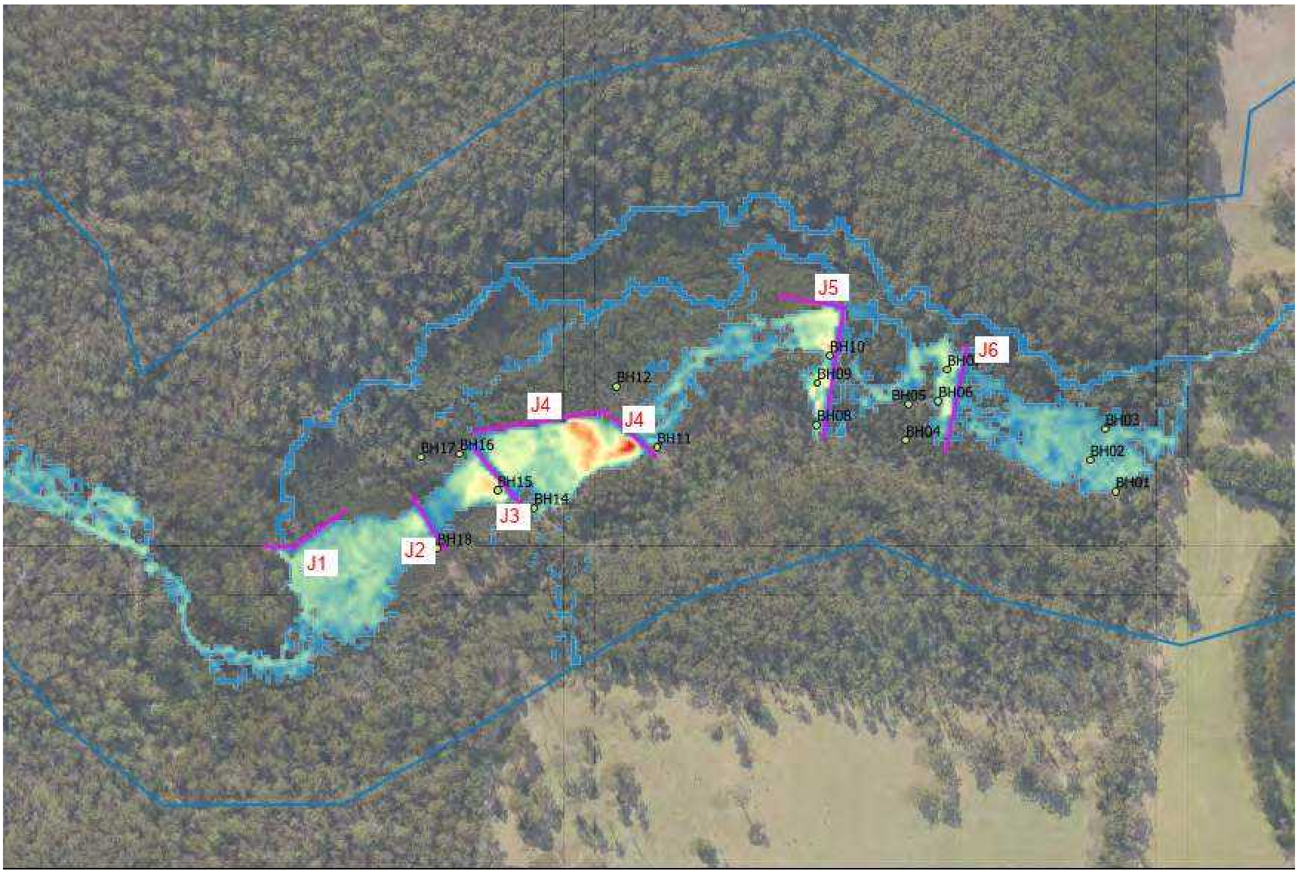

Figure 6.1: Preferred Barier configuration (from GHD 2020 draft)

The numbering scheme in the concept was an outcome of the iterative process followed, which resulted in a somewhat confusing codification. For this design the barriers have been re-numbered from upstream to downstream, as listed in **Table 6.1**. Barriers 7 and 8 have been amalgamated into a single barrier. The pool level refers to the lowest water level that can be held upstream of by each barrier.

The Barrier Level refers to the top of the barrier listed in concept design. Most barriers are designed to overflow at Pool Level, with the following exceptions:

- The north part of J4 is slightly higher, to block flow
- The two barriers at the west of the swamp (J1 & J2) elevate the water as part of the scheme to regulate the distribution of flow between the Big Swamp and Boundary Creek. The pool level is to be set by the regulator in barrier J1.

Table 6.1: Barrier Numbering and Concept Design Levels

Previous number (GHD 2020)	Adopted Number	Concept Barrier Level (m AHD)	Concept Pool Level (m AHD)
1	J1	148.7	148.5
5	J2	148.7	148.5
6	J3	147.9	147.9
7	J4 – north	147.7	147.6
8	J4 – east	147.6	147.6
3	J5	144.9	144.9
9	J6	142.7	142.7

6.4 Design Basis

The principles followed in the design layout are outlined below.

The alignments are to follow the concept design alignment as closely as practicable. The concept alignments aim to spread water evenly across the width of the swamp, to maximise the wetted area downstream, as well as upstream. As such the barriers chose a path that maximises spread and are not necessarily the shortest path across the swamp. Attempts were made to refine the alignment to bring the barriers closer to the existing tracks and apply standard minimum radii at changes in direction, however these were not to compromise on the lateral spread of water at the barrier.

Existing groundwater monitoring bores are to be retained undamaged and be relatively accessible from the barriers. Whilst it would be desirable for barriers to follow the cleared paths that link the monitoring bores, this was only occasionally achievable. The cleared paths were built to link the bores and were not conceived as embankment alignments. Where the bank is offset, typically slightly to the east of the cleared path, the design still gains some benefit in terms of the vegetation clearance.

The barrier ends are to tie into higher ground. This is to reduce the risk of outflanking. This recognises that the natural ground material is not engineered and is vulnerable to erosion (which could be reduced via rock banking). It also allows for survey inaccuracy. High ground is defined as land 0.25 m higher than the design pool level. The barrier cut off is to extend beyond the intersect of the pool into adjoining high ground.

The barrier crest is designed to maximise the later spread of water, and as such should not prematurely rise at the abutments.

Curved alignments have a minimum15 m radius. This is a typical minimum radius for vehicle movement and hence construction practicality.

The sheet pile crest is designed 0.05 m higher than the pool level in most barriers. This allows for "V" notch weirs to be installed at intervals across the crest, with the invert of the V set at pool level.

6.5 Barrier Descriptions

6.5.1 Barrier J1

Barrier J1 aims to elevate the water level in Boundary Creek and direct water into the swamp. Its level is set at the same elevation as barrier J2. As shown in **Figure 6.1** the intention is to distribute water between two flow paths:

- In Boundary Creek, through the regulator in Barrier J1
- To the swamp via Barrier J2.

The crest level at the regulator in Boundary Creek is set 0.4 m higher than the target pool level, to provide freeboard at the regulator gate. This is to raise the pedestrian access platform well above water level.

The crest level in the remainder of barrier J1 is set 0.2 m higher than the target pool level as per the concept design. This is to create the driving head so that the pool level can be manipulated to regulate the flow over Barrier J2.

The bank alignment is generally as per the concept design, but slightly shorter.

Access to this bank for construction and operation of the regulator is difficult and this is discussed further in section 9. The design assumes construction access from the east, through the swamp rather than the more direct but steep path from the west.

6.5.2 Barrier J2

Barrier J2 is at the head of the swamp and works in conjunction with Barrier J1 and the regulator to control inflow.

The alignment is as per the concept, with the exception that it has been extended to the east to take in what may be a fire trench. As the intervening ground between the trench and swamp is only 0.2 m higher than the target level, there is a risk of outflanking the barrier via this path.

The crest of the barrier is set 0.2 m above the pool level. This barrier includes two short lowered sections each equivalent to a pile width, set to pool level. This is to replicate the concept design which provides a single 2 m weir to distribute the flow.

6.5.3 Barrier J3

The Barrier J3 alignment closely follows a string of three monitoring wells, BH14, BH15 and BH16. Compared to the concept, the alignment has been refined to bring it closer to the existing cleared access path and the bores. The north-west end is curved upstream to better tie into higher ground. The south east end is extended to cross a drainage line (possibly an old fire trench) which is continuous and parallel to the marked fire trench on the south-east side. The south-east end is located on the cleared access.

The need for this barrier was reviewed during the design. It is 0.3 m higher than barrier J4, and there is a considerable overlap of the pools. The design team chose to retain the barrier in the design rather than revisit the hydraulic modelling.

6.5.4 Barrier J4

Two separate hydraulic barriers shown in the concept (7 & 8) are amalgamated to form Barrier J4. The alignment is identical to the concept, with the exception that the two are joined, and a curved alignment is added at the intersection. This is to avoid a weakness in the barrier in the gap between the two.

The western section acts as a block bank and has a crest level 0.1 m higher than the remainder.

The banks are joined to ensure the hydraulic barrier is continuous. In practice they would be joined by the construction access path.

6.5.5 Barrier J5

Barrier J5 closely follows a line of bores, BH08, BH09 and BH10. The alignment has been refined to run closer to the bores and access path to limit land clearing. At the north end, the alignment curves to meet high ground.

Compared to the concept design it is located slightly west at its southern end. This does not limit the lateral spread of water. At the southern end abutment an apparent strip of slightly higher ground may need to be cut through (if it exists and is not just an anomaly of the ground model) to maximise the lateral spread of water.

At the northern end the bank does not follow high ground as far west as the concept. It is 35 m shorter and it is unclear why the concept showed the bank extending further.

6.5.6 Barrier J6

Barrier J6 is the final bank. It follows the line shown in the concept design, and downstream of a line of bores, BH05, BH06 and BH7. Consideration was given to relocating the alignment closer to the bores and access track; however, this would significantly limit the lateral spread of water, and size of the pond.

6.5.7 Eastern Outflow

The concept does not specify a barrier at the eastern outflow.

The existing agricultural drain at the eastern boundary is to be retained. This collects outflow from the swamp and directs it to the creek. If the agricultural drain were filled, then out-flow from the swamp would spill more frequently across the farmland. The intention is that there would be no change to the hydraulic behaviour at the eastern boundary.

The treatment of the existing fire trench that flows into a drain is documented in section 8.

6.6 Bank Quantities

An estimate of quantities has been made to establish the general magnitude of any embankment works, refer Table 6.2.

Quantities assume the longitudinal profiles shown in the design drawings are installed and that a rock embankment is built up to the "Design Bank Level" shown on the longitudinal sections.

Quantities were extracted from the AutoCad Civil 3D model. The raw quantities do not make any adjustment for bulking, compaction, settlement, or material loss, except as stated. These must be included at a later date. Quantities assume:

- Additional 0.1 m thickness under the full plan area, for settlement, rock loss and survey error.
- A 1.0 m long apron is applied to banks over 0.45 m high, and that there is a total length of 100 m of this.
- Quantities are rounded up to the nearest 10 cum.

The additional allowance of 0.1 m results in an increase of fill in the order of 400 m^3. This is intended to provide some safety margin to the total quantities, however it also indicates that the preference is to minimise any stripping, particularly if it needs to be disposed of off site.

Table 6.2:

Bank	Plan Area (m^2)	Fill (m^3)
J1	280	90
J2	290	80
J3	530	200
J4	940	540
J5	800	350
J6	480	150
Totals	3320	1410

7. Flow Control Regulator

7.1 Overview

A flow control regulator is to be installed in Boundary Creek at Barrier J1. Its purpose to raise the water level to enable the manipulation of the flow distribution between the creek and the swamp. The intent is that a proportion of low flows and supplementary flows in the order of 2 ML/d which might otherwise remain in Boundary Creek will be pushed through the swamp whilst still retaining flow in the creek. The site is located immediately downstream of the first natural overflow.

The concept design (GHD 2020) modelled a 50%-50% flow split between the creek and swamp. It assumed equal sized weirs in barrier J1 and J2, each 2 m long. This was a modelling expedient which avoided the complexity of modelling a gate; and provided an indicative estimate of how it might be operated.

The hydraulic behavior of the creek and swamp are still not entirely certain. Observations from a recent field inspection downstream of the regulator site suggest there may be more cross connection between the two than the surface water model predicts. This is not necessarily problematic; but reinforces the need for an adaptive management approach to optimize the flow distribution. The regulator will aid with this management of flow distribution.

7.2 Control Philosophy

This regulator gate is to be a fixed crest overshot lay flat style gate.

It will operate as a fixed structure most of the time. It is not proposed to be actively operated on a weekly or even monthly basis. The intention is that the geometry of the regulator gate, combined with the geometry of the two slots in barrier J2, will automatically affect a flow split that meets the functional requirements, and which is similar to that trialed in the hydraulic model. The gate enables the flow split to be adjusted if necessary; and may be adjusted on a seasonal basis by lowering it in wetter periods.

7.3 Regulator Design

The regulator superstructure is designed as a continuation of the sheet pile hydraulic barrier. Sheet pile is used as the upstream hydraulic barrier and structure walls. Mass concrete is used as the foundation to support the regulator gate. Concrete is otherwise avoided in structural applications.

The design intentionally avoids the need to import substantial volumes of cast insitu concrete or the necessity to bring large volumes of materials. The use of concrete is minimised due to durability concerns with steel reinforced concrete. The concrete that is used – mass concrete on the floor – is specified to improve durability in potentially acid water and groundwater conditions. Whilst the conditions elsewhere in the swamp are poor for reinforced concrete, it was considered that in the upper reach the conditions are less aggressive, and some concrete could reasonably be used.

7.4 Gate Design

The gate is to be procured as a bespoke item to a generally standard design.

The following items will be procured from the gate manufacturer:

- Lay flat overshot gate designed for a 1.22 m wide opening and to be floor mounted
- Manual hand wheel operated actuator (lockable with Barwon Water padlock)
- Integral walkway and handrails for the width of the regulator supported by either the gate or walls
- Top beams and cross beam on the sheet pile walls.
- Adjustable fittings affect a watertight seal between the regulator sides walls and the upstream sheet pile wall

All gate and steel components are to be stainless steel, grade 316.

7.5 PVC Sheet Piles

Identical size PVC sheet piles are specified for the hydraulic barrier cut off and the regulator. The piles are sized for strength and serviceability for the most adverse case encountered in the project.

Proprietary corner pieces will be needed at each of the regulator wall intersections.

The quality piles selected durability under ultraviolet light exposure needs to be assured. Piles are available from credible suppliers with guarantees exceeding 50 years for UV exposure, and this will be required.

7.6 Construction

Access for construction is potentially problematic. The better access for construction is from the south across the swamp. The works will need to be staged in a manner that allows the foundations of hydraulic barriers at J1 and J2 to be installed in order to provide access for the regulator construction.

7.7 Operation Access

The primary access for operation will be across the swamp via barrier J2 and J1. This will normally be by pedestrian access and would include inspection to ensure the flow distribution is functioning adequately.

This access way would only be suitable at lower flows, as it would involve stepping across the flowing water channels. At high flows the northern access would need to be used. This involves gaining access to the northern side of boundary creek, driving to the site by forest tracks, and then walking down the slope on a pedestrian path. The pedestrian access path is to be installed as part of this project.

8. Fire Trench and Drain Filling

A remedial action identified in the REPP is infilling *the existing fire trenches and agricultural drain at the eastern end to allow the swamp to retain more water over the winter months.*

This section describes the approach to infilling the fire trench and reinstating natural drainage paths on the southern side of the swamp.

It is not proposed to fill the agricultural drain at the eastern boundary as part of these works and the reasoning behind this is explained below.

8.1 Fire Trench Objectives

The primary objective of filling the fire trench is to prevent it diverting surface runoff around the swamp and to reinstate the natural flow paths. The intent is that the inflow will contribute to maintaining a saturated environment in the swamp.

The fire trench was built in 2011 to prevent the spread of a peat fire. This function is to be maintained. The organic peaty material in the spoil banks is therefore not considered a suitable fill material, and the trench is to be filled with non-organic fill.

The fill material and level of compaction should aim to reinstate permeability characteristics similar to the original material. This is so that the flow of groundwater is not interrupted or diverted.

During the construction of the fire trench, large trees were retained. The number of these is unknown, however they are to be retained, and the works should not unnecessarily reduce their viability.

8.2 Fire Trench Filling

The fire trench is to be filled over its entire length along the southern side of the swamp. At the eastern end, where it continues into the body of the swamp, it is to be filled up to the edge of the swamp, to a point it can be practically constructed without disturbing PASS soils or draining the swamp.

Sections of impermeable fill are to be installed intermittently to act as blockages to flow along the trench. These are located in line with the access to each hydraulic barrier.

Fill material is to be a clean mineral fill, imported to site. It should be broadly similar to the existing material identified in the top 2 m of boreholes YS01, YS04, and TB01a, with the exception that it should not be organic or peaty. These materials are classified Silt, Fine Sand, light Clay, and mixtures thereof.

The surface area to be filled will be cleared by slashing, but not excavated. The clean fill would be placed over the top of this and filled to slightly proud of the original natural surface. Compaction would be by track rolling, but not so heavily compacted as to be impermeable water. Topsoil would then be placed over the top.

Existing spoil banks are to be breached at intervals to ensure free flow of surface drainage. The excess material may be spread as shallow topsoil over the filled fire trench, provided it is suitable quality and not containing Acid Sulfate Soils. The remainder of the existing soil banks are to be retained as unchanged. Generally, they will be altered only where it is convenient to assist with the work.

8.3 Agricultural Drains

It is not proposed to infill the agricultural drain at the east boundary of the site, as part of these works. Whist this is listed as a recommendation in the REPP, the basis for doing so has not been properly established.

The drain currently intercepts overflow from the swamp, and directs it to the north, along the fence line, into boundary creek just upstream of hydrographic station 233276. If the drain were filled, this overflow would discharge across the pasture to the east, and presumably it was built to prevent this.

The hydraulic design for filling of this area was not investigated in the most recent round of hydraulic modelling (GHD 2020). Jacobs (2018) developed a conceptual structure at this point which aimed to retain the outflow capability whilst retaining water upstream.

The need for filling the eastern agricultural drain was considered by the project team. The consensus was that at present water ponds adequately in the area, and that there is no need for additional retention of water. Consequently, the decision was made to leave this area unchanged.

9. Access and Clearing

The following provides information on requirements for construction access and ongoing operational access.

9.1 Functional Considerations

The following issues need to be considered:

- Access is categorised into two broad types:
  - Permanent operation access that will need to be retained for operation, for as long as necessary to rehabilitate the site
  - Temporary Construction access, where access is no longer required after completion of construction
- The footprint of the works is to be minimised to the extent practical. It is expected that the temporary construction access swill be rehabilitated over time.
- Access ways need to be adequate width and quality to allow efficient construction of the work.

9.2 Permanent Operation Access

Permanent in the context of this project refers to as long as necessary for the site to be rehabilitated; to the point that equipment and infrastructure does not need operating or maintaining and is removed or decommissioned when appropriate.

The permanent access paths are the preferred paths for primary construction access and the carriage of materials and heavy machinery to site. They are described in Table 4.1. Whilst access is also possible along the fire trench path (track 10) it is anticipated that the main pathway for materials will be by track 3.

Table 9.1: Operational Access

Track	Location	Description	Physical Requirement
1	Yeodene- Forest Road to the farmhouse parking	Existing two-wheel drive access.	Gravel and maintain during construction.
2	Farmhouse to south-east corner of the site	Existing unformed access track to the south east corner of the forest. Gradient approximately 5%.	Form access and gravel. 3 m wide access.
3	South forest boundary to barrier J2	This is the better of the existing pathways to the upstream end of the swamp.	Form and gravel. Some tree clearing. Required for efficient delivery of construction material and for ongoing access to the regulator and hydrographic station.
4	Boundary to hydrographic station 233275	Existing unformed track to hydrographic station from Track 4	Maintain in current condition or better.
5	Regulator Access, Bank J1 & J2	This will be a new track that leads from Track 4. It crosses the proposed Bank J2 and J1 to access the regulator	Utilize bank J1 and J2 as designed to access the regulator at most times, except during high flows.

Track	Location	Description	Physical Requirement
			Form and gravel 3 m wide access track to link the banks and Track 4
6	North Regulator Access	A network of existing four-wheel drive forest roads exists on the north side of the swamp and includes a creek crossing at hydrographic station 233275	A secondary access path is required to the regulator from the north side. Vehicle access direct to the regulator from the north is considered too steep and intrusive. It is proposed to cut a pedestrian access path linking an existing forest road for a distance of xx down the hill to the regulator. This is a vertical height of 10 m. Access to the start would be by existing forest tracks which will remain unchanged.

Please refer to the design drawings for locations of access tracks.

9.3 Construction Access

The area required for construction access is shown on the design drawings.

Table 9.2: Construction Access

Track	Location	Description	Physical Requirement
10	Southern fire track and trench	Existing unformed parallel to fire trench.	Retain the unformed access track at the completion of the work, in a similar condition as the existing.
Fire trench	Fire Trench	Existing fire trenching and spoil bank. Overgrown.	Clear sufficiently to fill the fire trench, topsoil, and redirect drainage.
13	Bank J3	From track 7 – across the hydraulic barrier J3 and linking the regulator. The temporary access includes a vehicle turning and lay down area	Level and topsoil the cleared areas beyond the constructed barrier.
14	Bank J4	From track 7 – across the hydraulic barrier J4. Link to Track 8 to allow vehicle turning.	Level and topsoil the cleared areas beyond the constructed barrier.
15	Bank J5	From track 7 – across bank J5 and slightly beyond. Construction vehicles will need to reverse out.	Level and topsoil the cleared areas beyond the constructed barrier.
16	Bank J6	From track 7 – across bank J6 and slightly beyond. Construction vehicles will need to reverse out.	Level and topsoil the cleared areas beyond the constructed barrier.

Appendix A. Geotechnical Investigation

Jacobs

Memorandum

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Subject	**Geotechnical Investigation Report**	**Project Name**	Yeodene Big Swamp Hydraulic Barriers
Attention	Tyson Fehring	**Project No.**	IA258200
From	John Paouros		
Date	25 June 2021		
Copies to	**Des Andrews, Lee Wei Ong, Neville Paynter**		

1. Introduction

1.1 Background

The 'Yeodene Big Swamp' project involves the detailed design of hydraulic barriers throughout the swamp in order to maintain a near-constant water level at or above target levels. The barriers also require some form of flow control to allow flexibility to optimize the flow regime to meet the inundation requirements for acid sulphate soils (ASS) within the swamp and the flow regime downstream of the swamp.

Barwon Water has commissioned Jacobs to undertake a geotechnical investigation on the ground conditions of the site and the detailed design of the hydraulic barriers. This memorandum presents the findings from the geotechnical investigation undertaken at the swamp that will assist in the assessment of a suitable hydraulic barrier system.

1.2 Objective and scope

This memorandum aims to provide information on the subsurface conditions which will aid and facilitate the geotechnical assessment of the proposed hydraulic barriers.

The scope of work comprised the following:

- Review of available geotechnical information.
- Undertake a geotechnical investigation of the site by conducting seven cone penetrometer tests (CPT), including collecting soil samples from three hand auger holes.
- Collection of soil samples for visual classification and geotechnical laboratory testing.
- Reporting of field investigation and laboratory test results; and
- Provide advice and recommendations for the hydraulic barrier design.

2. Existing site information

2.1 Published geological information

The Geological Survey of Victoria (1996) map sheet for the region (Colac 1:250,000) indicates that the site is likely to be underlain by alluvial flood plain deposits (Qra), shallow marine and lagoonal deposits of Demons Bluff (T_{ed}) and Dilwyn (T_{ad}) Formations.

These deposits comprise mainly of silt, clay, sandy clay, fine and clayey sand with carbonaceous pyrite and arenaceous foraminifera. An approximate location of the site is shown on the extract from the geological map in Figure 2.1.

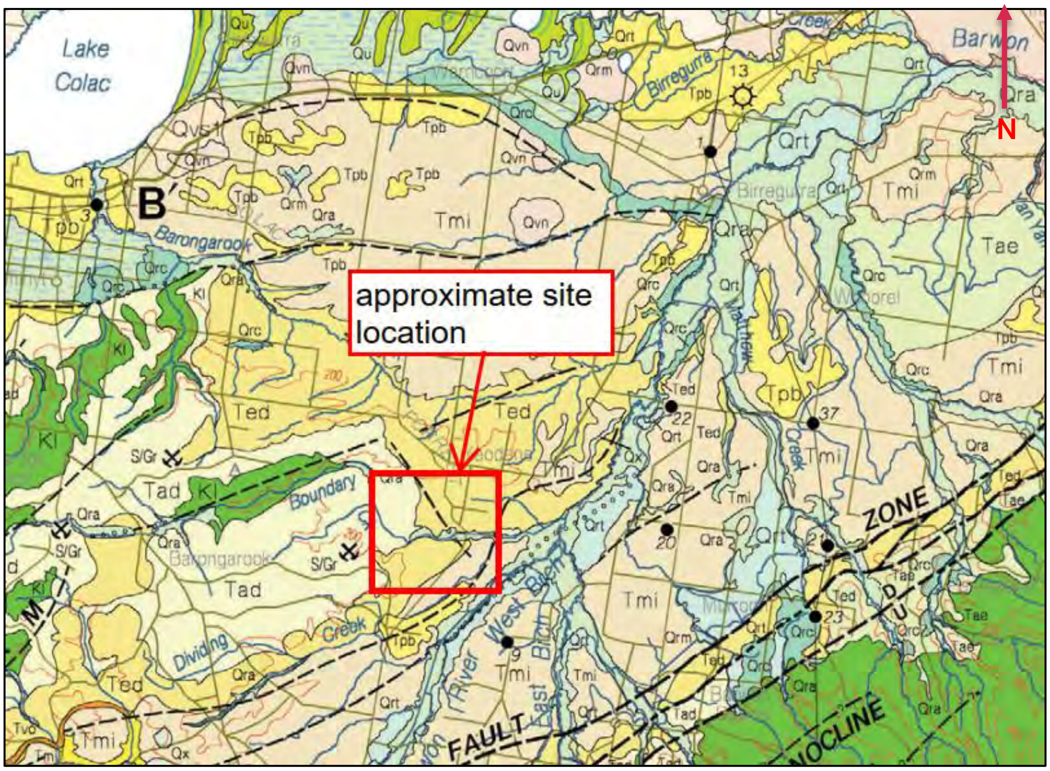


Figure 2.1: Extract from 1:250 000 Colac geological map sheet (Geological Survey of Victoria, 1996) (not to scale)

2.2 Site conditions

Yeodene Big Swamp is located on Boundary Creek approximately 15 km south east of Colac, to the west of Colac-Forrest Road and about four kilometres upstream from the confluence of Boundary Creek and Barwon River. The site slopes downwards towards the east of Boundary Creek and is vegetated with trees and shrubs.

All investigation locations were accessible by foot and an all-terrain CPT truck and support vehicles. At the time of the investigation, the areas were covered with moderate grass and no obstructing services were present.

2.3 Past investigations

A hydrogeological investigation was previously performed by Jacobs in May 2019 which comprised the drilling of eighteen boreholes with standpipe piezometer. The investigation was undertaken across the entire extent of the swamp. The maximum depth of the borehole investigated was approximately 6.0 mbgl. Silty clay, sandy clay and clayey silt was generally encountered overlying clayey and silty sand. The results of the investigation indicate the material present on site to be consistent to that of alluvial floodplain deposits and Demons Bluff and Dilwyn formations. However, there was some variability in the depth of the subsurface clay and sand layers.

In May 2014, an investigation at the Yeodene swamp was performed by SKM (now Jacobs) which comprised of three deep boreholes. The maximum borehole depth was approximately 36.5 m bgl. Silty and sandy clay was generally encountered overlying sand and silty sand at the depths of 9m and 13mbgl. Similarly, the findings of the report indicate the subsurface conditions to be consistent to that of Demons Bluff and Dilwyn formations.

It was noted that no soil penetration testing was undertaken in the previous investigations.

3. Geotechnical investigation

3.1 Fieldwork

As part of the hydraulic barrier detailed design, a geotechnical investigation was carried out in April and May 2021 which comprised of three hand auger holes and seven cone penetrometer tests (CPT). The completed CPT locations is presented in **Appendix A** along with a graphical summary of the findings from the cone penetrometer and previously completed borehole investigations.

The geotechnical investigation was completed in general compliance with Australian Standard AS1726-2017 *Geotechnical Site Investigations* and Jacobs' standard work procedures.

The geotechnical field investigation was undertaken by a geotechnical engineer from Jacobs, which undertook a site walkover, managed the field investigations, nominated sampling, testing intervals and depths and recorded descriptions of material encountered.

Prior to commencement, the investigation locations were checked for underground services by lodging an enquiry on the dial-before-you-dig database. No nearby services were shown to be present in the general area of the investigation.

The completed fieldwork involved:

- Excavation of three holes by hand auger (BH01, BH06 & BH10), to depths of 1.5 m bgl and collection of soil samples for laboratory testing.
- Seven cone penetrometer tests (CPT-01, CPT-02, CPT-05, CPT-08, CPT-10 to 11 and CPT-15), to depths up to 19.6 m bgl or when refusal was encountered.

The investigation locations were completed adjacent to the boreholes completed in 2019 by Jacobs. The coordinates of the cone penetrometer tests were recorded with a hand-held GPS unit, providing a relative accuracy of +/- 5.0 m.

Table 3.1: **Summary of hand auger and CPT site investigation.**

Location ID	Easting (MGA94 Zone 54)	Northing (MGA94 Zone 54)	Terminated depth (m below ground level)
BH01	735858.90	5743834.90	1.5
BH06	735712.20	5743922.10	1.5
BH10	735622.30	5743966.90	1.5
CPT-01	735870.00	5743774.50	3.8*
CPT-02	735857.00	5743807.10	19.6*
CPT-05	735688.20	5743920.40	9.6*
CPT-08	735609.90	5743908.60	8.5*
CPT-10	735622.00	5743965.10	15.0
CPT-11	735472.00	5743898.30	15.0
CPT-15	735338.50	5743865.40	5.6*

*Note: cone penetrometer test terminated due to refusal.

3.2 Laboratory testing

Laboratory tests were conducted on the soil samples retrieved from the hand auger holes to assess the characteristics of the materials encountered during the investigation. Laboratory testing was performed at NATA accredited laboratories in accordance with the relevant Australian standard for each test.

The type and quantities of testing are outlined in Table 3.2 below.

Table 3.2: **Summary of soil laboratory testing.**

Laboratory test	Australian Standard	No. of tests
Moisture Content	AS1289.2.1.1	3
Particle Size Distribution	AS1289.3.6.1	3
Atterberg limits with linear shrinkage	AS1289.3.1.2, 3.2.1, 3.3.1, 3.4.1	3
Emerson classification number	AS1289.3.8.1	3

Laboratory test	Australian Standard	No. of tests
Soil chemistry (pH, sulphates, chloride, resistivity)	pH: AS1289.4.3.1, in house LTM-GEN-7090 SO_4: AS1289.4.2.1, in house LTM-INO-4110 Cl: in-house LTM-INO-4090 Resistivity: AS1289.4.4.1	3

4. Result of geotechnical investigation

4.1 Laboratory test results

The results of the laboratory testing are summarised in Tables 4.1, 4.2 and 4.3 with the corresponding laboratory test certificates presented in **Appendix B.**

Table 4.1. Summary of laboratory test results – soil classification

Location ID	Sample Depth (m bgl)	Moisture Content (%)	Atterberg Limits (%)				Particle Size Distribution (%)			
			Liquid Limit	Plastic Limit	Plasticity Index	Linear Shrinkage	Gravel	Sand	Fines	
									Silt	Clay
BH01	0.5 – 1.0	155	82	44	38	8.5	2	25	32	41
BH06	0.5 – 1.0	140	74	64	10	5.0	3	19	24	54
BH10	0.5 – 1.0	101	-	-	-	-	53	38	3	6

Table 4.2. Summary of laboratory test results - Emerson class

Location ID	Sample Depth (m bgl)	Emerson Class Number
BH01	0.5 – 1.0	3
BH06	0.5 – 1.0	3
BH10	0.5 – 1.0	3

Table 4.3. Summary of laboratory test results – soil chemistry

Location ID	Sample Depth (m bgl)	pH	Sulphate SO_4 (mg/kg)	Chloride (mg/kg)	Resistivity (ohm.m)	Moisture Content (%)
BH01	0.5 – 1.0	5.5	680	140	71	59
BH06	0.5 – 1.0	4.3	380	450	130	64
BH10	0.5 – 1.0	3.9	450	190	63	47

*The pH values of soil samples were determined from 1:5 aqueous extract at 25°C.

4.2 Subsurface conditions

The three hand auger holes completed adjacent to the previous boreholes generally encountered alluvial soil comprising silty clay from ground surface. Sandy gravel was however encountered at the depth between 0.5 m and 1.0 m in BH10.

A description of the ground model and subsurface profile encountered at the seven CPT locations during the investigation is summarised in Table 4.4 below. These descriptions are based on data collected from the cone penetrometer test results. Robertson & Campanella (1983) charts, as well as the Geologismiki CPeT-IT software were used to assist in classifying the soil material encountered by the CPT tests. The raw CPT data containing the cone penetrometer test results are provided in **Appendix B.**

The findings of the field investigation indicate the subsurface conditions to be broadly consistent with the information presented in the geological maps and previous investigation works undertaken at the site.

Table 4.4. Summary of subsurface profile at the CPT investigation locations.

Location ID	Material Description	Depth range (m bgl)
CPT-01	Silty SAND, loose, dry to moist. Silty CLAY/Clayey SILT, firm. Silty SAND, loose. Silty CLAY, firm. Silty SAND: loose, fine grained.	0.0 – 1.2 1.2 – 1.8 1.8 – 2.8 2.8 – 3.3 3.3 – 3.8
CPT-02	CLAY/Silty CLAY, soft, wet. SAND/Silty SAND, medium dense. Silty SAND, medium dense.	0.0 – 4.8 4.8 – 8.5 8.5 – 19.6
CPT-05	CLAY, very soft to soft, low plasticity, moist to wet. Silty CLAY, firm.	0.0 – 6.0 6.0 – 9.6
CPT-08	CLAY/Silty CLAY, soft, moist to wet. SAND/Silty SAND, dense, wet.	0.0 – 3.8 3.8 – 8.5
CPT-10	CLAY/Silty CLAY, very soft to soft, wet. SAND/Silty SAND, loose to medium dense.	0.0 – 6.0 6.0 – 15.0
CPT-11	CLAY/Silty CLAY, firm, dry to moist. SAND/Silty SAND, loose to medium dense.	0.0 – 5.0 5.0 – 15.0

Location ID	Material Description	Depth range (m bgl)
CPT-15	CLAY/Silty CLAY, soft, low to medium plasticity, moist to wet. Silty SAND, loose, wet.	0.0 – 3.0 3.0 – 5.6

4.3 Groundwater observations

Groundwater was observed during Jacobs' previous site investigations to be either at the ground surface or within 1 to 2m below ground level. It should be noted that groundwater levels may fluctuate between seasons and/or flow events.

5. Discussion and recommendations

It is understood that a range of options are being considered for the hydraulic barrier system. This includes earth banks, sand filled geotextile bag or tubes, rock banks with geotextile barriers, concrete wall, or cantilevered sheet pile barriers.

Based on the investigation results, it is recommended that the following considerations be taken into account for the selection of the appropriate type of hydraulic barrier and detailed design of the system:

- The soil aggressivity test results indicate the pH values ranging between 3.9 and 5.5. Based on these results, and what is specified in Table 6.5.2 (C) of AS2159-2009, the exposure classification of the soil is considered as severe. It is recommended that corrosion protection be considered in the design of the hydraulic barrier. If sheet pile wall option is considered, a PVC type of sheet pile product may be considered in lieu of steel sheet pile to reduce the risk of corrosion.

- The results of the geotechnical investigation indicate the subsurface conditions comprised of predominately very soft to soft silty clay from the ground surface to depths ranging from ground surface level to a depth of 6.0 m below ground level. Without geogrid/geotextile support, the ground conditions at the swamp would unlikely provide a competent subgrade or foundation to support the proposed earth banks during and after the earthwork construction.

- If a sheet pile wall is considered, the pile embedment length should be assessed to limit wall deflection due to the soft soil layer.

- The design of the hydraulic barriers needs to consider the effect that they will have in controlling surface water flows; as well as the impact the wall may have on groundwater flow should it intercept an aquifer. Based on the test data, it is considered that a sand aquifer may be encountered at depths between 3.0 m and 6.0 m below ground. For sheet pile wall design, consideration should be given to avoid intercepting the aquifers that may potentially cut-off groundwater flows within the swamp.

- Design of the hydraulic barrier should take into consideration the water level and pressure acting on the barrier, construction sequence and method of placement of material for the hydraulic barrier structure. This includes temporary works such as construction loadings and access of earthwork plant and equipment to the earth banks.

- The subsurface conditions are likely to be variable across the investigation area. The depth to the sand aquifer layer was observed to be shallower along the southern extent of the site. The thickness of the overlying very soft to soft clay layer increases towards the middle of the swamp.

- Geotechnical design parameters have been interpreted based on the CPT results for each proposed earth bank. The CPT results were analysed using Geologismiki CPeT-IT software to assess the in-situ soil strength and properties. The uncorrected cone resistance (qc) values were corrected for overburden pressure and a default cone factor (N_{kt}) of 15 was used to assist in developing the soil design parameters. Output graphs from the Geologismiki CPeT-IT software interpretation are presented in **Appendix C.** The recommended soil profile and design parameters are presented in Table 5.1 below.

Table 5.1. Recommended ground model and soil design parameters at each bank.

Location	Layer	Description	Inferred depth (m bgl)	Unit weight, γ (kN/m^3)	Undrained Shear Strength, S_u (kPa)	Angle of friction, ϕ (degrees)	Elastic modulus, E (MPa)	Poisson ratio, v'
Bank J1, J2 and J3 (CPT-15)	1	Silty CLAY	0.0 – 3.0	16	16	-	2	0.35
	2	Silty SAND	3.0 – 5.6	19	-	34	15	0.30
Bank J4 (CPT-11)	1	Silty CLAY	0.0 – 5.0	17	48	-	10	0.35
	2	Silty SAND	5.0 – 15.0	19	-	34	15	0.30
Bank J5 (CPT-10)	1	Silty CLAY	0.0 – 6.0	16	15	-	2	0.35
	2	Silty SAND	6.0 – 15.0	19	-	34	20	0.30
Bank J6 (CPT-05)	1	CLAY	0.0 – 6.0	16	11	-	2	0.35
	2	Silty CLAY/ SILT	6.0 – 9.6	17	35	-	10	0.35

6. References

1) 1:250 000 Colac Geological Map Series (1996), A.H.M VandenBerg, Geological Survey of Victoria

2) Australian Standard – AS 1726-2017, 'Geotechnical Site Investigations', Standards Australia, published by SAI Global Limited

3) Jacobs (2019). Yeodene Big Swamp ASS field investigation – Appendix A, Piezometer Installation Details, dated May 2019

4) Look, B.G. (2007). Handbook of Geotechnical Investigation and Design Tables, Taylor and Francis Group, London, UK

5) Robertson, P.K. and Cabal, K.L (2015). Guide to Cone Penetration Testing for Geotechnical Engineering, Gregg Drilling and Testing Inc., California, USA

6) SKM (2014). Yeodene Monitoring Program, Borehole logs, dated May 2014.

Appendix A – Site test location plans

LEGEND

Borehole investigation - Jacobs, 2019

CPT investigation - Jacobs, 2021

PLAN
SCALE 1: 500

WORK IN PROGRESS

SCALE 1:500

10 8 6 4 2 0 10 20 30 40 50m

PRELIMINARY SKETCH			
PROJECT BIG SWAMP - DETAILED DESIGN			
SKETCH TITLE DETAILED PLAN - -			
SCALE AS SHOWN	DRAWN NP	DATE 26-04-21	SKETCH No. IA248200-SKETCH-0004

LEGEND

- Borehole investigation - Jacobs, 2019
- CPT investigation - Jacobs, 2021

PLAN
SCALE 1: 500

WORK IN PROGRESS

SCALE 1:500

10 8 6 4 2 0 10 20 30 40 50m

PRELIMINARY SKETCH

PROJECT BIG SWAMP - DETAILED DESIGN			
SKETCH TITLE DETAILED PLAN - -			
SCALE AS SHOWN	DRAWN NP	DATE 26-04-21	SKETCH No. IA248200-SKETCH-0005

LEGEND

Borehole investigation - Jacobs, 2019

CPT investigation - Jacobs, 2021

PLAN

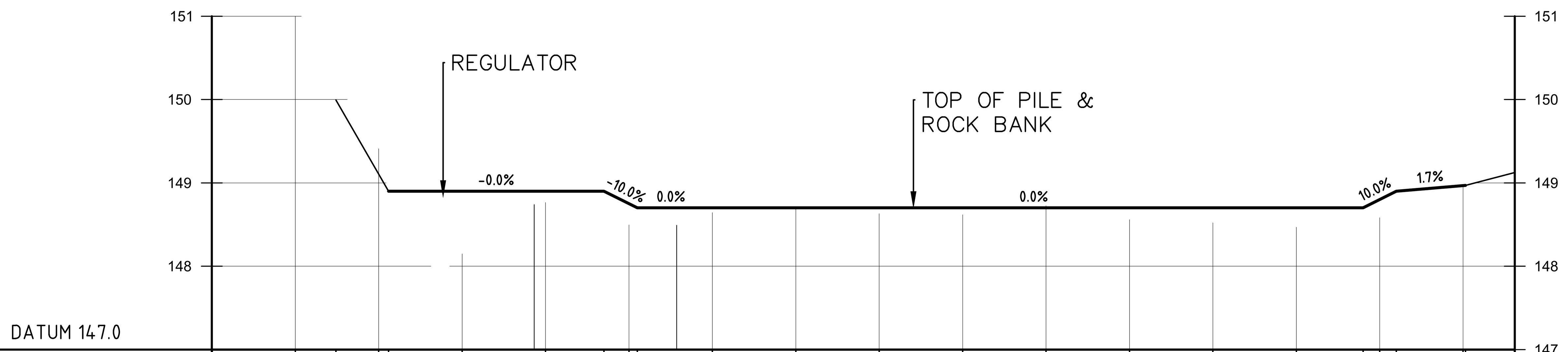
SCALE 1: 500

WORK IN PROGRESS

SCALE 1:500

10 8 6 4 2 0 10 20 30 40 50m

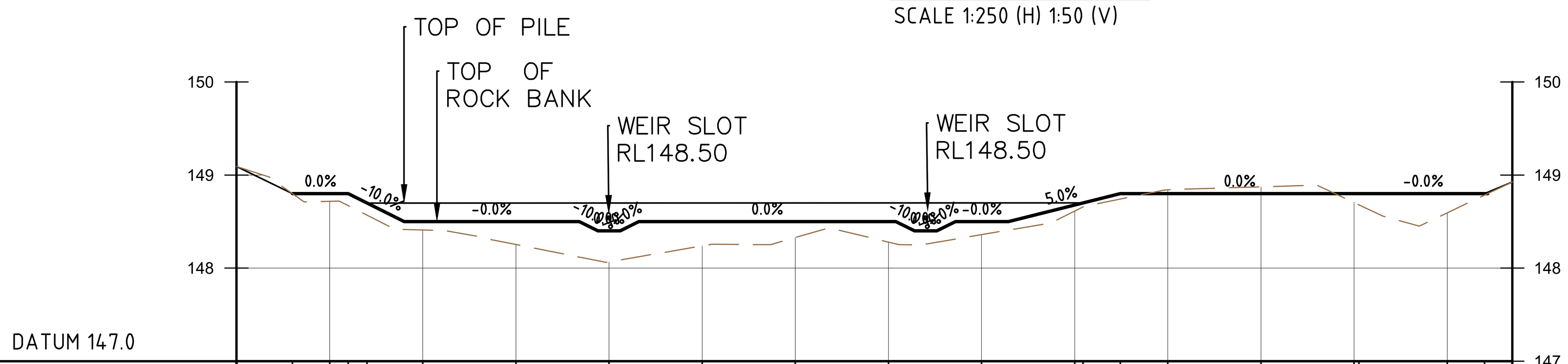
PRELIMINARY SKETCH			
PROJECT BIG SWAMP - DETAILED DESIGN			
SKETCH TITLE DETAILED PLAN - -			
SCALE AS SHOWN	DRAWN NP	DATE 26-04-21	SKETCH No. IA248200-SKETCH-0003



RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00				153.69
5.00				151.18
7.44	149.99			
10.00	149.10			149.41
10.58	148.90	148.90		
15.00	148.90	148.90	0.75	148.15
20.00	148.90	148.90	0.14	148.76
23.50	148.90	148.90		
25.00	148.75	148.75	0.26	148.49
25.50	148.70	148.70		
30.00	148.70	148.70	0.06	148.64
35.00	148.70	148.70	-0.02	148.72
40.00	148.70	148.70	0.07	148.63
45.00	148.70	148.70	0.08	148.62
50.00	148.70	148.70	-0.03	148.73
55.00	148.70	148.70	0.14	148.56
60.00	148.70	148.70	0.18	148.52
65.00	148.70	148.70	0.23	148.47
69.00	148.70	148.70	0.22	148.58
70.00	148.80	148.80		
71.00	148.90	148.90		
75.00	148.97	148.97	0.01	148.96
78.10	149.12			149.12

BANK J1 - SECTION

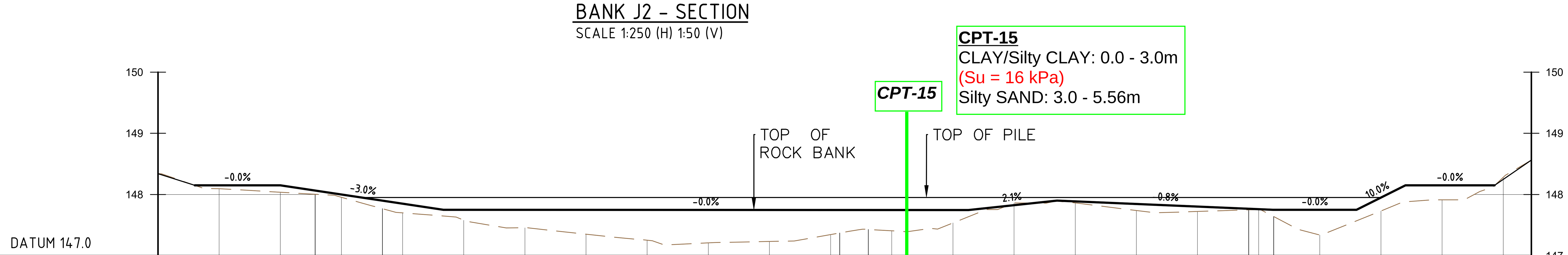
SCALE 1:250 (H) 1:50 (V)



RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	149.09			149.09
3.00	148.80	148.80		
5.00	148.80	148.80	0.08	148.72
6.00	148.80 148.70	148.80		
9.00		148.50		
10.00	148.70	148.50	0.09	148.41
15.00	148.70	148.50	0.25	148.25
18.40		148.50		
19.40		148.40		
20.00	148.70	148.40	0.33	148.07
20.60		148.40		
21.60		148.50		
25.00	148.70	148.50	0.26	148.24
30.00	148.70	148.50	0.17	148.33
35.00	148.70	148.50	0.22	148.28
35.40		148.40		
36.40		148.40		
37.60		148.40		
38.60		148.50		
40.00	148.70	148.50	0.14	148.36
41.45		148.50		
45.00	148.70	148.68	0.07	148.61
47.45	148.80	148.80		
50.00	148.80	148.80	-0.04	148.84
55.00	148.80	148.80	-0.07	148.87
60.00	148.80	148.80	0.10	148.70
65.00	148.80	148.80	0.21	148.59
67.17	148.80	148.80		
68.50	148.93			148.93

BANK J2 - SECTION

SCALE 1:250 (H) 1:50 (V)



RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
	148.34			148.34
	148.15	148.15		
5.00	148.15	148.15	0.05	148.10
10.00	148.15	148.15	0.11	148.04
15.00	148.00	148.00	0.05	147.95
	147.95			
20.00	147.95	147.85	0.15	147.70
		147.75		
25.00	147.95	147.75	0.17	147.58
30.00	147.95	147.75	0.29	147.46
35.00	147.95	147.75	0.40	147.35
40.00	147.95	147.75	0.50	147.25
45.00	147.95	147.75	0.54	147.21
50.00	147.95	147.75	0.51	147.23
55.00	147.95	147.75	0.40	147.34
60.00	147.95	147.75	0.34	147.41
65.00	147.95	147.75	0.21	147.54
		147.75		
70.00	147.95	147.82	-0.04	147.86
		147.90		
75.00	147.95	147.89	0.03	147.86
80.00	147.95	147.85	0.11	147.74
85.00	147.95	147.80	0.08	147.72
90.00	147.95	147.76	0.01	147.75
		147.75		
95.00	147.95	147.75	0.41	147.34
		147.75		
100.00	147.95	147.95	0.22	147.73
100.32	148.15	148.15		
105.00	148.15	148.15	0.24	147.91
110.00	148.15 148.25	148.15		148.28
	148.56			148.56

BANK J3- SECTION

SCALE 1:250 (H) 1:50 (V)

WORK IN PROGRESS

SCALE 1:250 (A1) 5 4 3 2 1 0 5 10 15 20 25m

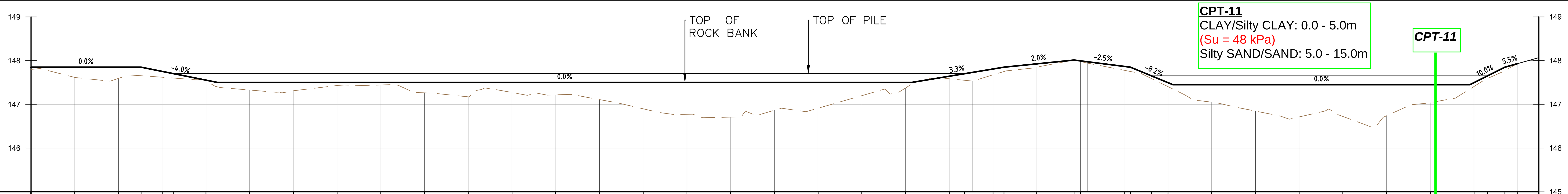
SCALE 1:50 (A1) 1 0.5 0 1 2 3 4 5m

PRELIMINARY SKETCH

PROJECT
BIG SWAMP - DETAILED DESIGN

SKETCH TITLE
SECTIONS
-
-

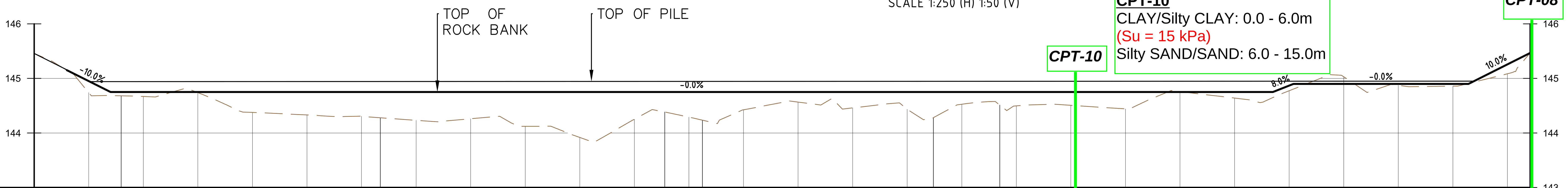
SCALE	DRAWN	DATE	SKETCH No.
AS SHOWN	NP	27-05-21	IA248200-SKETCH-0006



CPT-11
CLAY/Silty CLAY: 0.0 - 5.0m
(Su = 48 kPa)
Silty SAND/SAND: 5.0 - 15.0m

RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	147.85	147.85	0.05	147.80
5.00	147.85	147.85	0.23	147.62
10.00	147.85	147.85	0.26	147.59
12.58	147.85	147.85		
15.00	147.75 / 147.70	147.75	0.13	147.62
20.00 / 21.33	147.70	147.55 / 147.50	0.01	147.54
25.00	147.70	147.50	0.17	147.33
30.00	147.70	147.50	0.19	147.31
35.00	147.70	147.50	0.07	147.43
40.00	147.70	147.50	0.06	147.44
45.00	147.70	147.50	0.24	147.26
50.00	147.70	147.50	0.33	147.17
55.00	147.70	147.50	0.23	147.27
60.00	147.70	147.50	0.28	147.22
65.00	147.70	147.50	0.39	147.11
70.00	147.70	147.50	0.60	146.90
75.00	147.70	147.50	0.73	146.77
80.00	147.70	147.50	0.79	146.71
85.00	147.70	147.50	0.64	146.86
90.00	147.70	147.50	0.59	146.91
95.00	147.70	147.50	0.30	147.20
100.00 / 100.68	147.70	147.50 / 147.50	0.13	147.37
105.00	147.70 / 147.70	147.64	0.06	147.58
110.00 / 111.25	147.81 / 147.85	147.81 / 147.85	0.13	147.68
115.00	147.93	147.93	0.08	147.85
119.27 / 120.00	148.01 / 147.99	148.01 / 147.99	0.02	147.98
125.00 / 125.71	147.87 / 147.85	147.87 / 147.85	0.09	147.78
130.00 / 130.58	147.65 / 147.65	147.50 / 147.45	0.09	147.41
135.00	147.65	147.45	0.40	147.05
140.00	147.65	147.45	0.60	146.85
145.00	147.65	147.45	0.74	146.71
150.00	147.65	147.45	0.73	146.72
155.00	147.65	147.45	0.71	146.74
160.00	147.65	147.45	0.41	147.04
164.53 / 165.00	147.65 / 147.65	147.45 / 147.50	0.09	147.41
168.53	147.85	147.85		
170.00	147.93	147.93	0.00	147.93
172.41	148.07			148.07

BANK J4 - SECTION
SCALE 1:250 (H) 1:50 (V)

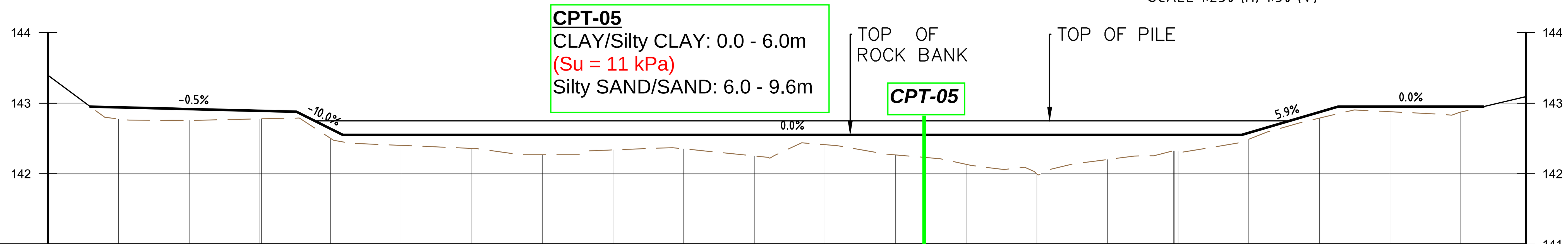


CPT-10
CLAY/Silty CLAY: 0.0 - 6.0m
(Su = 15 kPa)
Silty SAND/SAND: 6.0 - 15.0m

CPT-08
CLAY/Silty CLAY: 0.0 - 3.8m
(Su = 19 kPa)
Silty SAND/SAND: 3.8 - 8.5m

RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	145.46			145.46
3.00	145.16	145.15		
5.00	144.96 / 144.94	144.95	0.21	144.74
7.00		144.75		
10.00	144.94	144.75	0.08	144.67
15.00	144.94	144.75	0.01	144.74
20.00	144.94	144.75	0.37	144.38
25.00	144.94	144.75	0.42	144.33
30.00	144.94	144.75	0.44	144.31
35.00	144.94	144.75	0.52	144.23
40.00	144.94	144.75	0.49	144.26
45.00	144.94	144.75	0.63	144.12
50.00	144.94	144.75	0.83	143.92
55.00	144.94	144.75	0.50	144.25
60.00	144.94	144.75	0.46	144.29
65.00	144.95	144.75	0.33	144.42
70.00	144.95	144.75	0.18	144.57
75.00	144.95	144.75	0.29	144.46
80.00	144.95	144.75	0.31	144.44
85.00	144.95	144.75	0.22	144.53
90.00	144.95	144.75	0.25	144.50
95.00	144.95	144.75	0.24	144.51
100.00	144.95	144.75	0.31	144.44
105.00	144.95	144.75	-0.01	144.76
110.00	144.95	144.75	0.11	144.64
113.51		144.75		
115.00 / 115.59	144.95	144.87 / 144.90	0.10	144.77
120.00	144.95	144.90	-0.13	145.03
125.00	144.95	144.90	0.03	144.87
130.00	144.95	144.90	0.04	144.86
131.43	144.95	144.90		
135.00	145.26	145.26	0.17	145.09
137.08	145.47	145.47	0.00	145.47

BANK J5 - SECTION
SCALE 1:250 (H) 1:50 (V)

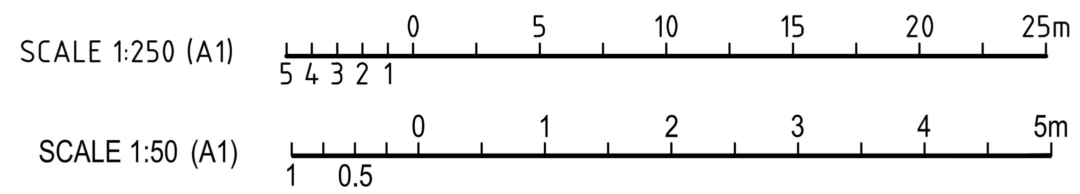


CPT-05
CLAY/Silty CLAY: 0.0 - 6.0m
(Su = 11 kPa)
Silty SAND/SAND: 6.0 - 9.6m

RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	143.39			143.39
3.00	142.95	142.95		
5.00	142.94	142.94	0.16	142.78
10.00	142.92	142.92	0.16	142.75
15.00	142.89	142.89	0.11	142.78
17.59	142.88	142.88		
20.00 / 20.87	142.75 / 142.75	142.64 / 142.55	0.13	142.50
25.00	142.75	142.55	0.15	142.40
30.00	142.75	142.55	0.19	142.36
35.00	142.75	142.55	0.28	142.27
40.00	142.75	142.55	0.21	142.34
45.00	142.75	142.55	0.20	142.35
50.00	142.75	142.55	0.30	142.25
55.00	142.75	142.55	0.14	142.41
60.00	142.75	142.55	0.28	142.27
65.00	142.75	142.55	0.42	142.13
70.00	142.75	142.55	0.55	142.00
75.00	142.75	142.55	0.35	142.20
80.00	142.75	142.55	0.24	142.31
84.51 / 85.00	142.75	142.55 / 142.58	0.09	142.49
90.00	142.75 / 142.87	142.87	0.08	142.79
91.32	142.95	142.95		
95.00	142.95	142.95	0.07	142.88
100.00	142.95	142.95	0.08	142.87
101.62	142.95	142.95		
104.62	143.09			143.09

BANK J6 - SECTION
SCALE 1:250 (H) 1:50 (V)

WORK IN PROGRESS



PRELIMINARY SKETCH

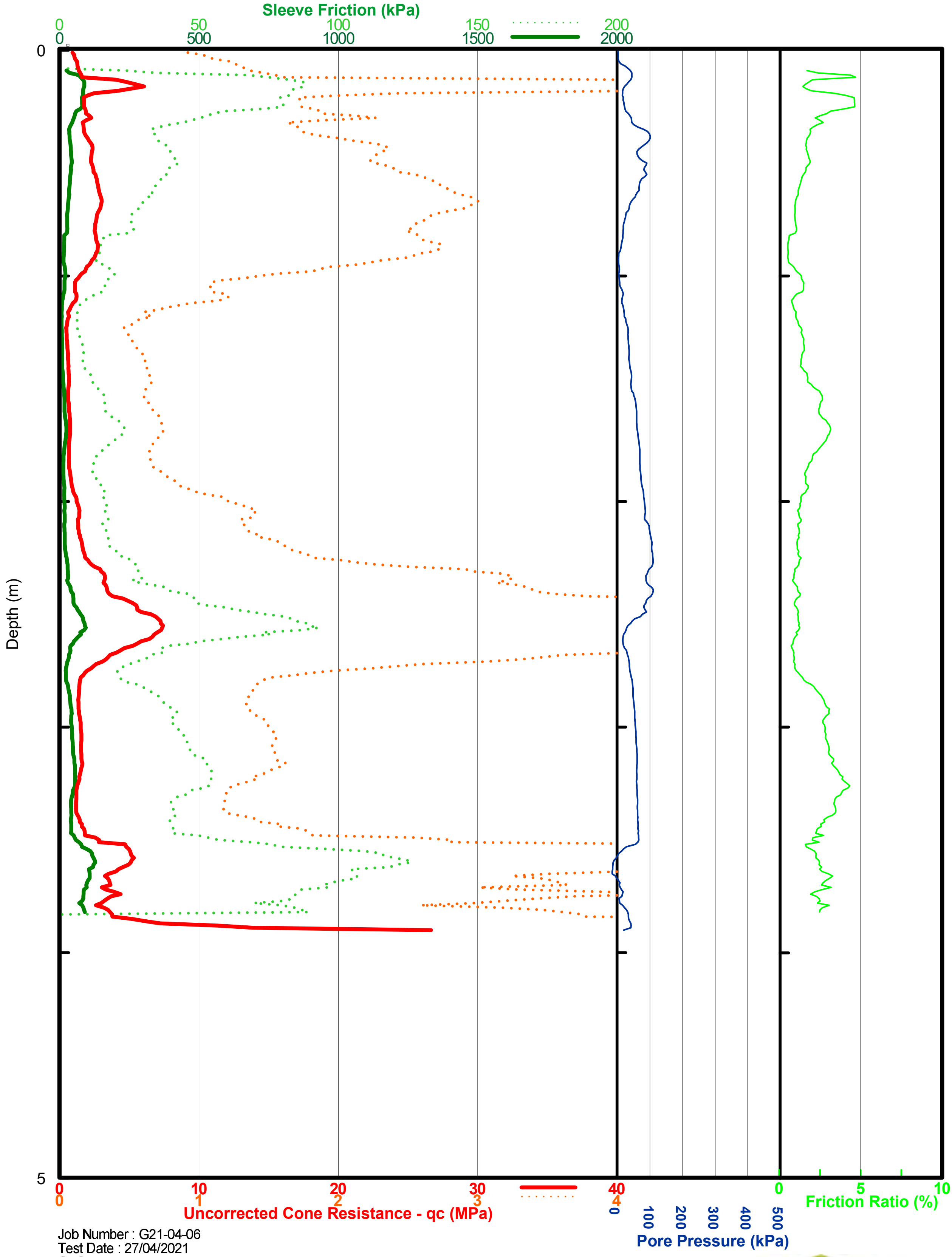
PROJECT BIG SWAMP - DETAILED DESIGN			
SKETCH TITLE SECTIONS - -			
SCALE AS SHOWN	DRAWN NP	DATE 27-05-21	SKETCH No. IA248200-SKETCH-0007

Appendix B – Cone penetrometer and laboratory test results

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-01



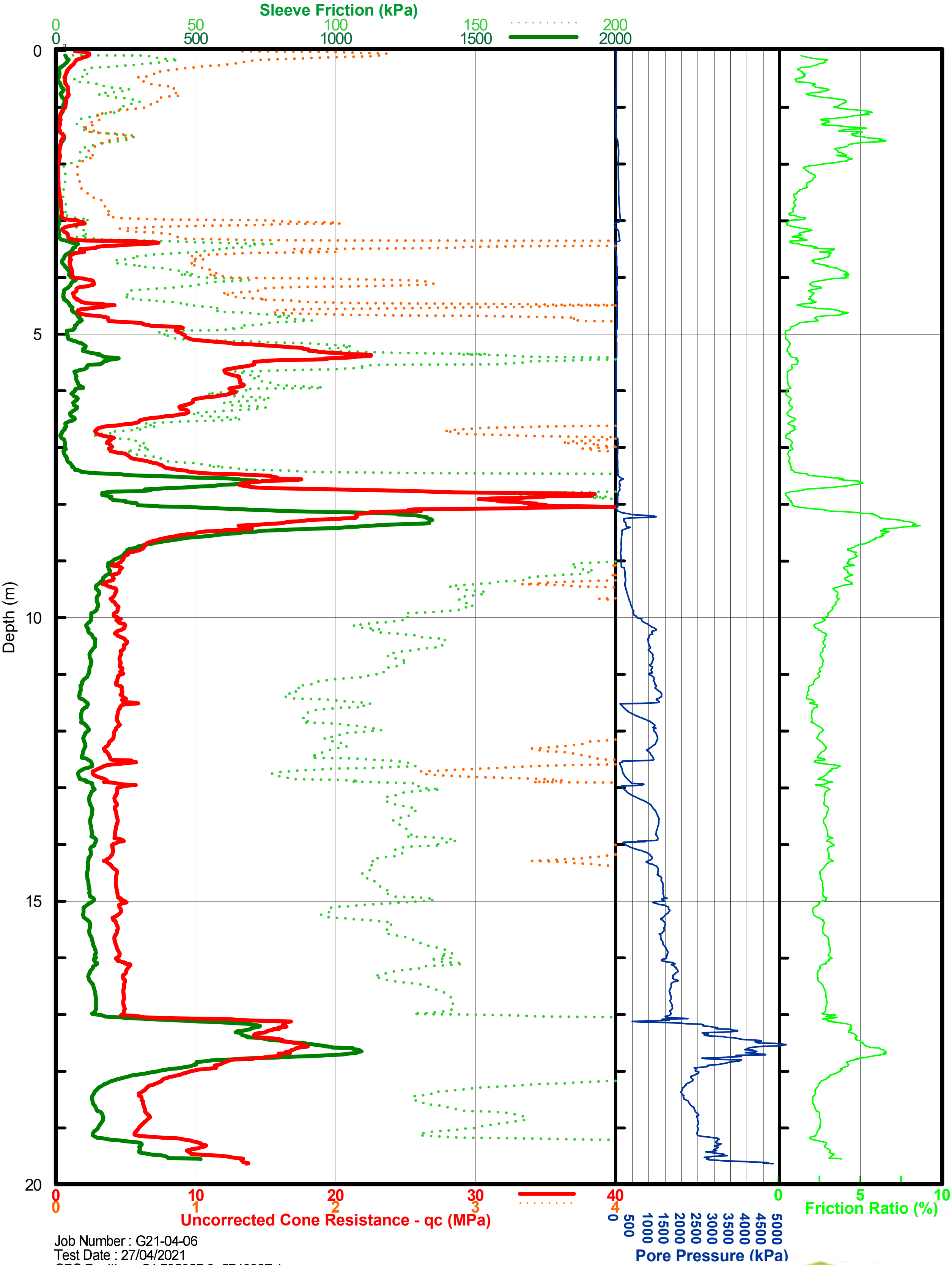
Job Number : G21-04-06
Test Date : 27/04/2021
GPS Position : 54 735870.0, 5743774.5
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3C
Predrill Depth : 0.00m
Cone Stabilisation @ : 0.89m
Dissipation Tests @ : N/A
Terminated Due To : Abrupt Tilt

Cone Number : C10CFIIP.C19135
Calibration Date : 8/12/2021
Cone Capacity : 100MPa
Cone Diameter : 35.92mm
Cone NAR : 0.784
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-02



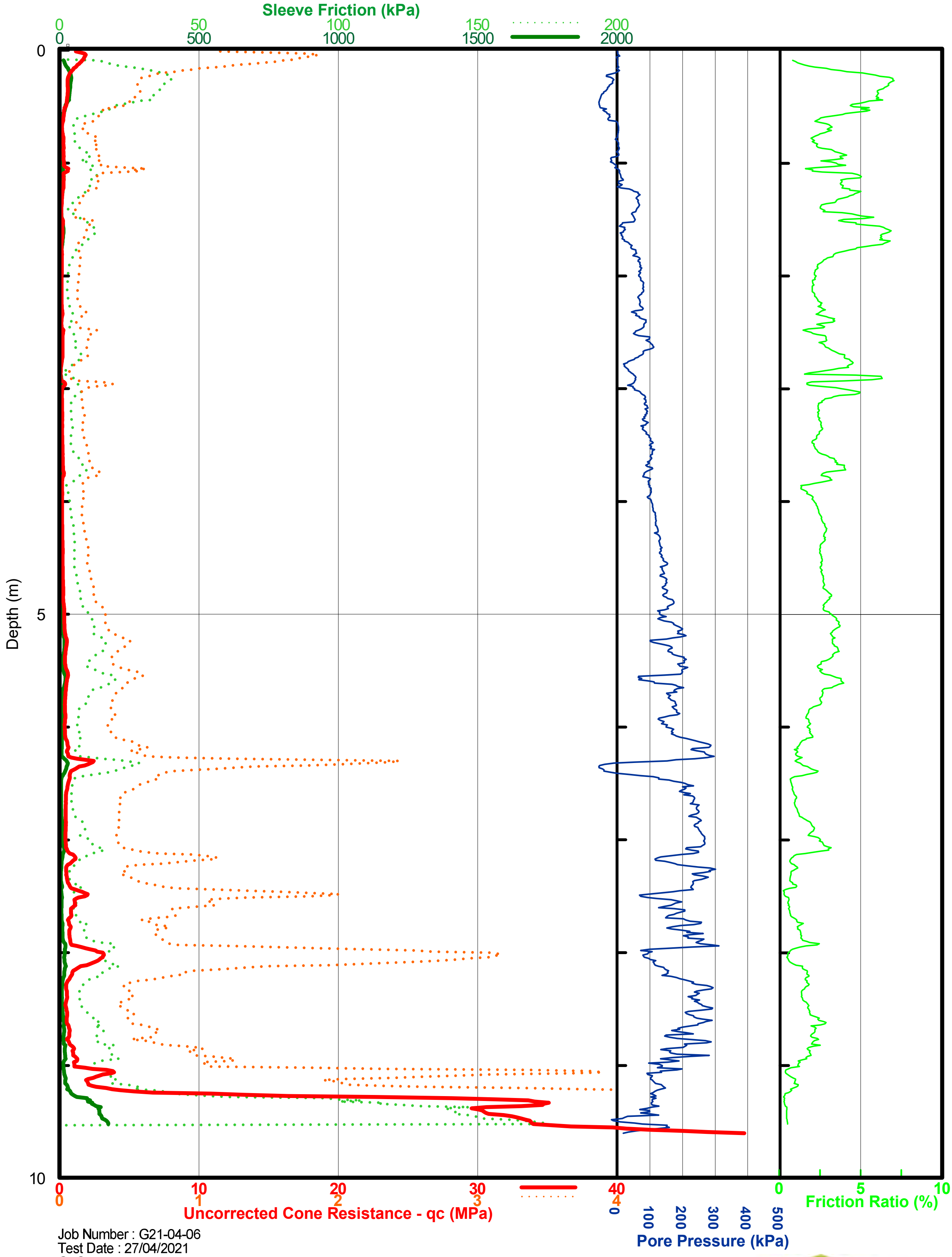
Job Number : G21-04-06
Test Date : 27/04/2021
GPS Position : 54 735857.0, 5743807.1
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3C
Predrill Depth : 0.00m
Cone Stabilisation @ : 0.81m, 6.83m
Dissipation Tests @ : N/A
Terminated Due To : Lifted Rig

Cone Number : C10CFIIP.C19135
Calibration Date : 8/12/2021
Cone Capacity : 100MPa
Cone Diameter : 35.92mm
Cone NAR : 0.784
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-05



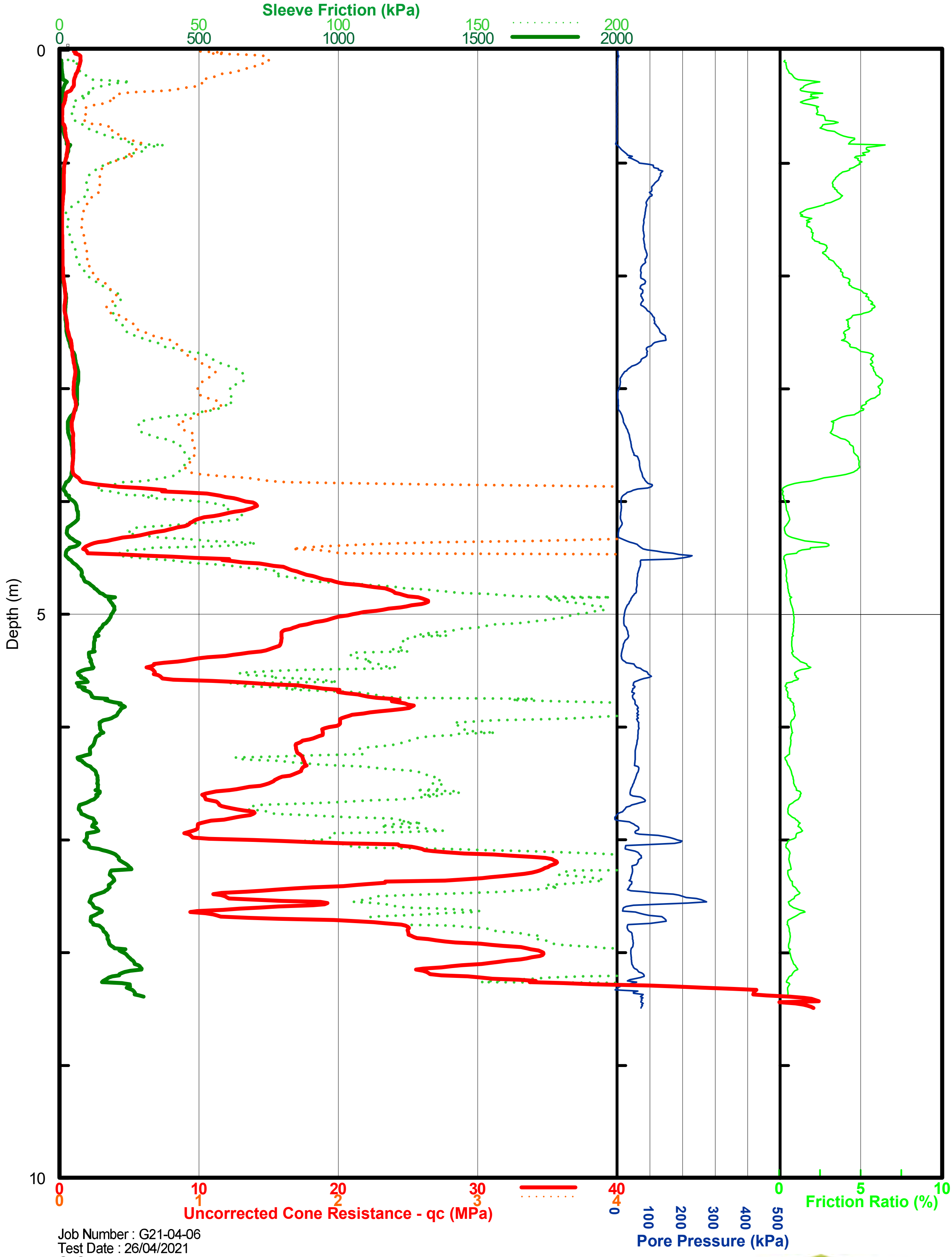
Job Number : G21-04-06
Test Date : 27/04/2021
GPS Position : 54 735688.2, 5743920.4
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3C
Predrill Depth : 0.00m
Cone Stabilisation @ : 0.51m
Dissipation Tests @ : N/A
Terminated Due To : Equipment at Risk

Cone Number : C10CFIIP.C19135
Calibration Date : 8/12/2021
Cone Capacity : 100MPa
Cone Diameter : 35.92mm
Cone NAR : 0.784
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-08



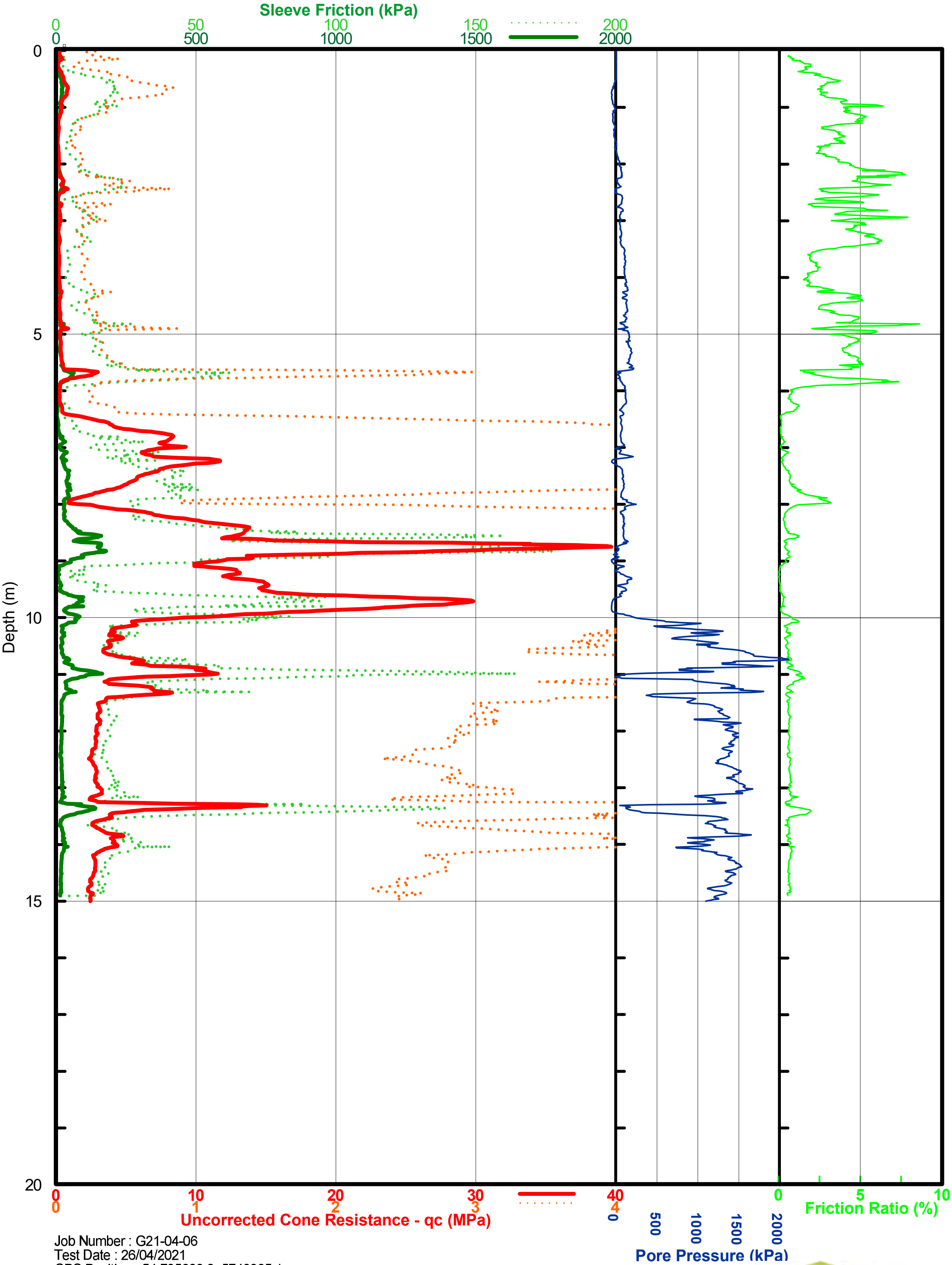
Job Number : G21-04-06
Test Date : 26/04/2021
GPS Position : 54 735609.9, 5743908.6
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3S
Predrill Depth : 0.00m
Cone Stabilisation @ : 0.93m
Dissipation Tests @ : N/A
Terminated Due To : Lifted Rig

Cone Number : S15CFIIP.S19020
Calibration Date : 7/12/2020
Cone Capacity : 100MPa
Cone Diameter : 43.73mm
Cone NAR : 0.798
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-10



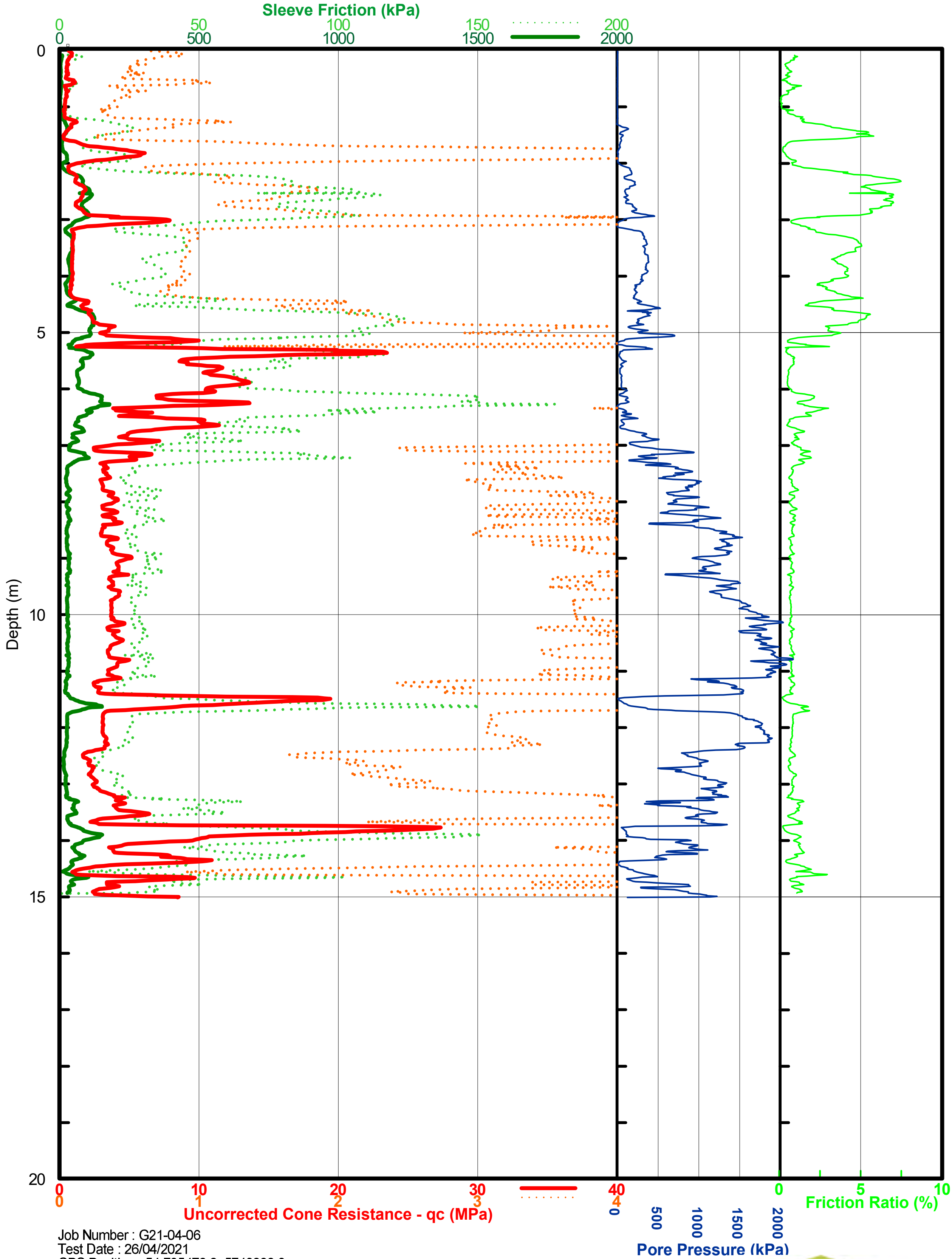
Job Number : G21-04-06
Test Date : 26/04/2021
GPS Position : 54 735622.0, 5743965.1
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3S
Predrill Depth : 0.00m
Cone Stabilisation @ : 1.07m, 1.67m, 9.93m
Dissipation Tests @ : N/A
Terminated Due To : Required Depth Reached

Cone Number : S15CFIIP.S19020
Calibration Date : 7/12/2020
Cone Capacity : 100MPa
Cone Diameter : 43.73mm
Cone NAR : 0.798
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-11



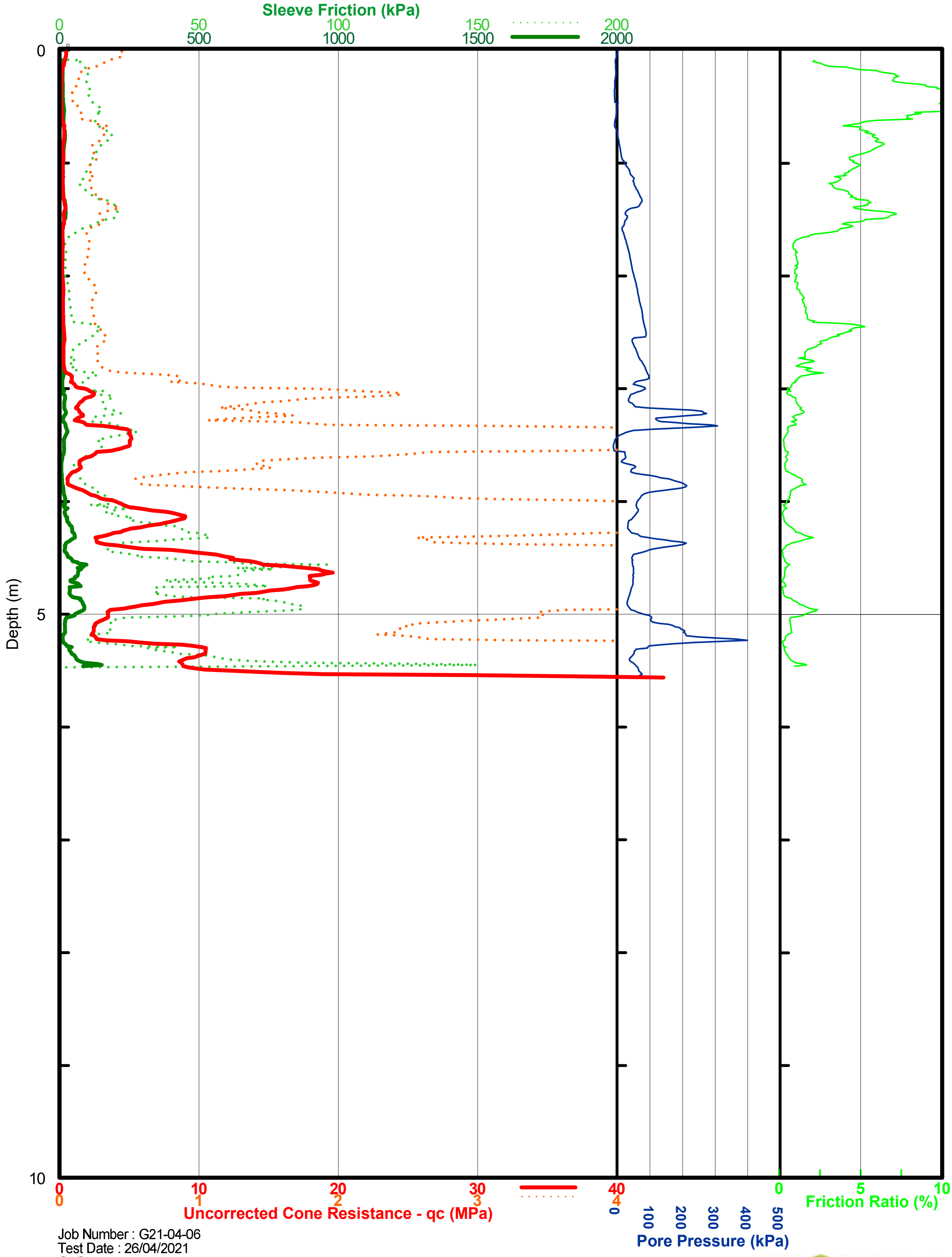
Job Number : G21-04-06
Test Date : 26/04/2021
GPS Position : 54 735472.0, 5743898.3
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3C
Predrill Depth : 0.00m
Cone Stabilisation @ : 1.04m
Dissipation Tests @ : N/A
Terminated Due To : Required Depth Reached

Cone Number : C10CFIIP.C19135
Calibration Date : 8/12/2021
Cone Capacity : 100MPa
Cone Diameter : 35.92mm
Cone NAR : 0.784
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

CONE PENETROMETER TEST RESULT

Jacobs
Yeodene Big Swamp Hydraulic Barriers
Yeodene VIC

CPT-15



Job Number : G21-04-06
Test Date : 26/04/2021
GPS Position : 54 735338.5, 5743865.4
GPS Format : WGS 84
Rig : Esme
Test Category : IGS-3S
Predrill Depth : 0.00m
Cone Stabilisation @ : 0.46m
Dissipation Tests @ : N/A
Terminated Due To : Lifted Rig

Cone Number : S15CFIIP.S19020
Calibration Date : 7/12/2020
Cone Capacity : 100MPa
Cone Diameter : 43.73mm
Cone NAR : 0.798
Tested By : Rory Sheehan
Checked By : Sergey Skrobotov

GroundScience
A C N 105 704 078
13 Brock Street Thomastown VIC 3074 P (03) 9464 4617 Email reception@groundscience.com.au

Particle Size Distribution & Hydrometer

Client:	JACOBS (MELBOURNE)	Job No.	GS5651/1
Project:	YEODENE BIG SWAMP	Date:	21-Apr-21
Location:	-	Report No.	AA
Lab Reference No.	**#S1**	Sample Identification:	**BH01 @ 0.5 - 1.0m**
Laboratory Specimen Classification:	**silty CLAY, high plasticity, black, with sand, trace gravel**		

Particle Size Distribution AS1289 3.6.3

Sieve Size	% Passing	Specification
63 mm	**100**	
53 mm	**100**	
37.5 mm	**100**	
26.5 mm	**100**	
19.0 mm	**100**	
13.2 mm	**100**	
9.5 mm	**100**	
6.7 mm	**100**	
4.75 mm	**100**	
2.36 mm	**98**	
1.18 mm	**95**	
600 um	**90**	
425 um	**88**	
300 um	**85**	
150 um	**78**	
75 um	**73**	
hydrometer values		
56 um	**71**	
28 um	**64**	
19 um	**58**	
14 um	**55**	
10 um	**53**	
1 um	**37**	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	**-**	
Plastic Limit	%	AS1289 3.2.1	**-**	
Plasticity Index	%	AS1289 3.3.1	**-**	
Linear Shrinkage	%	AS1289 3.4.1	**-**	
Moisture Content	%	AS1289 2.1.1	**154.7**	

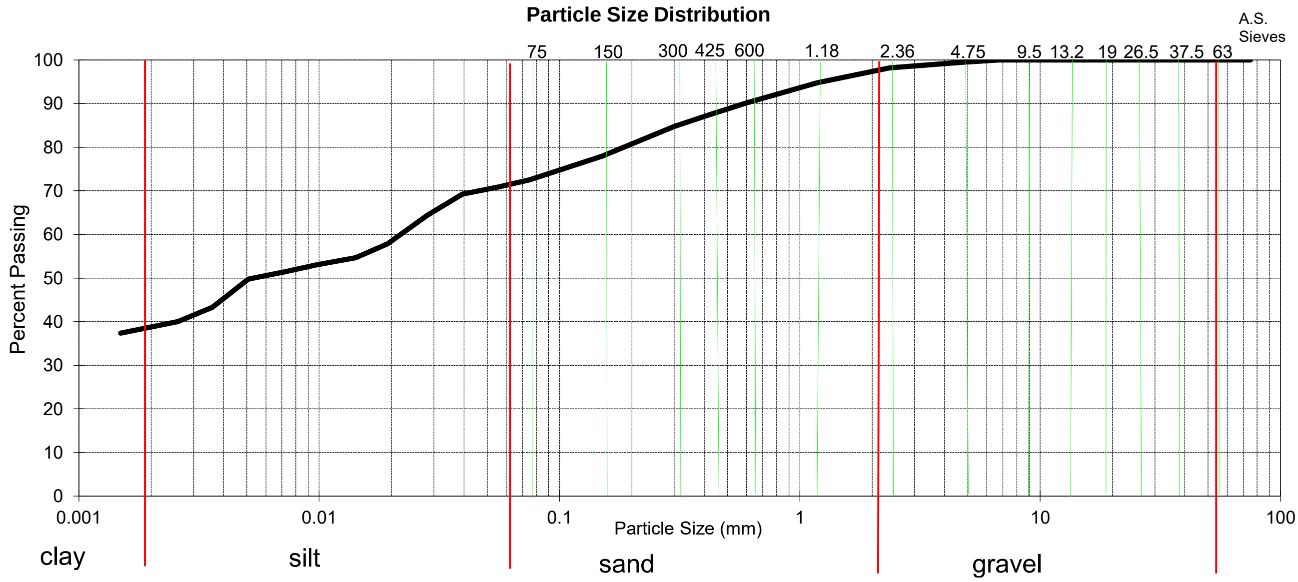
Sample History:	Oven Dried
Preparation Method:	Dry sieved
Cracking / Curling of linear shrinkage:	-
Linear shrinkage mould length:	0

ND = not determined NO = not obtainable NP = non plastic

Notes Dispersion : mechanical / hydrometer: g/l
sampled by client, tested as received.

Material properties

GRAVEL CONTENT =	**2**	%
SAND CONTENT =	**25**	%
SILT CONTENT =	**32**	%
CLAY CONTENT =	**41**	%



Date: 4/05/2021

NATA Accredited Laboratory No. 15055
Accredited for compliance with ISO/IEC 17025 - Testing

Pelin Atas Erden
Approved Signatory

Particle Size Distribution & Hydrometer

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13 Brock Street Thomastown VIC 3074 P (03) 9464 4617 Email reception@groundscience.com.au

Client:	JACOBS (MELBOURNE)	Job No.	GS5651/1
Project:	YEODENE BIG SWAMP	Date:	21-Apr-21
Location:	-	Report No.	AB
Lab Reference No.	**#S2**	Sample Identification:	**BH06 @ 0.5 - 1.0m**

Laboratory Specimen Classification: **silty CLAY, high plasticity, black, with sand, trace gravel**

Particle Size Distribution AS1289 3.6.3

Sieve Size	% Passing	Specification
63 mm	**100**	
53 mm	**100**	
37.5 mm	**100**	
26.5 mm	**100**	
19.0 mm	**100**	
13.2 mm	**100**	
9.5 mm	**100**	
6.7 mm	**100**	
4.75 mm	**100**	
2.36 mm	**97**	
1.18 mm	**93**	
600 um	**88**	
425 um	**86**	
300 um	**84**	
150 um	**80**	
75 um	**78**	
hydrometer values		
63 um	**76**	
32 um	**71**	
22 um	**67**	
16 um	**65**	
11 um	**62**	
2 um	**52**	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	**-**	
Plastic Limit	%	AS1289 3.2.1	**-**	
Plasticity Index	%	AS1289 3.3.1	**-**	
Linear Shrinkage	%	AS1289 3.4.1	**-**	
Moisture Content	%	AS1289 2.1.1	**140.0**	

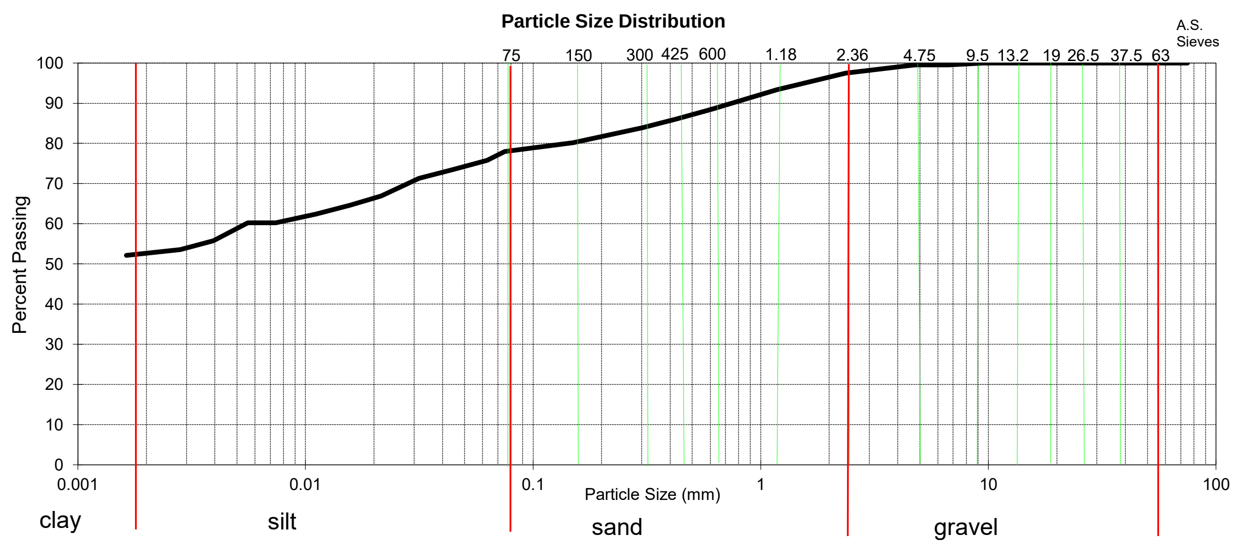
Sample History:	Oven Dried
Preparation Method:	Dry sieved
Cracking / Curling of linear shrinkage:	-
Linear shrinkage mould length:	-

ND = not determined NO = not obtainable NP = non plastic

Notes Dispersion : mechanical / hydrometer: g/l
sampled by client, tested as received.

Material properties

GRAVEL CONTENT =	**3**	%
SAND CONTENT =	**19**	%
SILT CONTENT =	**24**	%
CLAY CONTENT =	**54**	%



Date: 4/05/2021

NATA Accredited Laboratory No. 15055
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Tim Senserrick
Approved Signatory

GroundScience

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13 Brock Street Thomastown VIC 3074 P (03) 9464 4617 Email reception@groundscience.com.au

Particle Size Distribution & Hydrometer

Client:	JACOBS (MELBOURNE)	Job No.	GS5651/1
Project:	YEODENE BIG SWAMP	Date:	21-Apr-21
Location:	-	Report No.	AC
Lab Reference No.	**#S3**	Sample Identification:	**BH10 @ 0.5 - 1.0m**

Laboratory Specimen Classification: **sandy GRAVEL, fine to intermediate grained, brown, sand fine to coarse grained, with clay, trace silt**

Particle Size Distribution AS1289 3.6.3

Sieve Size	% Passing	Specification
63 mm	**100**	
53 mm	**100**	
37.5 mm	**100**	
26.5 mm	**100**	
19.0 mm	**100**	
13.2 mm	**85**	
9.5 mm	**71**	
6.7 mm	**63**	
4.75 mm	**58**	
2.36 mm	**47**	
1.18 mm	**37**	
600 um	**29**	
425 um	**25**	
300 um	**22**	
150 um	**15**	
75 um	**9**	
hydrometer values		
52 um	**9**	
26 um	**8**	
18 um	**8**	
13 um	**8**	
9 um	**8**	
1 um	**6**	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	**-**	
Plastic Limit	%	AS1289 3.2.1	**-**	
Plasticity Index	%	AS1289 3.3.1	**-**	
Linear Shrinkage	%	AS1289 3.4.1	**-**	
Moisture Content	%	AS1289 2.1.1	**100.7**	

Sample History:	Oven Dried
Preparation Method:	Dry sieved
Cracking / Curling of linear shrinkage:	-
Linear shrinkage mould length:	0

ND = not determined NO = not obtainable NP = non plastic

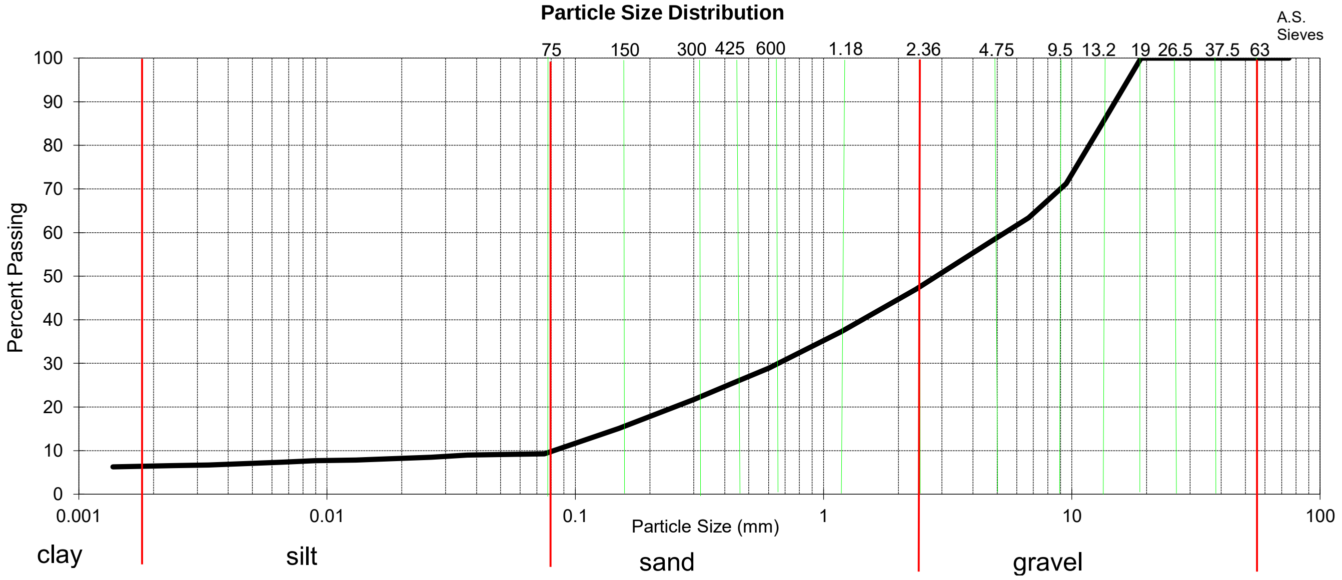
Notes Dispersion : mechanical / hydrometer: g/l

sampled by client, tested as received.

Material properties

GRAVEL CONTENT =	**53**	%
SAND CONTENT =	**38**	%
SILT CONTENT =	**3**	%
CLAY CONTENT =	**6**	%

Particle Size Distribution



Date: 4/05/2021

NATA Accredited Laboratory No. 15055

Accredited for compliance with ISO/IEC 17025 - Testing

Pelin Atas Erden

Approved Signatory

Material Test Report

Report Number:	**GS5651/1-1**
Issue Number:	1
Date Issued:	04/05/2021
Client:	Jacobs (Melbourne)
	452 Flinders St, Melbourne Victoria 3000
Contact:	Lee Wei Ong
Project Number:	GS5651/1
Project Name:	Yeodene Big Swamp
Project Location:	IA258200
Work Request:	3065
Sample Number:	56511-S1
Date Sampled:	19/04/2021
Dates Tested:	19/04/2021 - 26/04/2021
Sampling Method:	Sampled by Client - Tested as Received
	The results apply to the sample as received
Sample Location:	**BH01 , Depth: 0.5 - 1.0m**
Material:	silty CLAY, High Plasticity, black, with sand, trace gravel

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Phone: (03) 9464 4617
Email: tim@groundscience.com.au

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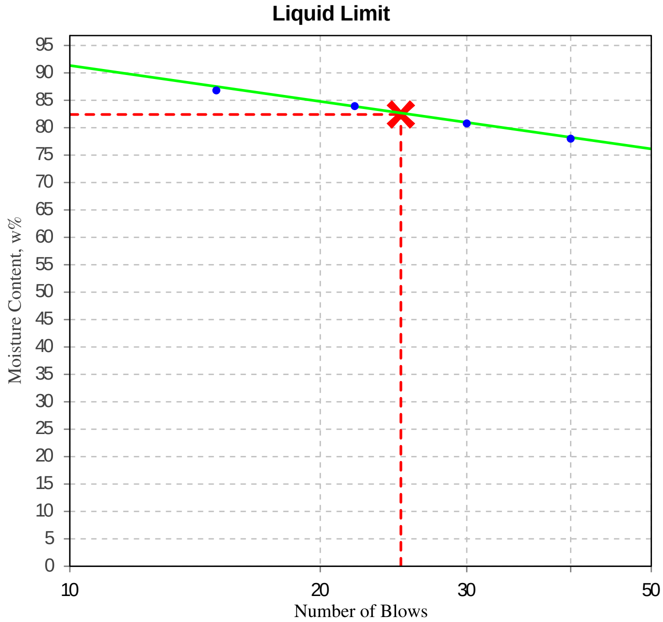
Approved Signatory: Tim Senserrick
Laboratory 21C

NATA Accredited Laboratory Number: 15055

Atterberg Limit (AS1289 3.1.1 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	82		
Plastic Limit (%)	44		
Plasticity Index (%)	**38**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.1		
Linear Shrinkage (%)	8.5		
Cracking Crumbling Curling	Cracking		

Emerson Class Number of a Soil (AS 1289 3.8.1)		Min	Max
Emerson Class	**3**		
Soil Description			
Nature of Water	Distilled		
Temperature of Water (^{o}C)	18		



Material Test Report

Report Number:	**GS5651/1-1**
Issue Number:	1
Date Issued:	04/05/2021
Client:	Jacobs (Melbourne)
	452 Flinders St, Melbourne Victoria 3000
Contact:	Lee Wei Ong
Project Number:	GS5651/1
Project Name:	Yeodene Big Swamp
Project Location:	IA258200
Work Request:	3065
Sample Number:	56511-S2
Date Sampled:	19/04/2021
Dates Tested:	19/04/2021 - 27/04/2021
Sampling Method:	Sampled by Client - Tested as Received
	The results apply to the sample as received
Sample Location:	**BH06 , Depth: 0.5 - 1.0m**
Material:	silty CLAY, High Plasticity, black, with sand, trace gravel

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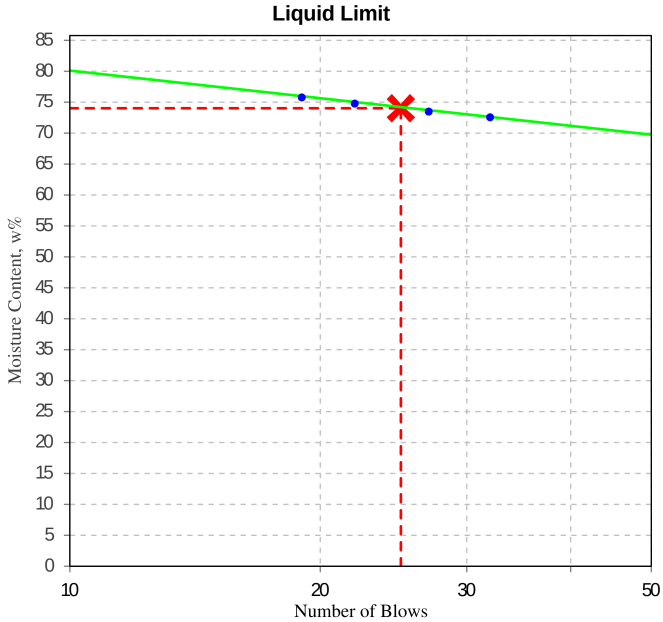
Approved Signatory: Tim Senserrick
Laboratory 21C
NATA Accredited Laboratory Number: 15055

Atterberg Limit (AS1289 3.1.1 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	74		
Plastic Limit (%)	64		
Plasticity Index (%)	**10**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.1		
Linear Shrinkage (%)	5.0		
Cracking Crumbling Curling	Cracking		

Emerson Class Number of a Soil (AS 1289 3.8.1)		Min	Max
Emerson Class	**3**		
Soil Description			
Nature of Water	Distilled		
Temperature of Water (^{o}C)	18		



Material Test Report

Ground Science Pty Ltd
Ground Science Laboratory
13 Brock Street Thomastown Victoria 3074
Phone: (03) 9464 4617
Email: tim@groundscience.com.au

Accredited for compliance with ISO/IEC 17025 - Testing

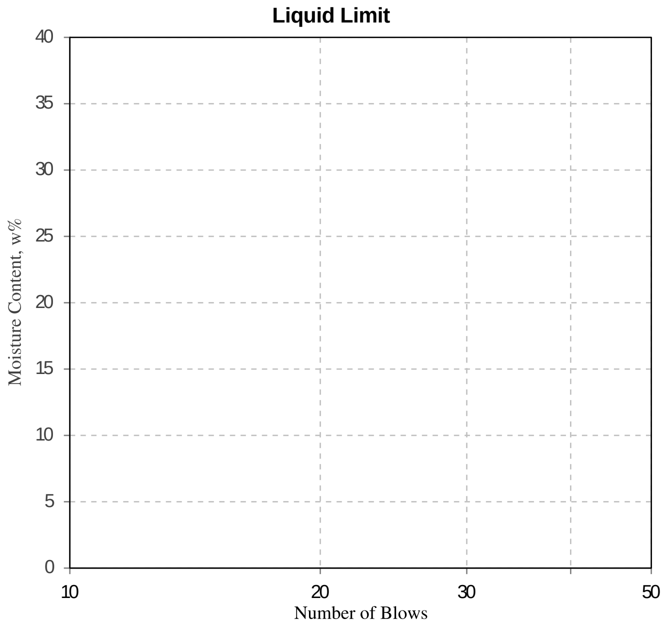
Approved Signatory: Tim Senserrick
Laboratory 21C
NATA Accredited Laboratory Number: 15055

Report Number: **GS5651/1-1**
Issue Number: 1
Date Issued: 04/05/2021
Client: Jacobs (Melbourne)
452 Flinders St, Melbourne Victoria 3000
Contact: Lee Wei Ong
Project Number: GS5651/1
Project Name: Yeodene Big Swamp
Project Location: IA258200
Work Request: 3065
Sample Number: 56511-S3
Date Sampled: 19/04/2021
Dates Tested: 19/04/2021 - 26/04/2021
Sampling Method: Sampled by Client - Tested as Received
The results apply to the sample as received
Sample Location: **BH10 , Depth: 0.5 - 1.0m**
Material: sandy GRAVEL, fine to intermediate grained, brown, sand fine to coarse grained, with clay, trace silt.

Atterberg Limit (AS1289 3.1.1 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	Not Obtainable		
Plastic Limit (%)	Not Obtainable		
Plasticity Index (%)	**Non Plastic**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.1		
Linear Shrinkage (%)	0.0		
Cracking Crumbling Curling	None		

Emerson Class Number of a Soil (AS 1289 3.8.1)		Min	Max
Emerson Class	**3**		
Soil Description			
Nature of Water	Distilled		
Temperature of Water (^{o}C)	18		



Material Test Report

Report Number: **GS5651/1-1**
Issue Number: 1
Date Issued: 04/05/2021
Client: Jacobs (Melbourne)
452 Flinders St, Melbourne Victoria 3000
Contact: Lee Wei Ong
Project Number: GS5651/1
Project Name: Yeodene Big Swamp
Project Location: IA258200
Work Request: 3065
Dates Tested: 19/04/2021 - 20/04/2021

Ground Science Pty Ltd
Ground Science Laboratory
13 Brock Street Thomastown Victoria 3074
Phone: (03) 9464 4617
Email: tim@groundscience.com.au
Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Tim Senserrick
Laboratory 21C
NATA Accredited Laboratory Number: 15055

Moisture Content AS 1289 2.1.1

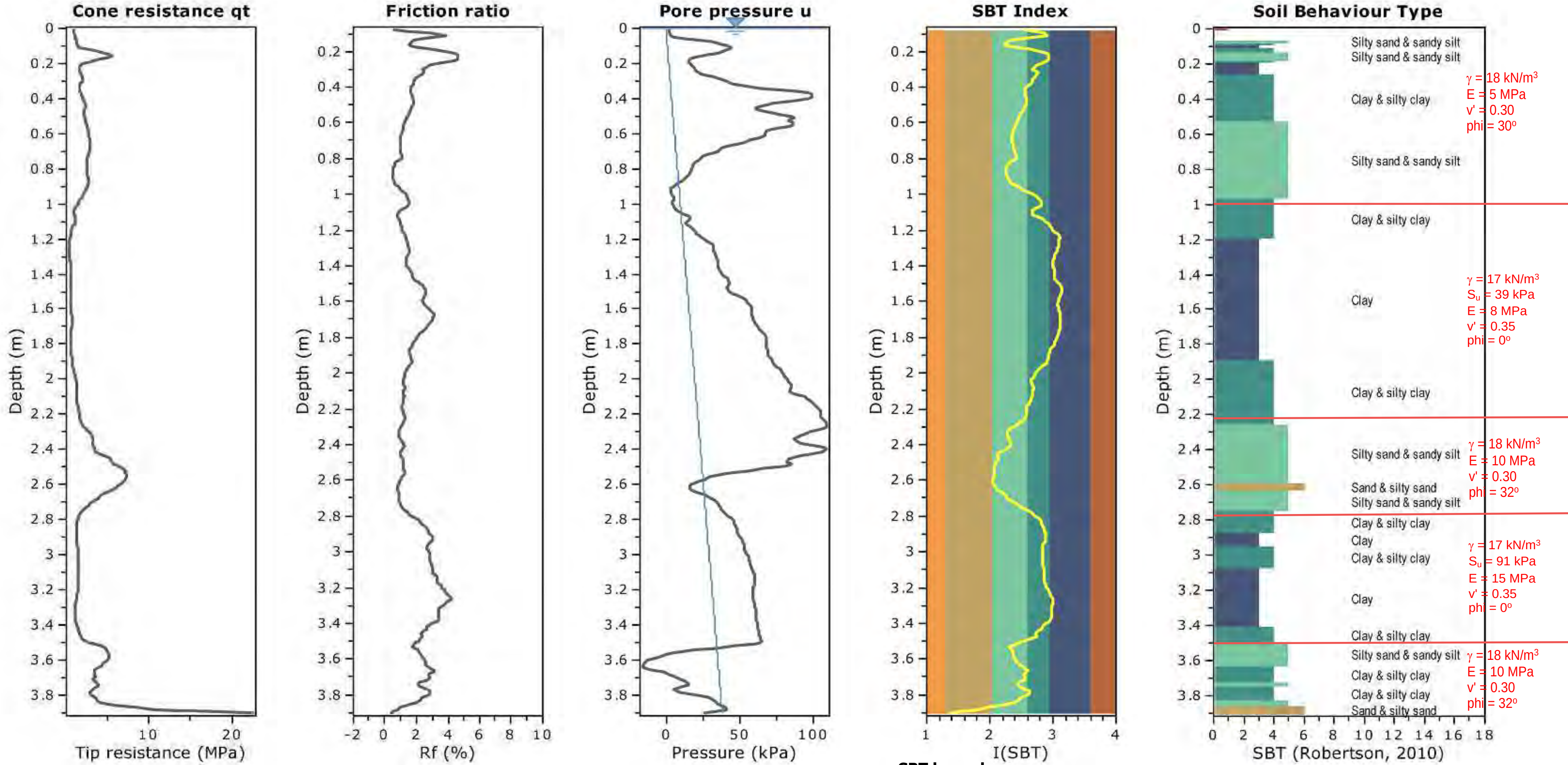
Sample Number	Sample Location	Moisture Content (%)	Material
56511-S1	BH01 , Depth: 0.5 - 1.0m	155 %	silty CLAY, High Plasticity, black, with sand, trace gravel
56511-S2	BH06 , Depth: 0.5 - 1.0m	140 %	silty CLAY, High Plasticity, black, with sand, trace gravel
56511-S3	BH10 , Depth: 0.5 - 1.0m	101 %	sandy GRAVEL, fine to intermediate grained, brown, sand fine to coarse grained, with clay, trace silt.

Appendix C – CPT interpretation

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-01
Total depth: 3.90 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: **Barwon Water Yeodene Swamp Hydraulic Barriers**
Location: **Yeodene, Victoria**



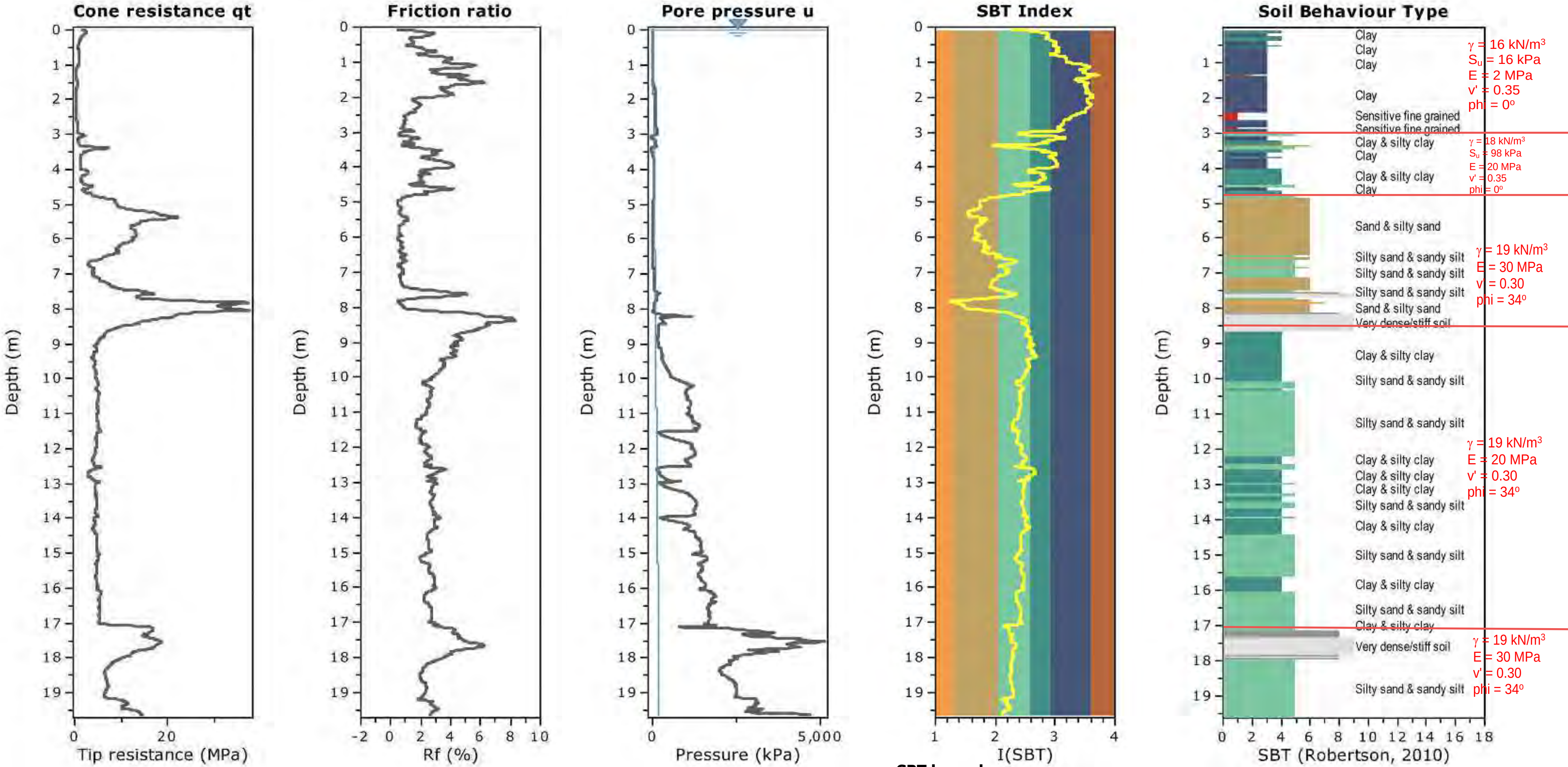
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-02
Total depth: 19.63 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: **Barwon Water Yeodene Swamp Hydraulic Barriers**
Location: **Yeodene, Victoria**



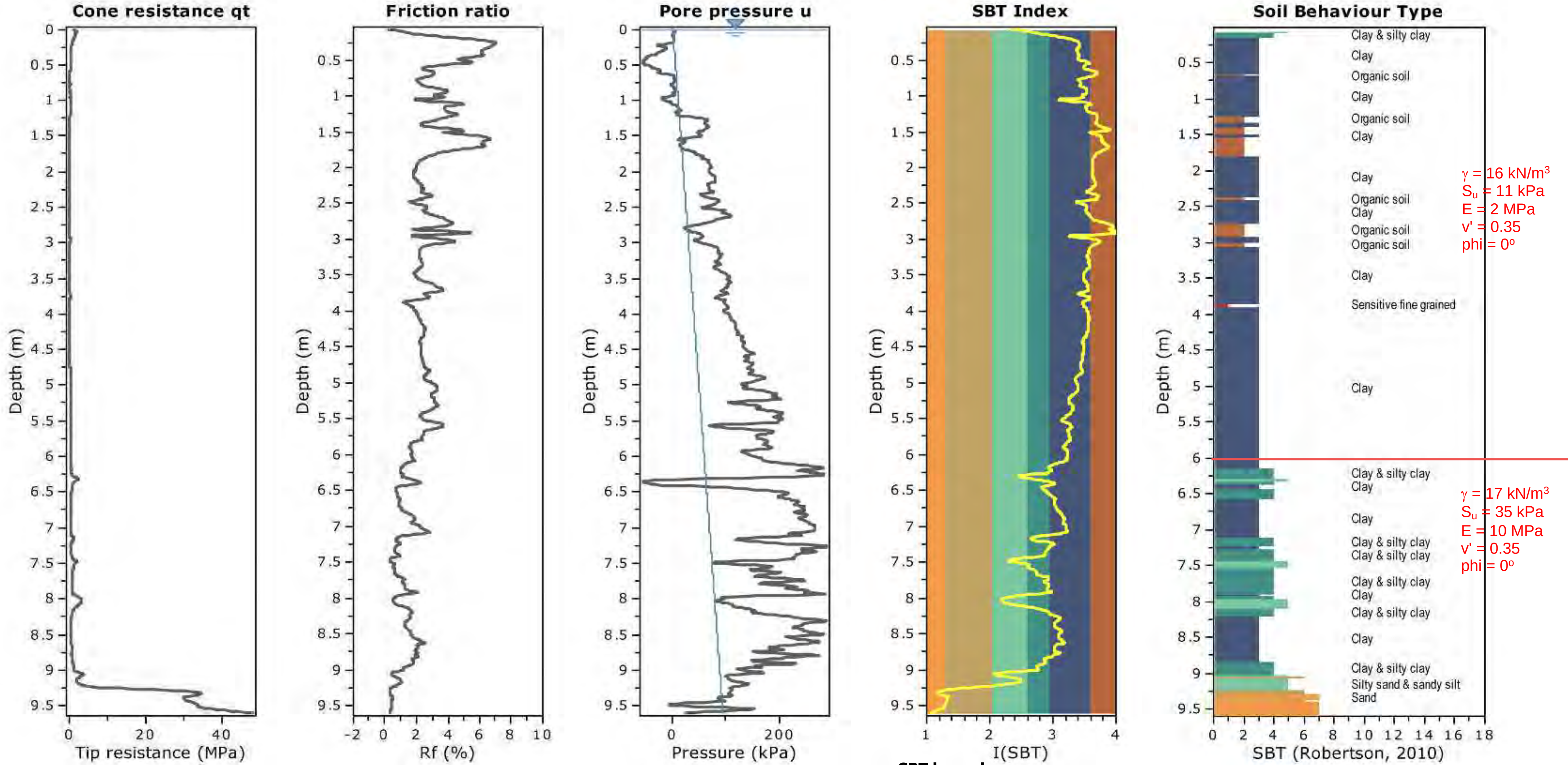
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-05
Total depth: 9.60 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: Barwon Water Yeodene Swamp Hydraulic Barriers
Location: Yeodene, Victoria



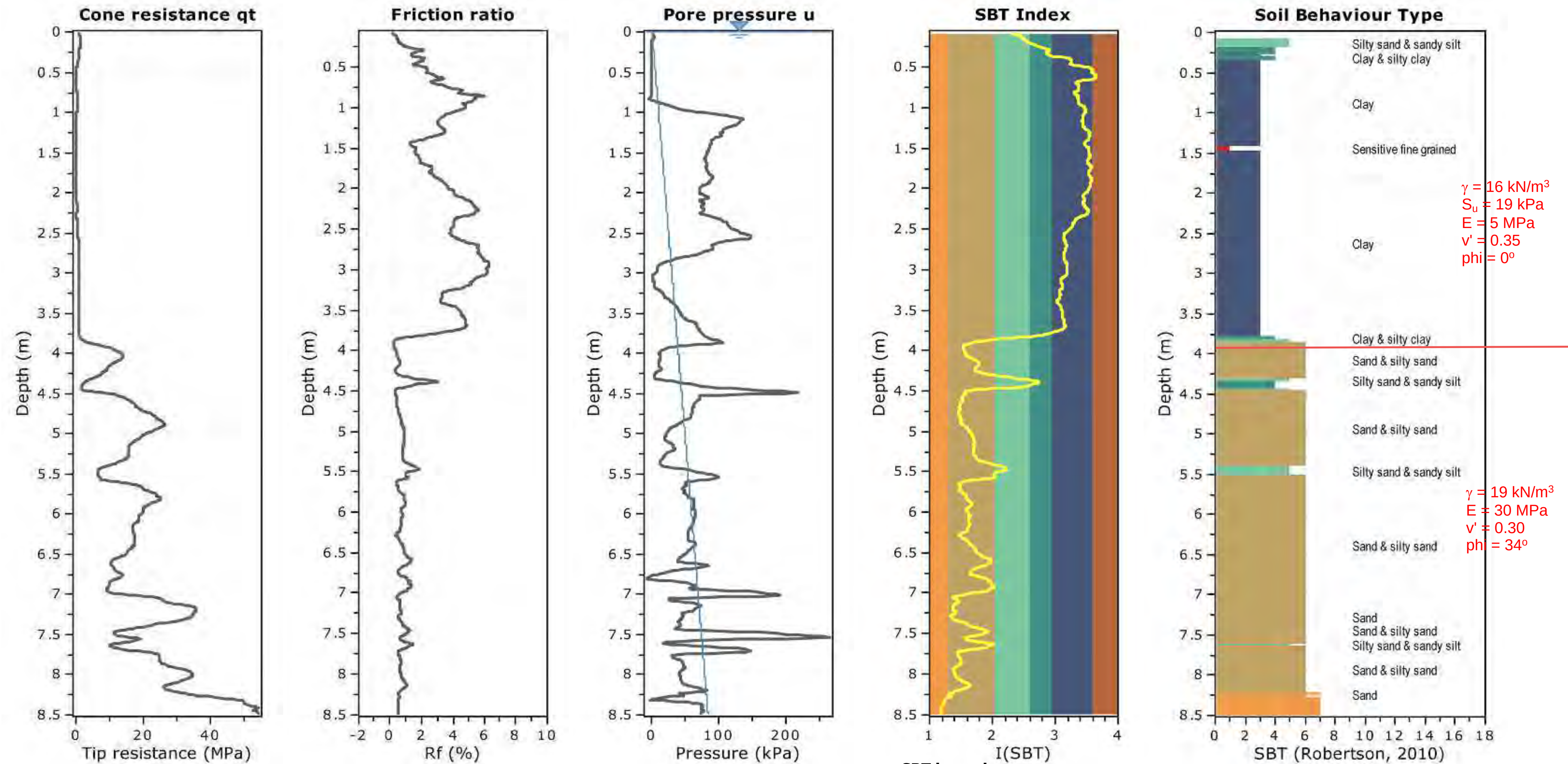
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-08
Total depth: 8.49 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: Barwon Water Yeodene Swamp Hydraulic Barriers
Location: Yeodene, Victoria



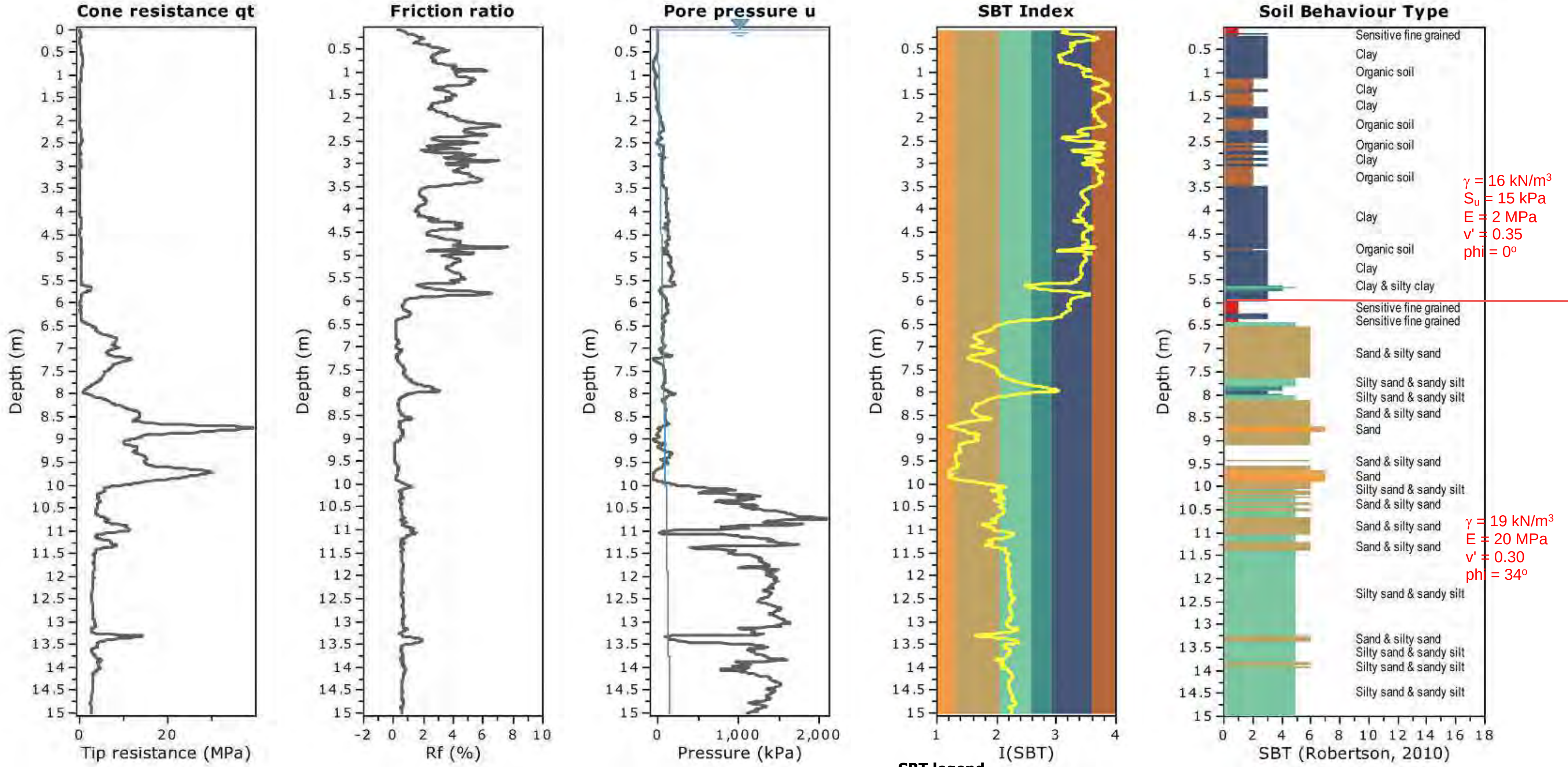
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-10
Total depth: 15.00 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: Barwon Water Yeodene Swamp Hydraulic Barriers
Location: Yeodene, Victoria



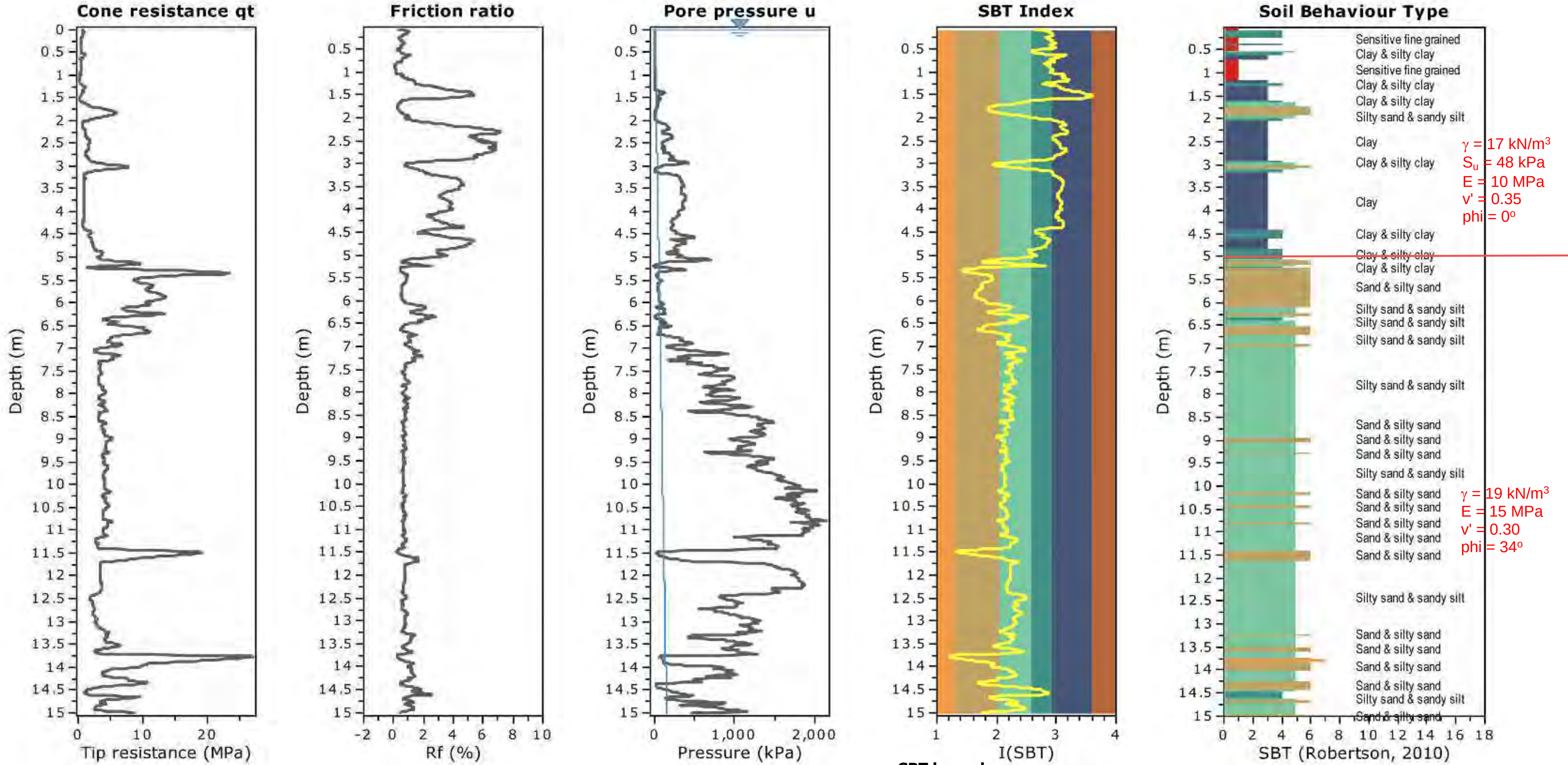
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-11
Total depth: 15.01 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: **Barwon Water Yeodene Swamp Hydraulic Barriers**
Location: **Yeodene, Victoria**



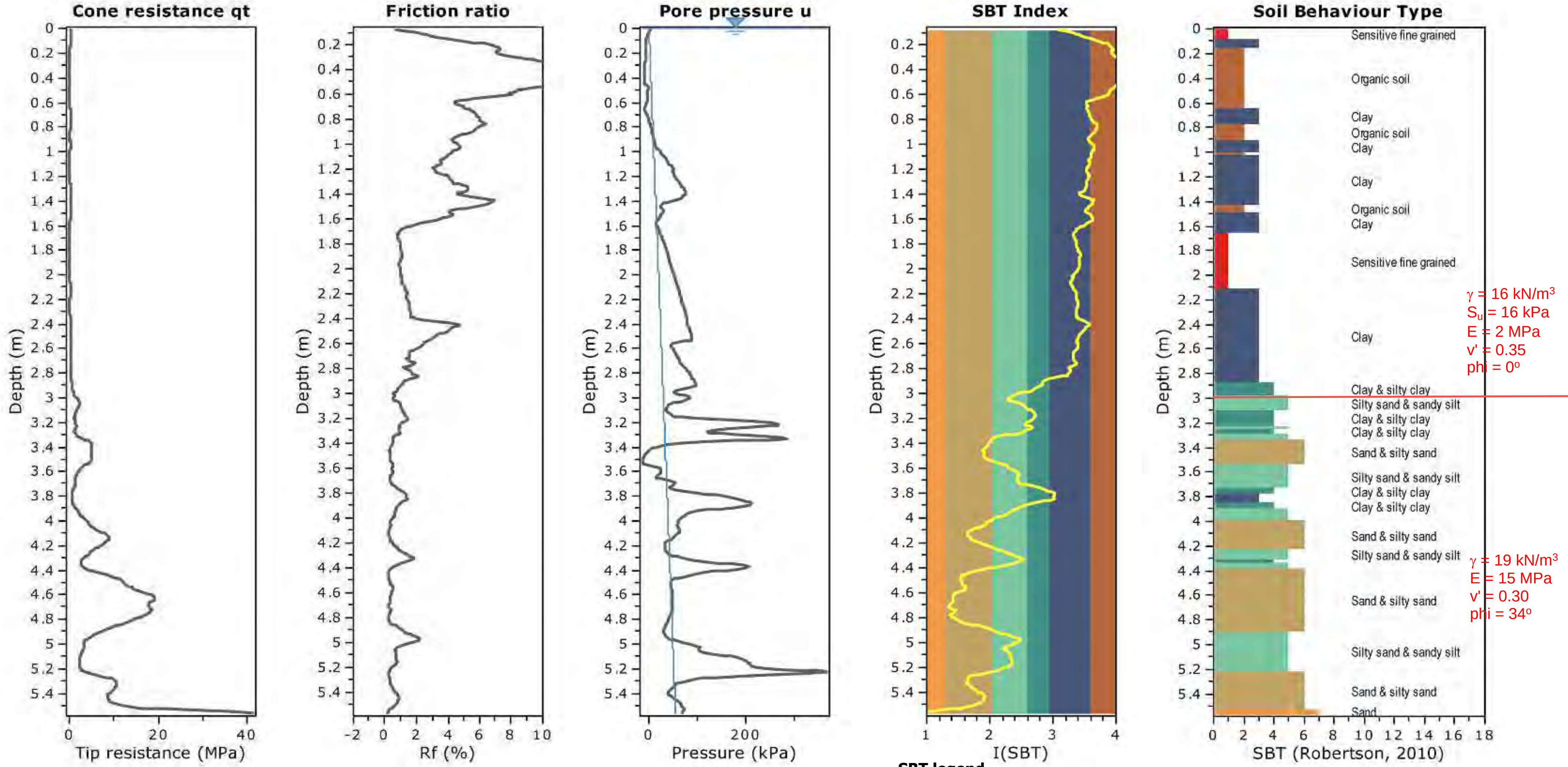
SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

GeoLogismiki
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

CPT: CPT-15
Total depth: 5.56 m, Date: 7/05/2021
Cone Type:
Cone Operator:

Project: Barwon Water Yeodene Swamp Hydraulic Barriers
Location: Yeodene, Victoria

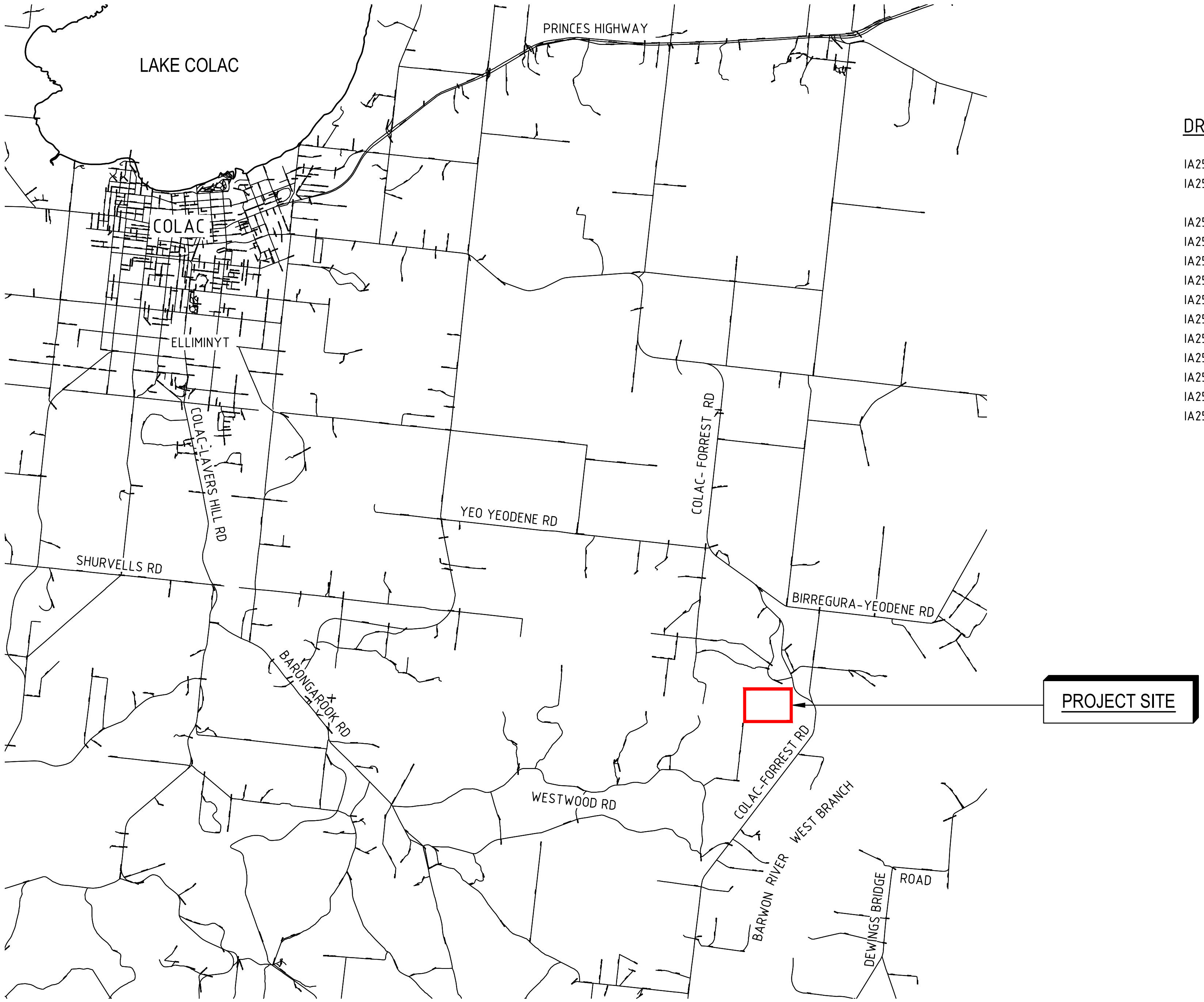


SBT legend

1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

Appendix B. Design Drawings

BIG SWAMP HYDRAULIC BARRIERS AND CONTINGENCY MEASURES



LOCALITY PLAN
SCALE 1:50000

DRAWING LIST

IA258200-DRG-C001	HYDRAULIC BARRIERS - COVER SHEET - LOCALITY PLAN AND DRAWING LIST
IA258200-DRG-G001	HYDRAULIC BARRIERS - GENERAL NOTES
IA258200-DRG-C002	HYDRAULIC BARRIERS - SITE PLAN
IA258200-DRG-C003	HYDRAULIC BARRIERS - BANK J1 - PLAN AND LONGITUDINAL SECTION
IA258200-DRG-C004	HYDRAULIC BARRIERS - BANK J2 - PLAN AND LONGITUDINAL SECTION
IA258200-DRG-C005	HYDRAULIC BARRIERS - BANK J3 - PLAN AND LONGITUDINAL SECTION
IA258200-DRG-C006	HYDRAULIC BARRIERS - BANK J4 - PLAN AND LONGITUDINAL SECTION - SHEET 1 OF 2
IA258200-DRG-C007	HYDRAULIC BARRIERS - BANK J4 - PLAN AND LONGITUDINAL SECTION - SHEET 2 OF 2
IA258200-DRG-C008	HYDRAULIC BARRIERS - BANK J5 - PLAN AND LONGITUDINAL SECTION
IA258200-DRG-C009	HYDRAULIC BARRIERS - BANK J6 - PLAN AND LONGITUDINAL SECTION
IA258200-DRG-C010	HYDRAULIC BARRIERS - TYPICAL CROSS SECTIONS OPTIONS
IA258200-DRG-C011	HYDRAULIC BARRIERS - FLOW CONTROL REGULATOR - ARRANGEMENT
IA258200-DRG-C012	HYDRAULIC BARRIERS - REGULATOR AND BARRIER - DETAILS

NOT FOR CONSTRUCTION

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

REFERENCES

DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW					

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

PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

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

DRG No. IA258200-DRG-C001 DRAWING DISCIPLINE: C SHEET NO. 1 of 1

HYDRAULIC BARRIERS
COVER SHEET
LOCALITY PLAN AND DRAWIGN LIST

REVISION A | F.C. | FILE No.

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

A1

Plot Date: 1 July 2021 - 12:58 PM Plotted by: Florance, Chris Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C001.dwg

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

GENERAL:

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

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

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

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

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

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

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

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

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

SURVEY AND SET OUT

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

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

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

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

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

SITE PREPARATION:

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

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

EMBANKMENT EARTHWORKS:

EW1. THE SURFACE UNDER THE PROPOSED EMBANKMENT IS TO BE CLEARED OF TREES AND VEGETATION.

EW2. TREES ARE TO BE CUT OFF OR REMOVED TO 300 mm BELOW NSL. THE ROOTS MAY REMAIN IN PLACE EXCEPT WHERE THEY CONFLICT WITH THE SHEET PILE.

EW3. THE SHEET PILE AXIS IS TO BE CLEARED OF BURIED TREES AND ROOTS, SUFFICIENT TO ALLOW THE PLACEMENT OF THE PILES.

EW4. THE ALIGNMENT MAY BE ALTERED TO AVOID TREES OR BURIED OBSTRUCTION SUBJECT TO APPROVAL OF THE SUPERINTENDENT.

ENVIRONMENTAL MANAGEMENT PLAN:

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

CONCRETE GENERAL:

C1. CONCRETE SHALL BE IN ACCORDANCE WITH AS3600 - 2018 CONCRETE STRUCTURES

C2. EXPOSURE CLASSIFICATION FOR DURABILITY IS C

C3. QUALITY OF CONCRETE TO BE AS FOLLOWS:
GRADE S50
SULFATE RESISTING CEMENT

C4. MINIMUM COVER TO REINFORCEMENT SHALL BE 65 mm, AND 85 mm IF CAST DIRECTLY AGAINST GROUND

C5. WATERSTOPS SHALL BE PROVIDED WHERE SHOWN ON THE DRAWINGS.

C6. CHAMFERS 25mm ARE REQUIRED ON EXPOSED CONCRETE CORNERS AND FILLETS WHERE SHOWN.

C7. THE USE OF CONCRETE ADMIXTURES WHERE REQUIRED SHALL BE SUBJECT TO THE APPROVAL OF THE SUPERINTENDENT AND SHALL CONFORM TO AS1478.1.

C8. SURFACE FINISHE SHALL BE STEEL TROWELLED.

C9. THE FINISHED CONCRETE SHALL BE A DENSE HOMOGENOUS MASS, COMPLETELY FILLING THE FORMWORK THOROUGHLY EMBEDDING THE REINFORCEMENT AND FREE OF STONE POCKETS. ALL CONCRETE SHALL BE COMPACTED WITH MECHANICAL VIBRATORS.

C10. USE PLACEMENT METHODS THAT WILL MINIMISE PLASTIC SETTLEMENT AND SHRINKAGE CRACKING. LIMIT VERTICAL FREE FALL TO 1.5m BY USE OF CHUTES, ETC. KEEP CHUTES VERTICAL, FULL AND IMMERSED IN PLACED CONCRETE. PLACE CONCRETE IN LAYERS AND BLEND SUCCEEDING LAYERS BY COMPACTION MAINTAIN A PLASTIC CONCRETE EDGE BETWEEN CONSTRUCTION JOINTS. PROPERLY COMPACT CONCRETE USING MECHANICAL VIBRATORS (AND HAND METHODS IF REQUIRED) TO REMOVE AIR BUBBLES AND GIVE MAXIMUM COMPACTION WITHOUT SEGREGATION OF CONCRETE. TAKE CARE TO AVOID CONTACT BETWEEN VIBRATORS AND PARTIALLY HARDENED CONCRETE, FORMWORK OR REINFORCEMENT. DO NOT USE VIBRATORS TO MOVE CONCRETE ALONG FORMS.

C11. PLACEMENT OF CONCRETE DURING HOT OR COLD WEATHER SHALL BE IN ACCORDANCE WITH GOOD PRACTICE.

C12. PROTECT FRESH CONCRETE FROM PREMATURE DRYING - PARTICULARLY IN HOT, WINDY OR DRY (LOW HUMIDITY) CONDITIONS, EXCESSIVELY HOT OR COLD TEMPERATURES, RAIN, ETC. PROVIDE WIND BREAKS. MAINTAIN CONCRETE AT A REASONABLY CONSTANT TEMPERATURE WITH MINIMUM MOISTURE LOSS FOR CURING PERIOD.

SHEET PILING:

SP1. SHEET PILES SHALL BE MANUFACTURED FROM PVC MATERIAL WITH THE FOLLOWING PROPERTIES:

A) SECTION PROPERTIES EQUIVALENT TO EITHER TIDEWALL SW50; CMI CL9000, OR APPROVED EQUIVALENT

B) EXTERNAL PILE SURFACE MANUFACTURED FROM VIRGIN PVC MATERIAL NOT LESS THAN 0.381 mm THICK

C) THE FULL COMPOSITE PRODUCT OF THE SUBSTRATE AND "CAPSTOCK" MATERIAL SHALL BE IN ACCORDANCE TIH TESTING REQUIRMENTS OF ASTM 4216 AND HAVE A MINIMUM CELL CLASSIFICATION FOR VIRGIN MATERIAL OF 1-42443-33.

D) PROVIDED WITH A MINIMUM 50 YEAR MANUFACTURERS WARRANTY

SP2. PROVIDE CORNER SECTIONS COMPATIBLE WITH THE SHEET PILE SECTIONS

SP3. ANY ALTERNATIVE SHEET PILE PROFILE PROPOSED BY THE CONTRACTOR SHALL BE SUBMITTED TO THE SUPERINTENDENT FOR APPROVAL.

SP4. THE DIMENSIONS OF THE STRUCTURE TO ACCOMMODATE THE SELECTED PILE PROFILE SHALL BE CONFIRMED PRIOR TO CONSTRUCTION.

ABBREVIATIONS:

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

STAINLESS STEEL:

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

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

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

ROCK MATERIALS:

B1. ROCK MATERIALS FOR ROCK BEACHING, AND FREE DRAINING BANK AGGREGATE SHALL COMPLY WITH THE FOLLOWING QUALITY REQUIREMENTS.

B2. SOUND ROCK AS DEFINED BY THE LIMITS IN AS 2758.0 APPENDIX C.

B3. HAVE A MINIMUM WET STRENGTH OF 100KN AND WET/DRY STRENGTH VARIATION NOT GREATER THAN 35% WHEN TESTED IN ACCORDANCE WITH AS 1141.22

B4. UNLESS NOTED OTHERWISE THE DEFAULT ROCK TYPE SHALL BE:

ROCK BEACHING FOR EMBANKMENTS - D50 = 75 mm

ROCK BEACHING AT REGULATOR - D50 = 150 mm

FREE DRAINING BANK AGGREGATE. NOMINAL 50 mm MAXIMUM, ANGULAR, CLEAN, GRADED TO BE FREE DRAINING WITH THE FOLLOWING GRADING:

SEIVE SIZE	% PASSING STANDARD SIEVE
50mm	95 - 100
20mm	35 - 70
10mm	10 - 30
5mm	0 - 5

B5. ROCK PLACED WITHIN THE SWAMP SHALL BE SEPARATED FROM THE NATURAL GROUND BY EITHER A GEOTEXTILE OR ANOTHER ROCK LAYER. USE BIDUM A34 OR EQUIVALENT WHERE NO OTHER MATERIAL IS SPECIFIED

B6 ROCK SIZE SPECIFIED BY MEAN DIAMETER D50 SHALL CONFIRM AS NEARLY AS PRACTICABLE TO THE FOLLOWING GRADING:

EQUIVALENT SPHERICAL DIAMETER PERCENTAGE PASSING BY WEIGHT

1.5 - 2.0 D50 .... 100%
D50........ 50%
0.3 - 0.4 D50........ 10 - 20%

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS						
No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW					

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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

Barwon Water
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DRG No. IA258200-DRG-G001 DRAWING DISCIPLINE: G SHEET NO. 1 of 1

HYDRAULIC BARRIERS
GENERAL NOTES

REVISION A | F.C. | FILE No.

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

A1

Plot Date: 1 July 2021 - 1:46 PM Plotted by: Florance, Chris Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-G001.dwg

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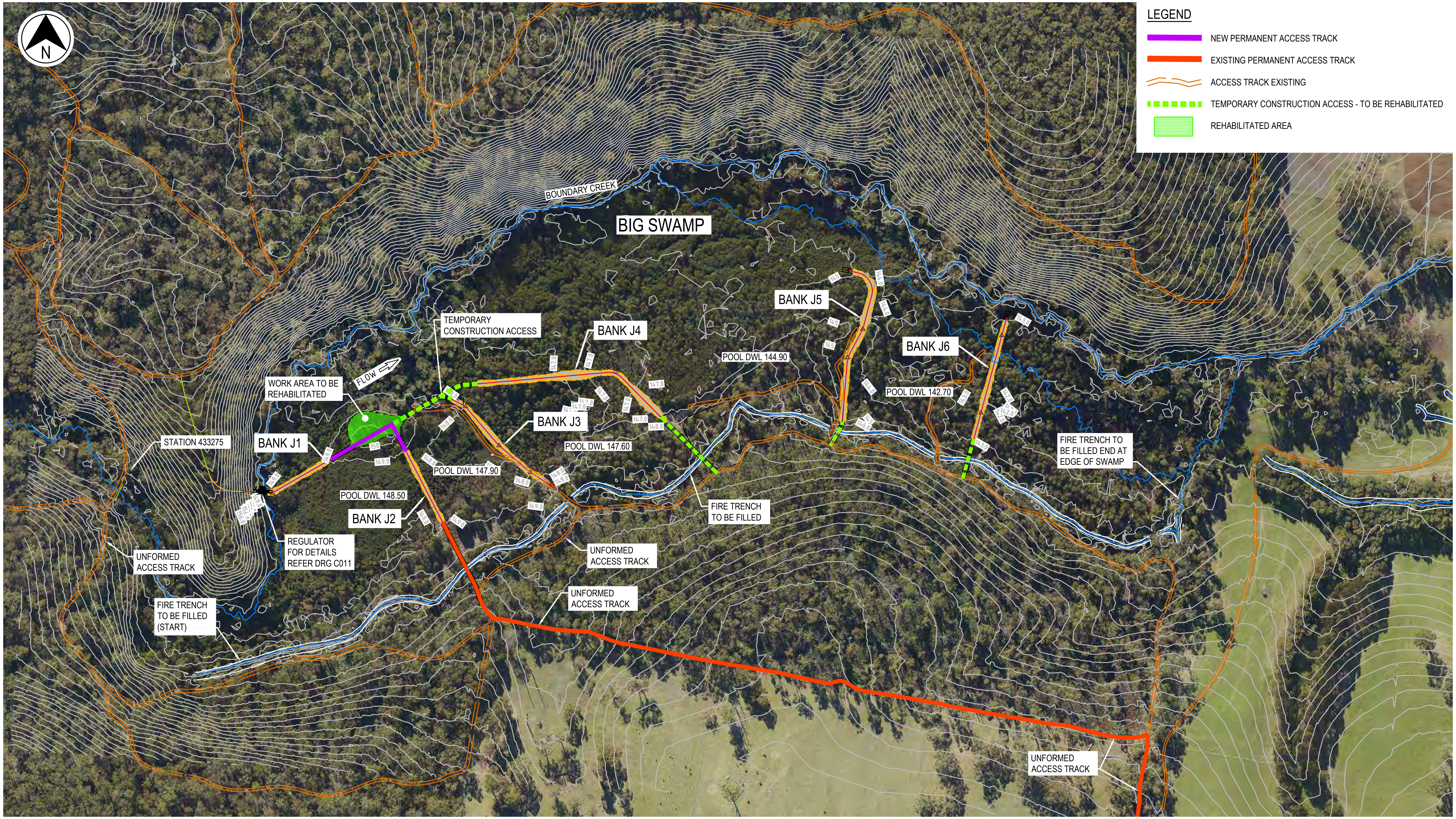

PLAN
SCALE 1:1500

SCALE 1:1500 (A1) 0 25 50 75 100 125m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
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DRG No. IA258200-DRG-C002
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

HYDRAULIC BARRIERS
SITE PLAN

REVISION A

DRAWN	DESIGNED	REVIEWED	APPROVED
J. PATEL	N. PAYNTER		
DRAFTING CHECK	DESIGN CHECK		

SCALES: PLAN 1:1000
SECTION HORIZ. VERT.
Scale for A1 sheet

F.C.
FILE No.
A1

Plot Date: 1 July 2021 - 1:51 PM Plotted by: Florance, Chris
Cad File No. C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C002.dwg

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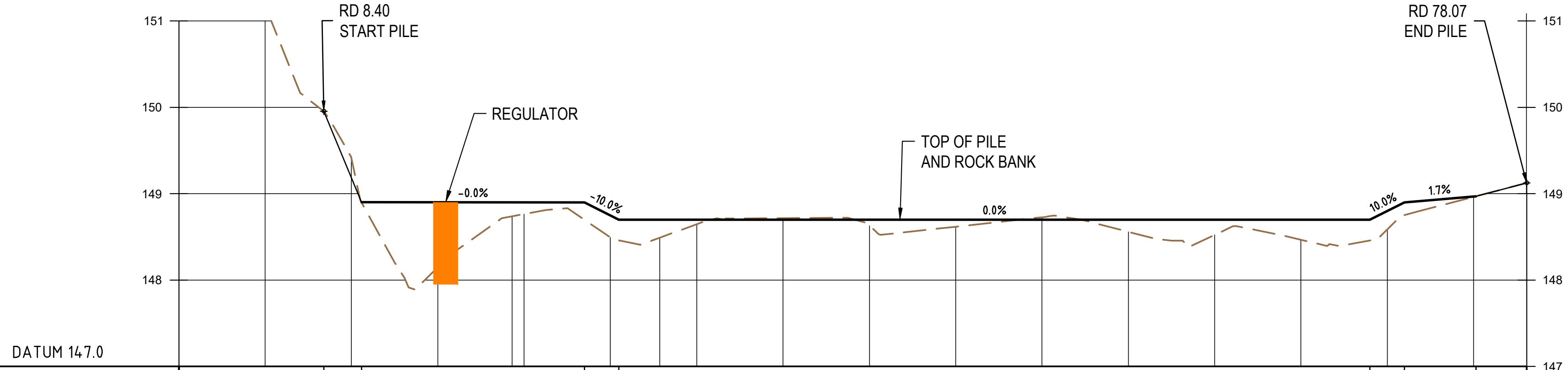
NOTES

1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.

PLAN
SCALE 1:200



RUNNING DISTANCE	EXISTING SURFACE	BANK HEIGHT	DESIGN BANK LEVEL	DESIGN TOP OF PILE
0.00	153.69			
5.00	151.18			
8.40	149.96			149.96
10.00	149.41			
10.58	148.90		148.90	148.90
15.00	148.15	0.75		
20.00	148.76	0.14		
23.49	148.70		148.90	148.90
25.00	148.49	0.26		
25.49	148.46		148.70	148.70
30.00	148.65	0.05		
35.00	148.72	-0.02		
40.00	148.63	0.07		
45.00	148.62	0.08		
50.00	148.73	-0.03		
55.00	148.56	0.14		
60.00	148.52	0.18		
65.00	148.47	0.23		
68.99	148.46		148.70	148.70
70.00	148.59	0.21		
70.99	148.75		148.90	148.90
75.00	148.96	0.00		
75.13	148.97		148.97	148.97
78.07	149.12			149.12

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW					

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JACOBS PROJECT NUMBER IA258200

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DRG No. IA258200-DRG-C003 DRAWING DISCIPLINE: C SHEET NO. 1 of 1

HYDRAULIC BARRIERS
BANK J1
PLAN AND LONGITUDINAL SECTION

REVISION A

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	N. PAYNTER			PLAN 1:200, SECTION HORIZ. 1:200, VERT. 1:40, Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

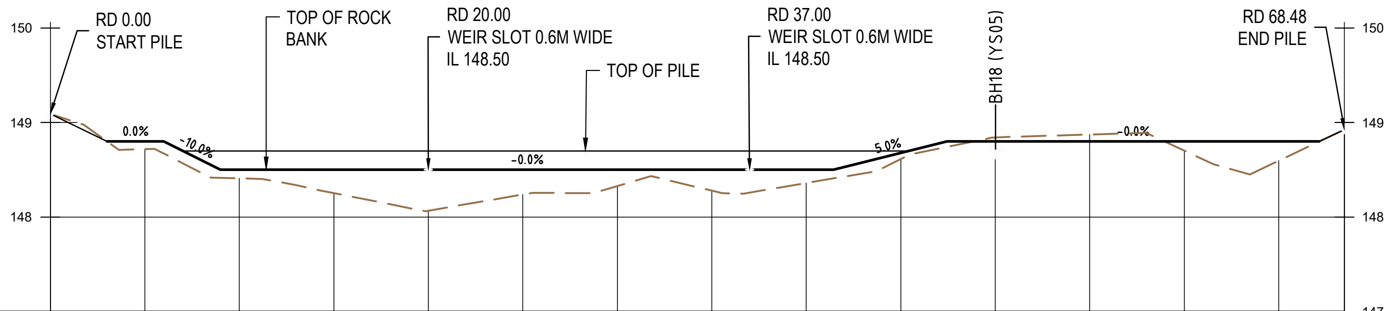
F.C. FILE No.

Plot Date: 1 July 2021 - 1:42 PM Plotted by: Florance, Chris Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C003.dwg

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

NOTES
1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.

PLAN
SCALE 1:200



RUNNING DISTANCE	0.00	3.00	5.00	6.00	9.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	41.45	45.00	47.45	50.00	55.00	60.00	65.00	67.15	68.48
DESIGN TOP OF PILE	149.09	148.80		148.80	148.70									148.70	148.80					148.80	148.93
DESIGN BANK LEVEL		148.80		148.80	148.50								148.50		148.80					148.80	
BANK HEIGHT			0.08			0.09	0.25	0.43	0.26	0.17	0.22	0.14		0.06		-0.04	-0.07	0.10	0.20		
EXISTING SURFACE	149.09		148.72			148.41	148.25	148.07	148.24	148.33	148.28	148.36		148.61		148.84	148.87	148.70	148.60		148.93

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

NOT FOR CONSTRUCTION

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m
SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

REFERENCES	
DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW					

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JACOBS PROJECT NUMBER IA258200

Barwon Water
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DRG No. IA258200-DRG-C004
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

HYDRAULIC BARRIERS
BANK J2
PLAN AND LONGITUDINAL SECTION

REVISION A
F.C.
FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	N . PAYNTER			PLAN 1:200
DRAFTING CHECK	DESIGN CHECK			SECTION HORIZ. 1:200 VERT. 1:40 Scale for A1 sheet

A1

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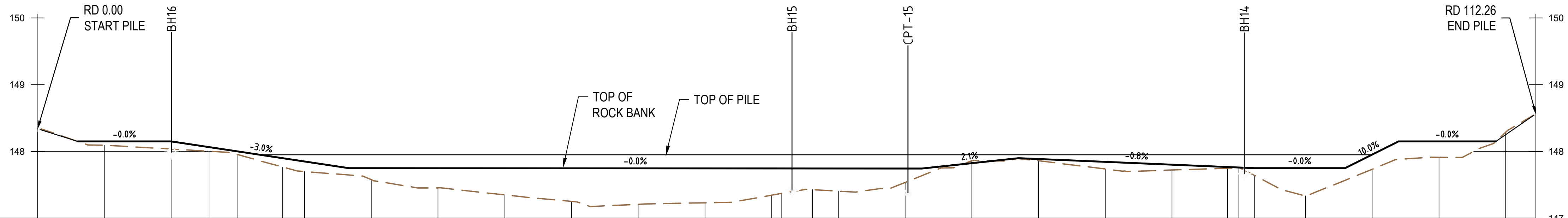
Plot Date: 1 July 2021 - 1:42 PM Plotted by: Florance, Chris
Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C004.dwg

NOTES

1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.
4. CUT 'V' SLOTS AT 1.2m CENTRES (EVERY SECOND PILE) ALONG BARRIER CREST. APPLY TO THE CREST WITH RL.147.95 OR AS ADVISED BY THE SUPERINTENDENT.
5. REFER DRAWINGS C011 FOR 'V' SLOT DETAILS.

PLAN
SCALE 1:200



RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	148.34			148.34
3.00	148.15	148.15		
5.00			0.05	148.10
10.00	148.15	148.15	0.11	148.04
15.00	147.95		0.05	147.95
20.00			0.15	147.70
23.33		147.75		
25.00			0.17	147.58
30.00			0.29	147.46
35.00			0.40	147.35
40.00			0.50	147.25
45.00			0.54	147.21
50.00			0.51	147.23
55.00			0.40	147.35
60.00			0.34	147.41
65.00			0.21	147.54
66.25		147.75		
70.00			-0.04	147.86
73.49		147.90		
75.00			0.03	147.86
80.00			0.11	147.74
85.00			0.08	147.72
90.00			0.01	147.75
91.16		147.75		
95.00			0.42	147.33
97.97		147.75		
100.00	147.95		0.22	147.73
101.97	148.15	148.15		
105.00			0.24	147.91
109.27	148.15	148.15		
110.00				148.29
112.26	148.56			148.56

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m
SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

NOT FOR CONSTRUCTION

REFERENCES	
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DRG No. IA258200-DRG-C005
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

HYDRAULIC BARRIERS
BANK J3
PLAN AND LONGITUDINAL SECTION

REVISION A
F.C.
FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED
J. PATEL	N. PAYNTER		
DRAFTING CHECK	DESIGN CHECK		

SCALES: PLAN 1:200; SECTION HORIZ. 1:200; VERT. 1:40; Scale for A1 sheet
A1

Plot Date: 29 June 2021 - 2:18 PM Plotted by: Florance, Chris Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C005.dwg

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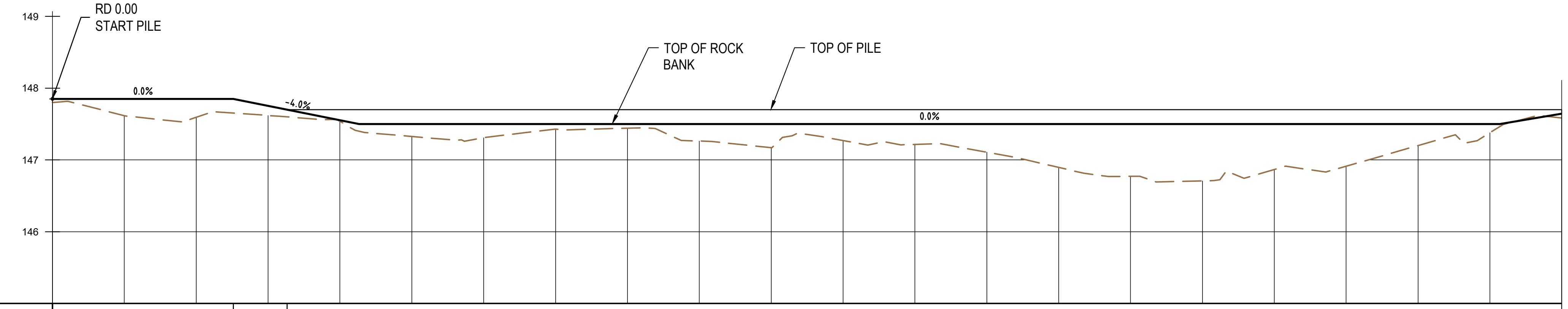
NOTES
1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.

PLAN
SCALE 1:200



RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	147.85	147.85	0.05	147.80
5.00			0.23	147.62
10.00			0.26	147.59
12.58	147.85	147.85		
15.00	147.70		0.13	147.62
20.00			0.02	147.54
21.33		147.50		
25.00			0.17	147.33
30.00			0.19	147.31
35.00			0.07	147.43
40.00			0.06	147.44
45.00			0.24	147.26
50.00			0.33	147.17
55.00			0.23	147.27
60.00			0.28	147.22
65.00			0.39	147.11
70.00			0.60	146.90
75.00			0.73	146.77
80.00			0.79	146.71
85.00			0.63	146.87
90.00			0.59	146.91
95.00			0.30	147.20
100.00			0.12	147.38
100.68		147.50		
105.00			0.06	147.58

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m
SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
A	ISSUE FOR REVIEW					

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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

HYDRAULIC BARRIERS
BANK J4
PLAN AND LONGITUDINAL SECTION - SHEET 1 OF 2

REVISION A

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES
J. PATEL	N . PAYNTER			PLAN 1:200; SECTION HORIZ. 1:200 VERT. 1:40; Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

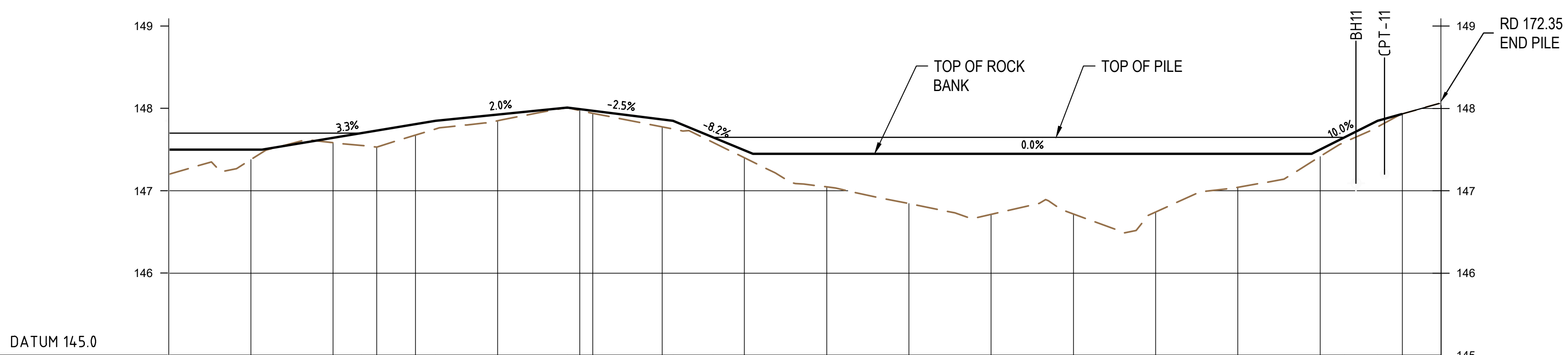
DRG No. IA258200-DRG-C006 DRAWING DISCIPLINE: C SHEET NO. 1 of 2

NOTES

1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.
4. CUT 'V' SLOTS AT 1.2m CENTRES (EVERY SECOND PILE) ALONG BARRIER CREST. APPLY TO THE CREST WITH RL.147.65 OR AS ADVISED BY THE SUPERINTENDENT.
5. REFER DRAWINGS C011 FOR 'V' SLOT DETAILS.

FOR CONTINUOUS REFER TO DRAWING NO IA258200-SK-C006

PLAN
SCALE 1:200



DESIGN TOP OF PILE	147.70	147.85	148.01	147.85	147.65	147.65	147.85	148.07															
DESIGN BANK LEVEL	147.50	147.85	148.01	147.85	147.45	147.45	147.85	147.93															
BANK HEIGHT	0.12	0.06	0.13	0.08	0.02	0.09	0.09	0.40	0.61	0.74	0.73	0.71	0.41	0.09									
EXISTING SURFACE	147.38	147.58	147.68	147.85	147.97	147.78	147.40	147.05	146.84	146.71	146.72	146.74	147.04	147.42	147.93	148.07							
RUNNING DISTANCE	100.00	100.68	105.00	110.00	111.21	115.00	119.23	120.00	125.00	125.67	130.00	130.52	135.00	140.00	145.00	150.00	155.00	160.00	164.49	165.00	168.49	169.96	170.00	172.35

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS						
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PROJECT NAME
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JACOBS PROJECT NUMBER IA258200

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DRG No. IA258200-DRG-C007 DRAWING DISCIPLINE: C SHEET NO. 2 of 2

HYDRAULIC BARRIERS
BANK J4
PLAN AND LONGITUDINAL SECTION - SHEET 2 OF 2

REVISION A

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	N. PAYNTER			PLAN 1:200; SECTION HORIZ. 1:200, VERT. 1:40; Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

F.C. FILE No.

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

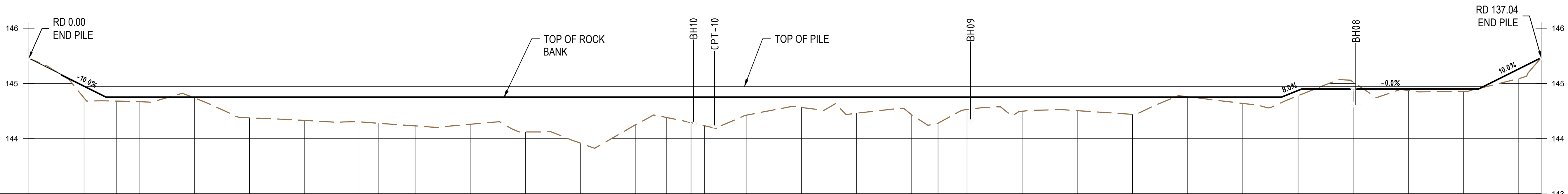
Plot Date: 29 June 2021 - 3:22 PM Plotted by: Florance, Chris Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C007.dwg

NOTES

1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.
4. CUT 'V' SLOTS AT 1.2m CENTRES (EVERY SECOND PILE) ALONG BARRIER CREST. APPLY TO THE CREST WITH RL.147.94 OR AS ADVISED BY THE SUPERINTENDENT.
5. REFER DRAWINGS C011 FOR 'V' SLOT DETAILS.

PLAN

SCALE 1:200



DATUM 143.0

RUNNING DISTANCE	DESIGN TOP OF PILE	DESIGN BANK LEVEL	BANK HEIGHT	EXISTING SURFACE
0.00	145.46			145.46
3.00	145.16	145.15		
5.00	144.94		0.21	144.74
7.00		144.75		
10.00			0.08	144.67
15.00			0.01	144.74
20.00			0.37	144.38
25.00			0.42	144.33
30.00			0.44	144.31
35.00			0.52	144.23
40.00			0.49	144.26
45.00			0.63	144.12
50.00			0.83	143.92
55.00			0.50	144.25
60.00			0.46	144.29
65.00			0.33	144.42
70.00			0.18	144.57
75.00			0.29	144.46
80.00			0.32	144.43
85.00			0.22	144.53
90.00			0.25	144.50
95.00			0.24	144.51
100.00			0.31	144.44
105.00			-0.01	144.76
110.00			0.11	144.64
113.48		144.75		
115.00		144.90	0.09	144.78
115.36				
120.00			-0.12	145.02
125.00			0.03	144.87
130.00			0.04	144.86
131.38	144.94	144.90		
135.00			0.17	145.09
137.04	145.47	145.47	0.00	145.47

LONGITUDINAL SECTION

SCALE 1:200 (H) 1:40 (V)

SCALE 1:40 (A1) 1 0.5 0 1 2 3 4m

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS						
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A	ISSUE FOR REVIEW					

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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

Barwon Water

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DRG No. IA258200-DRG-C008
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

HYDRAULIC BARRIERS
BANK J5
PLAN AND LONGITUDINAL SECTION

REVISION A

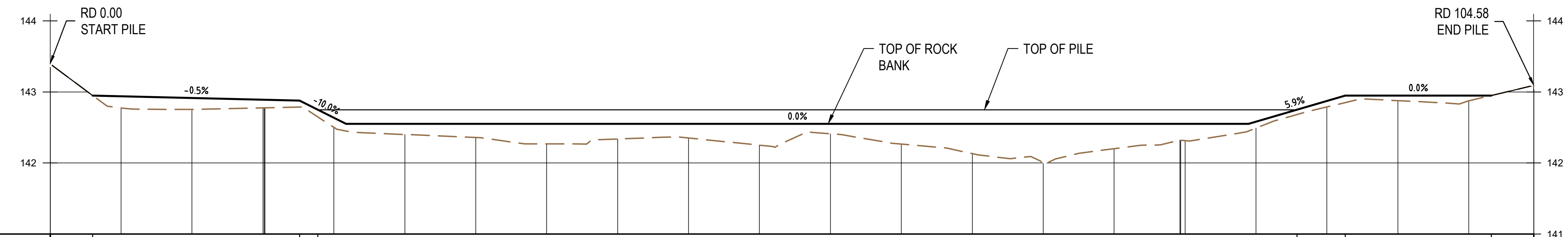
DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	N. PAYNTER			PLAN 1:200; SECTION HORIZ. 1:200; VERT. 1:40; Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

F.C.
FILE No.

NOTES

1. BARRIER ALIGNMENT AND GROUND LEVELS TO BE CONFIRMED BY SURVEY, REFER GENERAL NOTES, DRAWING IA258200-DRG-G001
2. FINAL VERTICAL PROFILE TO BE CONFIRMED BY SURVEY
3. DO NOT COMMENCE CONSTRUCTION UNTIL ALIGNMENT, VERTICAL PROFILE AND VEGETATION REMOVAL IS CONFIRMED.
4. CUT 'V' SLOTS AT 1.2m CENTRES (EVERY SECOND PILE) ALONG BARRIER CREST. APPLY TO THE CREST WITH RL.147.75 OR AS ADVISED BY THE SUPERINTENDENT.
5. REFER DRAWINGS C011 FOR 'V' SLOT DETAILS.

PLAN
SCALE 1:200



DESIGN TOP OF PILE	143.39	142.95				142.88	142.75																142.75	142.95			142.95	143.09
DESIGN BANK LEVEL		142.95				142.88		142.55													142.55			142.95			142.95	
BANK HEIGHT			0.16	0.16	0.11		0.13		0.15	0.19	0.28	0.21	0.20	0.30	0.14	0.28	0.42	0.56	0.35	0.24		0.09	0.08		0.07	0.07		
EXISTING SURFACE	143.39		142.78	142.75	142.78		142.50		142.40	142.36	142.27	142.34	142.35	142.25	142.41	142.27	142.13	141.99	142.20	142.31		142.49	142.79		142.88	142.88		143.09
RUNNING DISTANCE	0.00	3.00	5.00	10.00	15.00	17.59	20.00	20.86	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00	75.00	80.00	84.48	85.00	90.00	91.29	95.00	100.00	101.59	104.58

LONGITUDINAL SECTION
SCALE 1:200 (H) 1:40 (V)

NOT FOR CONSTRUCTION

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

REFERENCES	
DRAWING	TITLE

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

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DRG No. IA258200-DRG-C009
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

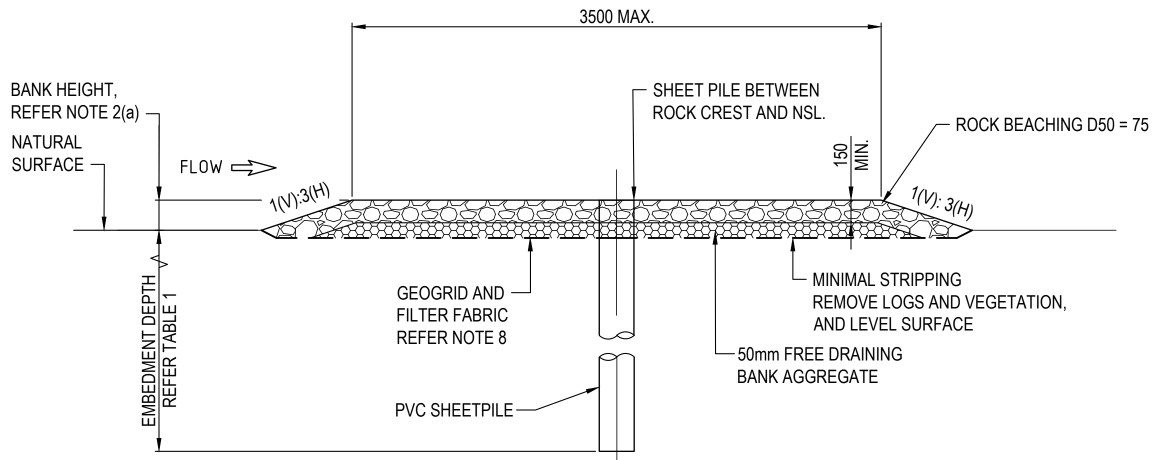
HYDRAULIC BARRIERS
BANK J6
PLAN AND LONGITUDINAL SECTION

REVISION A | F.C. | FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
J. PATEL	N. PAYNTER			PLAN 1:200; SECTION HORIZ. 1:200; VERT. 1:40
DRAFTING CHECK	DESIGN CHECK			Scale for A1 sheet

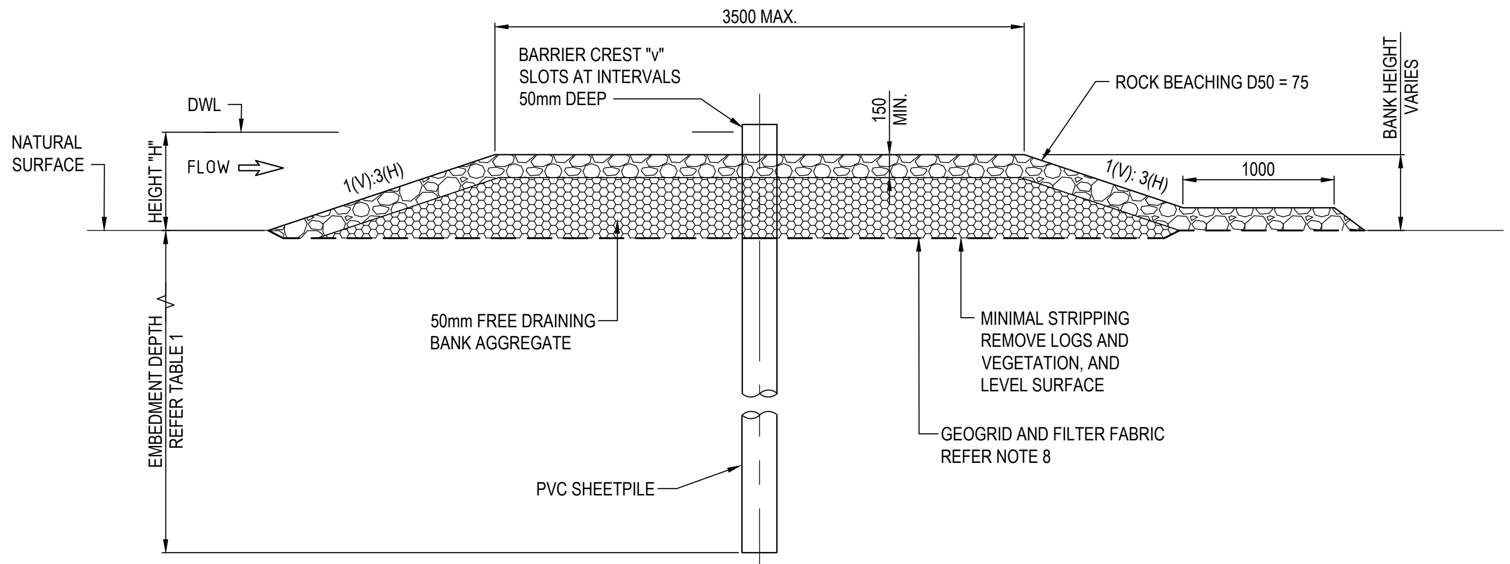
A1

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



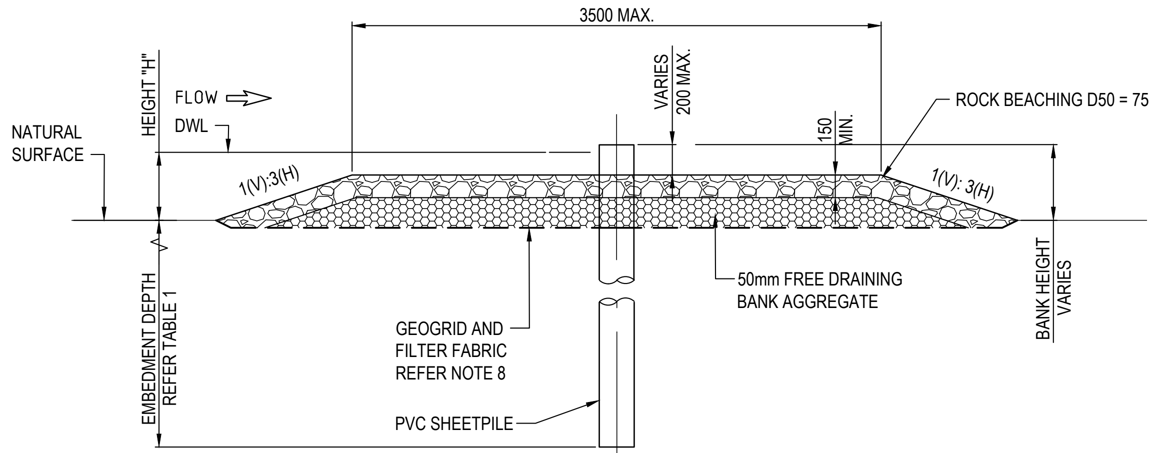
TYPICAL SECTION - DESIGN WATER LEVEL 0-300mm ABOVE NSL

SCALE 1:25



TYPICAL SECTION - DESIGN WATER LEVEL > 600mm ABOVE NSL

SCALE 1:25



TYPICAL SECTION - DESIGN WATER LEVEL 300-600mm ABOVE NSL

SCALE 1:25

TABLE 1 SHEET PILE SCHEDULE

HEIGHT (m)	MINIMUM EMBEDMENT DEPTH (m)	MAXIMUM EMBEDMENT DEPTH (m)	BANK	OTHER REQUIREMENTS
0 OR LESS DWL < NSL	1000	1500	J1 TO J6	EXTENDED PILES LATERALLY 3m MINIMUM INTO ABUTMENTS
0 - 300	1000	1500	J1 TO J6	
300 - 600	1500	2500	J1 TO J6	
600 - 900	1500	2500	J1 TO J4	
600 - 900	2000	3500	J5 TO J6	
900 - 1200	2000	3000	J1 TO J4	
900 - 1200	2000	4000	J5 TO J6	

PILE EMBEDMENT DEPTHS SHALL BE ALTERNATED TO ALLOW SUBSURFACE FLOW ie.MIN./MAX... ETC.
PILE DEPTH MAY BE ALTERNATED TO STRADDLE BURIED OBSTRUCTIONS.
HEIGHT "H" IS DEFINED AS THE MAXIMUM OF "DWL MINUS NSL" MEASURED OVER A LENGTH OF 4.5m CENTRED OVER THE POINT.

NOTES

1. THE CONTRACTOR SHALL ENSURE THAT THE CONSTRUCTION METHOD PREVENTS THE DISTURBANCE OF "ASS" AND "PASS" SOILS. THE CONTRACTOR SHALL INCLUDE THAT:
   a. ALL CONSTRUCTION TRAFFIC IS ON A SOUND SURFACE.
   b. COMBINED GEOGRID, GEOTEXTILE AND ROCK PLATFORMS ARE ADEQUATE TO SUPPORT THE WEIGHT OF THE PROPOSED PLANT AND EQUIPMENT AND TO PREVENT EXTRUSION OF THE UNDERLYING SOIL TO THE SURFACE.
   c. PLANT AND EQUIPMENT ARE THE SMALLEST PRACTICABLE
2. THE "DESIGN BANK LEVEL" AND "DESIGN TOP OF PILE" LEVEL SHALL BE CONFIRMED BY THE SUPERINTENDENT AFTER RECIEPT OF THE SURVEYED "NSL". THEY SHALL BE SET ON THE FOLLOWING PRINCIPLES:
   a. THE BANK THICKNESS IS TO BE THE MINIMUM NECESSARY TO ENABLE CONSTRUCTION TRAFFIC OVER THE GROUND SURFACE OF THE SWAMP WITHOUT EXTRUDING THE SOFT SOIL TO THE SURFACE. THIS SHOULD FOLLOW THE NATURAL SURFACE WITH MINIMAL EXCAVATION OR STRIPPING.
   b. THE TOP OF BANK IS TO BE RAISED TO "DWL" MINUS 150mm AT OVERFLOW SECTIONS.
   c. WITHIN THE BODY OF THE SWAMP THE TOP OF PILE SHALL BE THE MINIMUM LEVELS SHOWN ON THE DRAWINGS. THE TOP OF PILE SHOULD SLOPE UP THE ABUTMENTS TO A HEIGHT OF 250 mm ABOVE DWL.
3. THE CONTRACTOR SHOULD MAKE REFERENCE TO THE CPT DATA TO UNDERSTAND THE GROUND CONDITIONS.
4. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE DESIGN AND IMPLEMENTATION OF ALL TEMPORARY WORKS DURING CONSTRUCTION.
5. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE PROTECTION AND HANDLING OF THE SHEET PILES AND ASSOCIATED FITTINGS AT ALL TIMES. DURING HANDLING AND INSTALLATION, CARE SHALL BE EXERCISED TO AVOID DAMAGE TO THE SHEET PILE AND/OR COATING SYSTEMS.
6. ALL SHEET PILES SHALL BE PLACED TO THE EMBEDMENT DEPTH SHOWN IN TABLE 1, BASED ON THE HEIGHT OF THE DWL ABOVE SURVEYED GROUND LEVEL.
7. SHEETPILES MAY BE SHORTENED TO AVOID BURIED OBSTRUCTIONS SUBJECT TO THE LIMITS SHOWN IN TABLE 1.
8. GEOGRID AND FILTER GEOTEXTILE SHALL BE GEOSYNTHETICS COMBIGRID 40/40 OR APPROVED EQUIVALENT.
9. THE COMBINED GEOGRID, GEOTEXTILE AND FREE DRAINING BANK AGGREGATE AND ROCK BEACHING SHALL BE PLACED, WITH AN OPENING LEFT FOR THE INSTALLATION OF THE SHEET PILES. THE OPENING SHALL BE CLOSED UPON INSTALLATION OF THE SHEET PILES.
10. THE BANK IS TO BE CONSTRUCTED IN LIFTS NO GREATER THAN 300MM, ALTERNATING BETWEEN BOTH SIDES OF THE SHEET PILE WALL UNTIL THE DESIGN BANK LEVEL IS REACHED.

SCALE 1:25 (A1) 0.5 0 0.5 1.0 1.5 2.0 2.5m

NOT FOR CONSTRUCTION

REFERENCES	
DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

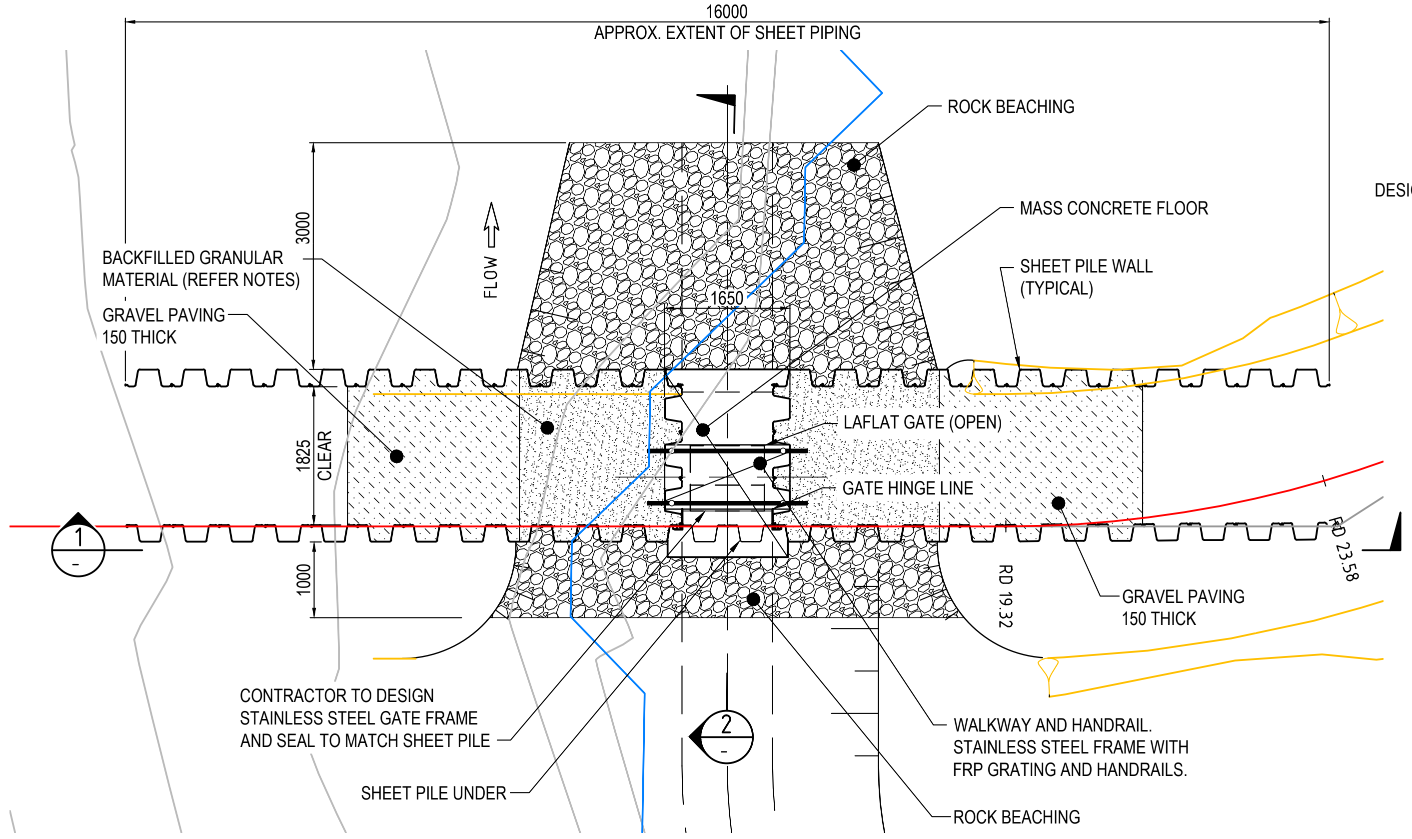
DRG No. IA258200-DRG-C010 DRAWING DISCIPLINE: C SHEET NO. 1 of 1

HYDRAULIC BARRIERS
TYPICAL CROSS SECTION OPTIONS

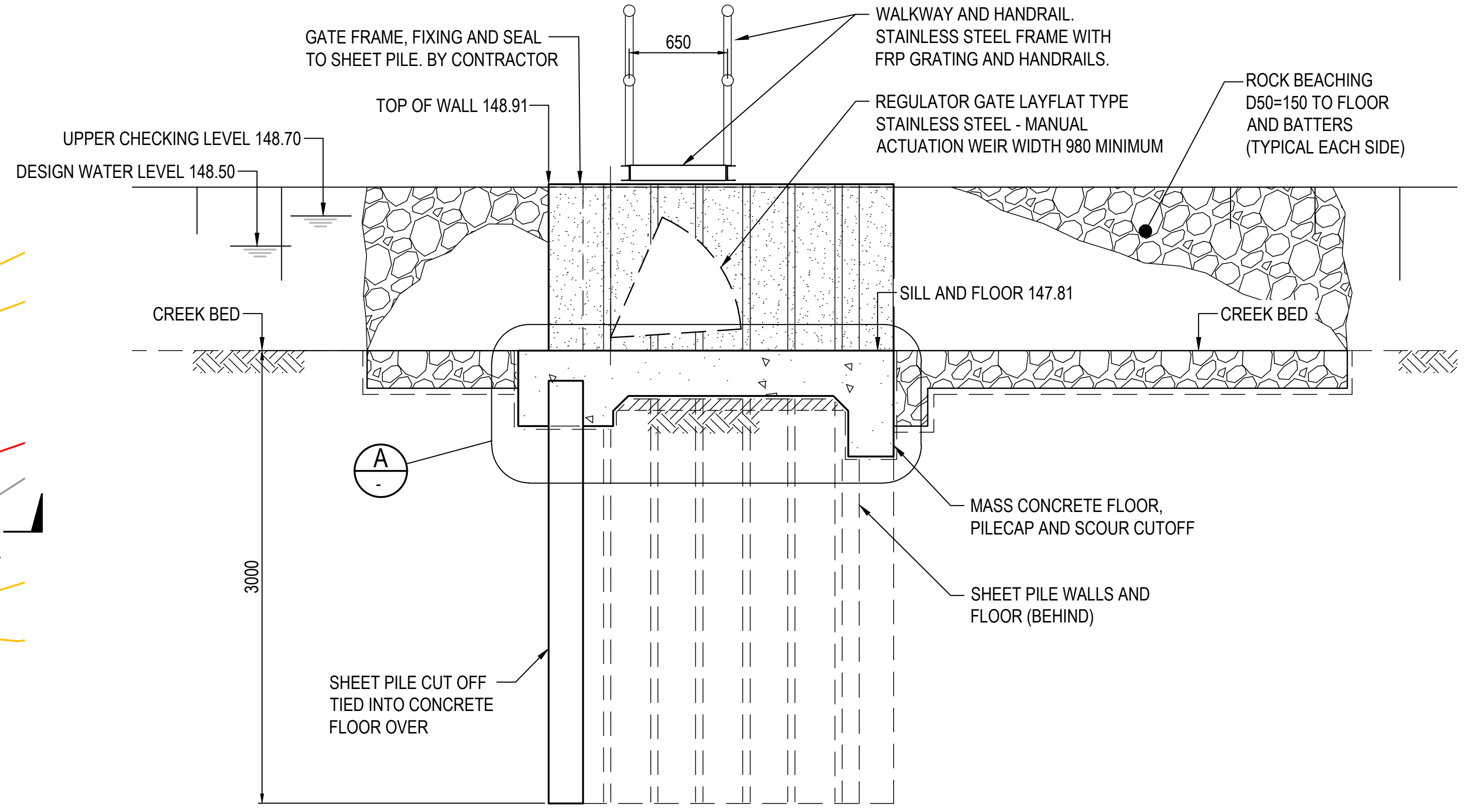
DRAWN	DESIGNED	REVIEWED	APPROVED
J. PATEL	N. PAYNTER		
DRAFTING CHECK	DESIGN CHECK		

REVISION A F.C. FILE No.

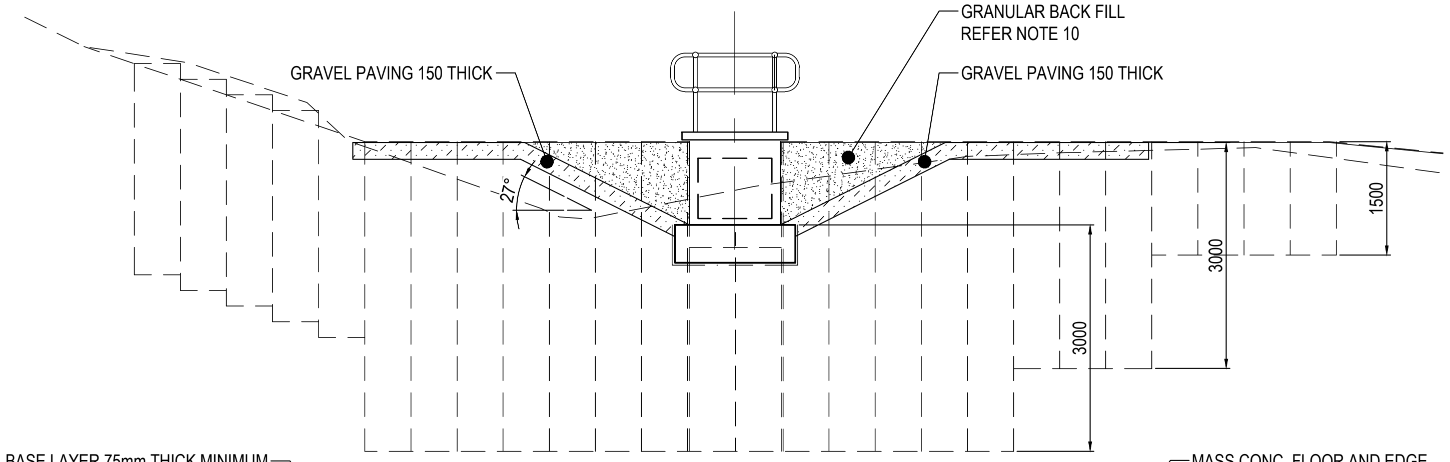
SCALES: PLAN 1:1000 SECTION HORIZ. VERT. Scale for A1 sheet A1



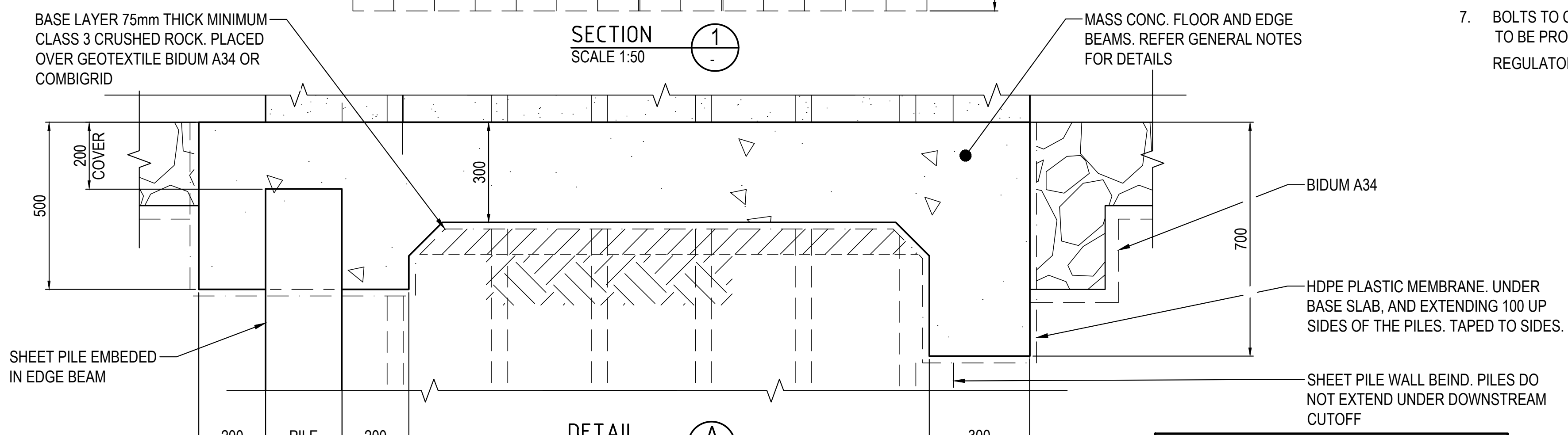
PLAN
SCALE 1:50



SECTION 2
SCALE 1:25



SECTION 1
SCALE 1:50



DETAIL A
SCALE 1:10

NOT FOR CONSTRUCTION

NOTES

1. FOR GENERAL NOTES REFER DRAWING G001.
2. THE REGULATOR SITE DIMENSIONS SHALL BE CONFIRMED BY SURVEY BY THE CONTRACTOR PRIOR TO ORDERING THE GATE. ANY DISCREPANCIES REFERRED TO THE SUPERINTENDENT.
3. THE REGULATOR DESIGN DIMENSIONS AND SIZE OF THE GATE IS TO BE CONFIRMED BY THE CONTRACTOR BASED ON THE SHEET PILES SELECTED.
4. THE REGULATOR STRUCTURE WALLS ARE TO BE FORMED FROM SHEET PILE SECTIONS AND COMPATIBLE PROPRIETRY CORNER SECTIONS.
5. THE CONCRETE REGULATOR FLOOR IS TO CAST AFTER THE SHEET PILE WALLS AND SHALL FILL AND CONFORM TO THE SHAPE OF THE PILE SECTIONS.
6. THE TOP OF THE SHEET PILE REGULATOR WALLS ARE TO BE TIED TOGETHER WITH STAINLESS STEEL CAPPING SECTIONS. THIS IS TO COMPRISE 100 X 100 X 6 EQUAL ANGLES ON EACH SIDE OF THE WALLS AND BOLTED TO EACH PILE. ALL MEMBERS TO BE FIXED AT THE CORNERS WITH COMMON 6MM PLATES. ALL BOLTS TO BE M16.
7. BOLTS TO COME WITH NUTS AND WASHERS. FIXINGS AGAINST SHEET PILES TO BE PROVIDED WITH LARGE FLAT DIN 9012 WASHERS.

   REGULATOR GATE

8. THE REGULATOR GATE SHALL BE TO A DESIGN PROVIDED BY THE CONTRACTOR AND SUBMITTED TO THE SUPERENTENDENT FOR APPROVAL. THE REGULATOR SHALL HAVE THE FOLLOWING FEATURES.
   - GATE TO BE A LAY FLAT TYPE
   - WIER INTERNAL WIDTH 980 MINIMUM
   - WHEN FULLY CLOSED HAVE A CHECKING LEVEL 900MM MINIMUM ABOVE THE FLOOR AND NO LOWER THAN THE CHECKING LEVEL SHOWN ON THE DESIGN
   - WHEN FULLY OPEN PROTRUDE TO GREATER THAN 200 MM ABOVE THE FLOOR LEVEL
   - FABRICATED FROM STAINLESS STEEL GRADE 304 MEMBERS, AND GRADE 316 BOLTS
   - MOUNT ONTO THE CONCRETE FLOOR AND BE FULLY SELF SUPPORTING WITHOUT BEARING ONTO THE SIDE WALLS
   - EQUIPPED WITH UPSTREAM SEALS TO MATCH THE UPSTREAM SHEET PILE WALLS, AND DESIGNED IN SUCH A WAY AS TO ALLOW DIFFERENTIAL MOVEMENT THROUGH FLOOR SETTLMENT
   - EQUIPPED WITH MANUAL LOCKABLE HANDWHEEL ACTUATOR. ACTUATOR TO BE LOCATED BETWEEN 700 AND 1200 ABOVE WALKWAY LEVEL
9. WALKWAY AND HANDRAIL TO COMPLY WITH AS 1657 AND TO BE FABRICATED FROM STAINLESS STEEL MEMEBERS AND FIXIINGS WITH FRP GRATING. THE WALKWAY MAY BE FIXED TO EITHER THE GATE OR THE REGULATOR WALLS.
10. BACKFILL BEHIND REGULATOR WALLS TO BE A CLEAN GRANULAR IMPORTED MATERIAL, VICROADS CLASS 4 CRUSHED ROCK OR SIMILAR, COMPACTED TO 95 PERCENT MDD.

SCALE 1:10 (A1) 200 100 0 200 400 600 800 1000mm
SCALE 1:25 (A1) 0.5 0 0.5 1.0 1.5 2.0 2.5m
SCALE 1:50 (A1) 1 0.5 0 1 2 3 4 5m

REFERENCES	
DRAWING	TITLE

REVISIONS						
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PROJECT NAME
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JACOBS PROJECT NUMBER IA258200

Barwon Water
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DRG No. IA258200-DRG-C011
DRAWING DISCIPLINE: C
SHEET NO. 1 of 1

HYDRAULIC BARRIERS
FLOW CONTROL REGULATOR
ARRANGEMENT

REVISION A
F.C.
FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED
N. PAYNTER	N. PAYNTER		
DRAFTING CHECK	DESIGN CHECK		

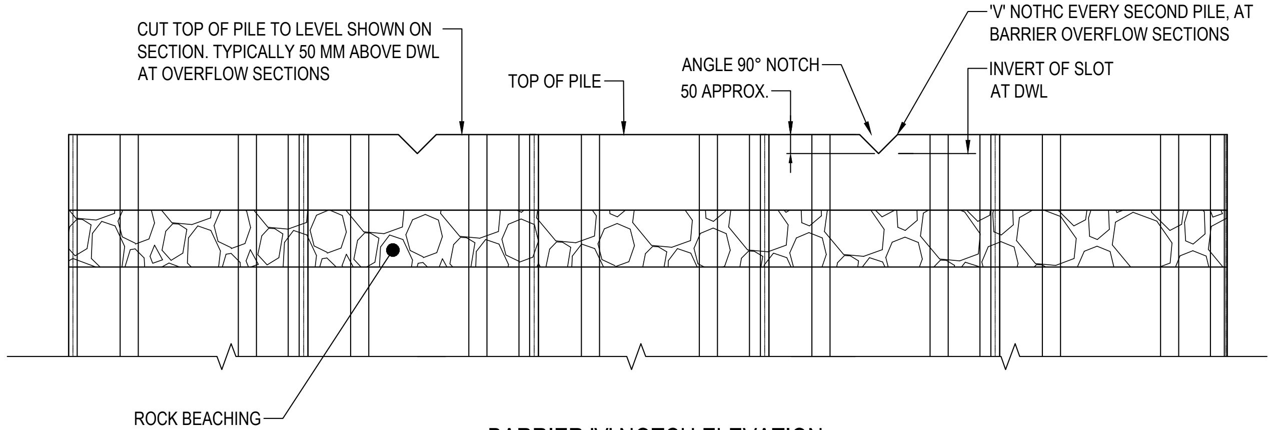
SCALES: PLAN 1:1000 SECTION HORIZ. VERT.
Scale for A1 sheet
A1

Plot Date: 1 July 2021 - 12:36 PM Plotted by: Florance, Chris
Cad File No: C:\users\florancr\appdata\local\projectwise\jacobs_anz_ie\d0489000\IA258200-DRG-C011.dwg

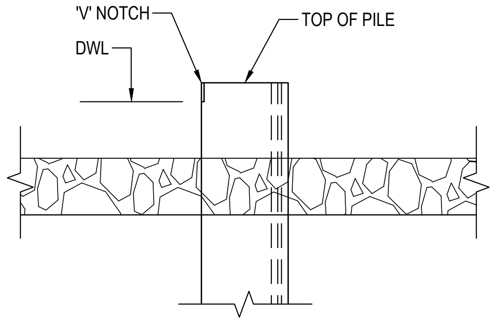
Note: * indicates signatures on original issue or last revision of drawing

NOTES

1. PILES TO BE CUT TO FINAL LEVEL AND "V" NOTCH TO BE CUT AFTER THE EMBANKMENT IS CONSTRUCTED AND CONSTRUCTION VEHICLE TRAFFIC HAS CEASED.
2. V NOTCH INVERT TO BE CUT TO A VERTICAL TOLLERANCE OF 5mm.
3. SHEET PILE JOINTING DETAIL IS TO APPLY AT ANY PILE LOCATION WHERE CORRECTION FOR PILE LEAN IS REQUIRED. DIMENSION AND ANGLE OF OVERLAP TO BE DETERMINED BY CONTRACTOR TO CORRECT PILE
4. MINUMUM BOLT EDGE DISTANCE 35 MM.



BARRIER 'V' NOTCH ELEVATION
SCALE 1:10



BARRIER 'V' NOTCH SETION
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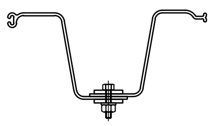

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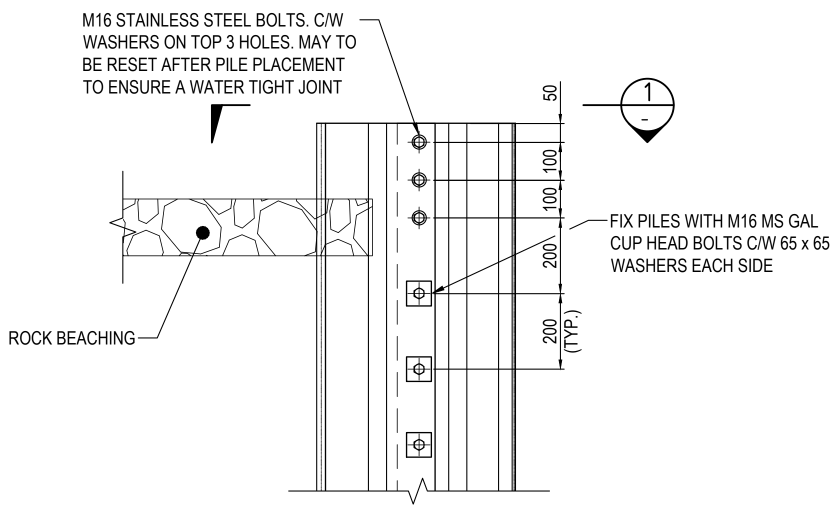

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REFERENCES

DRAWING	TITLE

REVISIONS

No.	REVISION DESCRIPTION	DRAWN CHECKED	DESIGN CHECKED	REVIEWED	APPROVED	DATE
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PROJECT NAME
BIG SWAMP HYDRAULIC BARRIERS
JACOBS PROJECT NUMBER IA258200

HYDRAULIC BARRIERS
REGULATOR AND BARRIER
DETAILS

REVISION A | F.C. | FILE No.

DRAWN	DESIGNED	REVIEWED	APPROVED	SCALES:
N. PAYNTER	N. PAYNTER			PLAN 1:10 SECTION HORIZ. VERT. Scale for A1 sheet
DRAFTING CHECK	DESIGN CHECK			A1

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

Appendix C

Big Swamp Success Target Assessment

Barwon Water

Big Swamp Success Target Assessment

1 July 2021

CDM Smith

listen. think. deliver.

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Figures

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Appendices

Document history & status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
A	24/06/21	J.Fawcett	J.Fawcett	24/06/21	Draft
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C	1/07/21	J.Fawcett	J.Fawcett	1/07/21	Final

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Author:	Roger Cranswick, Paul Foreman, Jakob Pretzsch-Kalsgaard, Jonathon Fawcett
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Document Title:	**Big Swamp Success Target Assessment**
Document Version:	1
Project Number:	1001104

Section 1 Introduction

1.1 Background

Barwon Water is currently implementing its remediation plan for Boundary Creek and Big Swamp. These remedial efforts follow the issuance of a section 78 Ministerial Notice in September 2018 which mandated the development and implementation of the Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP).

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

- The **Boundary Creek and Big Swamp Remediation Plan** to address remediation of confirmed impact in the Boundary Creek catchment resulting from historical management of groundwater extraction
- The **Surrounding Environment Investigation** to investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction

The REPP outlines an adaptive approach to improve water flows and quality as well as the vegetation and ecology in Boundary Creek and Big Swamp to mitigate downstream impacts on the Barwon River. To support this approach six (6) remediation actions were proposed within the REPP:

1. **Continued delivery of a supplementary flow** to meet the objective of maintaining minimum flows in Reach 3 of Boundary Creek all year round (recording a flow of at least 0.5 ML/day at the Yeodene stream gauge)
2. **Construction of a series of hydraulic barriers** to effectively distribute flows across the swamp to allow for a greater area to be inundated, increasing surface water flow connectivity across Big Swamp and preventing progressive water table decline in the perched alluvial aquifer
3. **Infilling the existing fire trenches and agricultural drain** at the eastern end of the swamp to allow the swamp to retain more water over the winter months
4. **Prevention of the encroachment of dry vegetation classes** (e.g. Swamp Gum) in Big Swamp to provide suitable conditions for wetland species to recolonise disturbed areas
5. **Ongoing data collection** to inform the adaptive monitoring approach including monitoring or surface water flow, groundwater levels, water quality for both groundwater and surface water, vegetation monitoring, macroinvertebrate survey, etc
6. **Additional data collection** and testing to inform the feasibility of the other contingency options (e.g. aerial liming, in-stream treatment and limestone sand)

To allow for measurable indicators for the effectiveness of the remediation activities for Boundary Creek and Big Swamp, the following success targets were devised:

1. Recovery trend for groundwater levels in the LTA
2. No further encroachment of terrestrial woodland into the swamp plain
3. No encroachment of Lowland Forest dominant species into areas of Damp Forest
4. No loss of structural or floristic diversity along the main channel and western end of the swamp
5. Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges
6. Maintain monitoring bore water levels at individual bores within Big Swamp above target water levels

7. At least 0.5 ML/day flow maintained at the Boundary Creek Yeodene stream gauge, maintained for a period of 2 years
8. Annual median pH equal to or greater than 6.5 at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years

Barwon Water has engaged CDM Smith Australia Pty Ltd (CDM Smith) to undertake an assessment on the alignment between the current level of information and knowledge regarding the rehabilitation of Boundary Creek and Big Swamp and the knowledge and data required to achieve the Success Targets.

1.2 Objective

The objective of this study is to assess whether the proposed Success Targets listed in the REPP are effective and measurable targets, based on the current level of information for the study area. The project will aim to answer the following questions:

1. Do the proposed Success Targets align with the expected changes to eco-hydrological processes as remediation actions take effect?
2. Are the proposed Success Targets measurable, such that the eco-hydrological processes can be monitored into the future and provide a measurable indication of remediation success?

1.3 Scope

The following outlines the scope of this assessment:

- Obtain and review historic data and information to determine baseline conditions of Boundary Creek & Big Swamp (pre-impact)
- Review current site data and information of Boundary Creek & Big Swamp (post-impact)
- Review predictive (modelled) data to assess the change in the system to remediation approaches
- Evaluation of proposed control measures
- Evaluation of proposed success targets
- Preparation of a concise report (this document) detailing the effectiveness and suitability of the success targets, this document will also address the components of ITRP review comments that relate to Success Targets, provided in Appendix B.

Section 2 Assessment of Success Targets

2.1 Overview

The following section provides an assessment of the success targets for Big Swamp based on the current information and data acquired from Barwon Water. The assessment has been categorised via four distinct groups which are presented in Table 1 along with their pertaining success target (s).

Table 1 Success targets of conceptual groups

Group	Success target
Lower Tertiary Aquifer	- Recovery trend for groundwater levels in the LTA
Quaternary Aquifer	- Maintain monitoring bore water levels at individual bores above target water levels (GHD,2021)[1]
Hydrology	- At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years
Eco-hydrology areas	- No further encroachment of terrestrial woodland into the swamp plain - No encroachment of Lowland Forest dominant species into areas of Damp Forest - No loss of structural or floristic diversity along the main channel and western end of the swamp - Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges
In relation to the Success Target Median pH equal to or greater than 6.5 at Boundary, the assessment will be limited to the acknowledgement of the target, and reference to its confirmation is dependent on future geochemical modelling. *In relation to reach 2 of Boundary Creek, directly downstream of the swamp, success targets are not assessed directly, however recommendation regarding improving the resilience of the waterway is discussed.*	

2.2 Methodology

The assessment of the Big Swamp Success Targets has been undertaken via three steps which are described below.

Step 1. Conceptualisation

1) A description of the baseline condition (i.e. pre-millennium drought and pre-pumping) of the Success Targets, including;
    a. the baseline groundwater levels in the LTA and alluvial aquifer
    b. the baseline vegetation assemblages
    c. the baseline streamflow
2) A description of the current condition of the Success Targets, including;
    a. the current groundwater levels in the LTA and alluvial aquifer

[1] The water level targets presented in this report are consistent with those outlined by GHD (2021) and differ to those presented by Barwon Water in the REPP. The difference in target water levels between the REPP and GHD (2021) is due to updated geological information regarding ASS depths across the swamp, with target water levels presented in GHD (2021) thought to provide more 'conservative' targets for water levels in Big Swamp.

   b. the current vegetation assemblages

   c. the current streamflow

3) Development of “Problem Statements” that detail the cause-and-affect processes that have driven the changes observed for the Success Target between the baseline and current periods

4) Consideration of whether there is adequate information to;

   a. support the Problem Statements

   b. predict the trajectory of the Success Targets

Step 2. Control measure evaluation

Step 2 assesses the relationship between eco-hydrological changes, remediation actions (control measures) and Success Targets to assess the effectiveness of the control measures in changing the trajectory of the Success Target, i.e. how do the control measures change the current condition of the swamp and how these changes respond relative to the success targets.

This task serves as a ‘score card’ that indicates how suitable each of the six control measures are in achieving the Success Targets.

Step 3. Success Target evaluation

Step 3 draws upon the outputs of Step 1 and Step 2, to provide an overall assessment of the alignment of the individual Success Targets with the proposed remediation actions, and how well current data and monitoring will be able to track the eco-hydrological changes and associated Success Targets into the future.

This step ultimately provides a holistic appraisal of the suitability of Success Targets, and where appropriate identify:

- Which Success Targets align with the expected changes to eco-hydrological processes as remediation actions take effect
- Which Success Targets are measurable based on the current monitoring network
- Where data gaps occur that prevent the Success Targets from being measured over time and what actions could be undertaken to reduce these data gaps

2.3 Review of data

Table 2 presents details of the data and information that have been provided by Barwon Water to inform the assessment of the Success Targets.

Table 2 Summary of site data and information

Group	Detail	Type	Source
Hydrogeology	Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design Technical Modelling Report	Report	GHD (2021)
	Big Swamp groundwater monitoring data 2019 – 2020	Spreadsheet	Barwon Water
	Modelled depth to water (historical and post remediation)	GIS	GHD (2021)
	Barwon Down Hydrogeological Studies 2016-17 - numerical model calibration and historical impacts	Report	Jacobs (2018a)
	Barwon Downs Technical Works Program - groundwater assessment report	Report	Jacobs (2018b)

<table>
<tr><th>Group</th><th>Detail</th><th>Type</th><th>Source</th></tr>
<tr><td rowspan="4">Hydrology</td><td>Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design Technical Modelling Report</td><td>Report</td><td>GHD (2021)</td></tr>
<tr><td>Stream gauge data for Yeodene, Big Swamp upstream and downstream</td><td>Spreadsheet</td><td>Barwon Water</td></tr>
<tr><td>Modelled preferred barrier alignment surface water inundation</td><td>GIS</td><td>GHD (2021)</td></tr>
<tr><td>Preferred barrier configuration (group 12)</td><td>GIS</td><td>GHD (2021)</td></tr>
<tr><td rowspan="2">Geochemistry</td><td>Big Swamp conceptual geochemical modelling report</td><td>Report</td><td>GHD (2019)</td></tr>
<tr><td>Big swamp water quality data</td><td>Spreadsheet</td><td>Barwon Water</td></tr>
<tr><td rowspan="6">Ecology</td><td>Big Swamp vegetation monitoring report</td><td>Report</td><td>ELA (2020)</td></tr>
<tr><td>Barwon River Macroinvertebrate sampling report – Spring and Autumn</td><td>Report</td><td rowspan="2">Austral research and consulting (2020)</td></tr>
<tr><td>Barwon River Macroinvertebrate sampling results</td><td>Report</td></tr>
<tr><td>The impacts of acid sulfate soils at Yeodene Swamp South Eastern Australia: An ecohydrological investigation</td><td>Report</td><td>Melissa Reidy (2019)</td></tr>
<tr><td>Historical aerial photography</td><td>Photo</td><td>Photomapping (2021)</td></tr>
<tr><td>Eco-hydrology zones</td><td>GIS</td><td>ELA (2020)</td></tr>
<tr><td>Climate</td><td>Pennyroyal creek rainfall</td><td>Spreadsheet</td><td>BOM (2021)</td></tr>
<tr><td>General</td><td>Boundary Creek, Big Swamp and surrounding Environment Remediation and Environmental Protection Plan</td><td>Report</td><td>Barwon Water 2019</td></tr>
</table>

2.4 Step 1 – Conceptualisation

2.4.1 Lower Tertiary Aquifer (LTA)

Baseline condition (pre-impact)

The baseline condition for the LTA is characterised as the balance, or dynamic equilibrium, existing between the temporally and spatially variable recharge and discharge processes across the groundwater basin (after Bredehoeft et al. 1982). This condition would be defined by relatively stable hydraulic gradients controlling groundwater-surface water exchange and inter-aquifer exchange fluxes (over decadal time periods). Starting in LTA recharge areas, vertical hydraulic gradients would have characteristic changes from downward to horizontal and then to upward in areas of discharge. The LTA is known to have been regionally artesian historically, and as such there would have been stable vertically upward hydraulic gradients between the LTA and overlying hydrostratigraphic units (HSUs). These overlying HSUs in turn, would then provide upward or horizontal fluxes to support shallower groundwater systems which may have dependent ecosystems and environmental values.

The shallow groundwater system associated with Big Swamp was historically supported by upward hydraulic vertical gradients and received groundwater discharge from the LTA. Relatively high or artesian hydraulic heads in the LTA would have provided groundwater discharge to Boundary Creek and maintained higher summer inflows through Big Swamp. These surface water inflows and relatively high LTA hydraulic heads adjacent to and below Big Swamp would have supported higher shallow groundwater levels within the alluvial aquifer, and resulted in more stable (mildly acidic to neutral) groundwater pH.

Current condition (post-impact)

As outlined in Table 6 of the REPP (Barwon Water, 2020) the success target for the LTA is a "recovery trend" being observed in selected SOBN locations. This target is not explicitly quantitative but can be considered successfully achieved where the LTA hydraulic heads, in areas of pumping-induced drawdown, are recovering (i.e. rising hydraulic heads). The hydrographs shown in Figure 1 demonstrate how such recovery trends are occurring in the near vicinity to the borefield (blue), some distance away (red) and near Boundary Creek (green). Meanwhile the hydrograph from the Barongarook High (light blue) shows a declining trend, likely caused by a combination of changes in the groundwater system discussed further below. Each type of hydrograph response has a trajectory towards a new dynamic equilibrium, which is the long-term balance between temporally and spatially variable recharge and discharge fluxes.

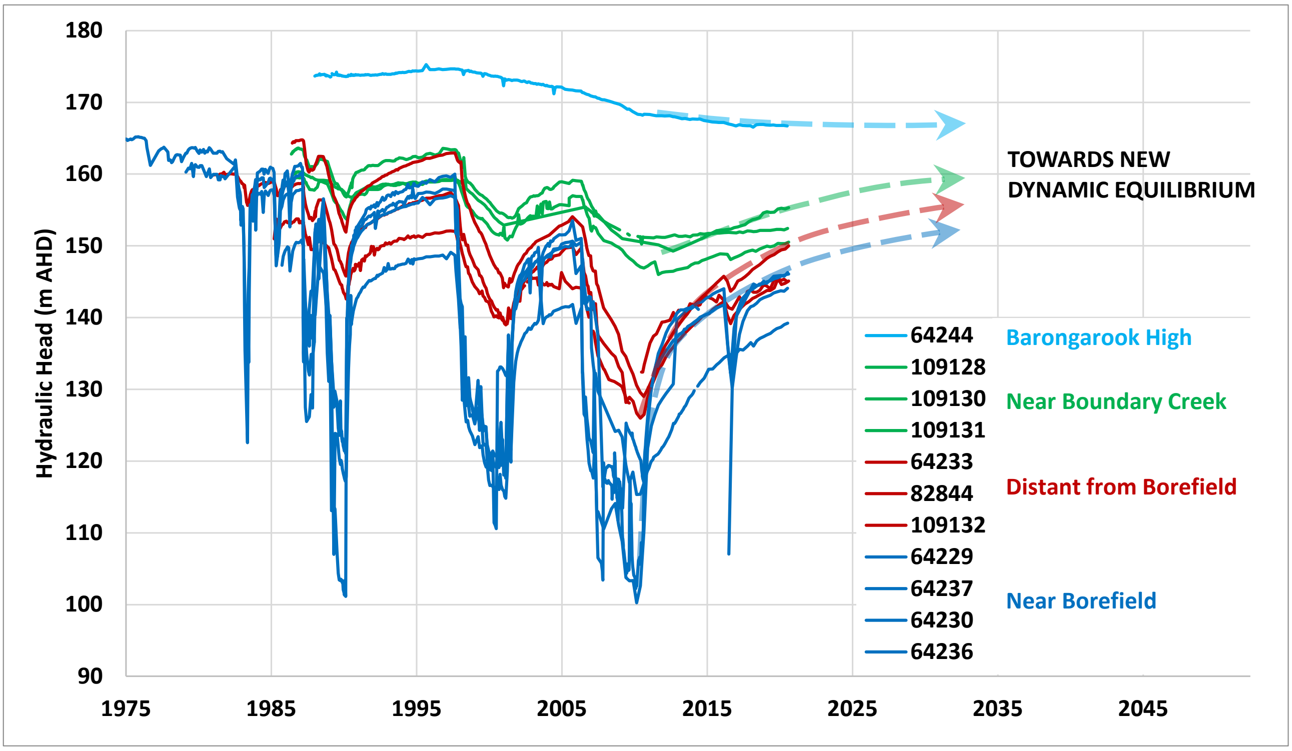

Figure 1 Selected hydrographs showing conceptual trajectory towards a new dynamic equilibrium

The historical borefield extraction has essentially intercepted (or captured) future groundwater discharge and imposed a temporary stress on the groundwater system. Initially this groundwater was sourced from storage, and then as the cone of depression expanded vertically and horizontally groundwater was sourced from induced leakage from the aquitards and storage from the aquifer (i.e. after Theis 1940; Bredehoeft et al. 1982). Since there is now no pumping from the borefield, the groundwater system will recover towards a new dynamic equilibrium according to established hydrogeological principles, likely over a period of many decades. The hydrogeological function of the aquifer is expected to return in the long-term, where recharge and discharge are balanced and hydraulic heads across all HSUs approach stability. A salient indicator of this more stable condition is the comparison of vertical hydraulic gradients between the LTA and overlying aquitard observation bores. Historically the vertical hydraulic gradients have generally been upwards regionally (i.e. pre-borefield extraction), were then downwards in many areas particularly near the borefield (i.e. during extraction) and are now returning to a new equilibrium (i.e. during recovery).

Given the the limitation of modelling and its uncertainty, groundwater modelling by Jacobs (2018a) demonstrates how the different components of the groundwater balance have responded dynamically to the temporary groundwater pumping from the borefield. The Jacobs (2018a) null scenario shows a gently declining trend in LTA heads (without pumping), which suggests the groundwater system was already approaching a new dynamic equilibrium (i.e. potentially in response to reduced recharge rates relative to prior-historical recharge rates). The observed LTA heads would be expected to approach the simulated null scenario heads, but are unlikely to reach them in the next few decades because the component of historically extracted groundwater sourced from storage will take a long time to be replaced under the new dynamic equilibrium. Irrespective of the hypothetical recovered levels, the groundwater system is likely heading towards a new and uncertain dynamic equilibrium. This uncertainty is driven by the fact that similar to climate (rainfall and potential evaporation), recharge is unlikely to be stationary and has changed considerably in the last century or so (i.e. under the influence of land clearance, revegetation, new responses to climate variability and climate change).

The LTA recovery was simulated in Jacobs (2018b) using a single groundwater model realisation and a moderate climate scenario. The predictions under this scenario shows the groundwater system responding as would be expected at indicative locations and how complete stabilization of groundwater levels is not achieved within the future period simulated (i.e. it is likely that a new dynamic equilibrium will not be fully achieved until after 2070 – see for example Figure 6-5 in Jacobs 2018b). As recommended in Jacobs (2018a), any future scenarios should also include appropriate uncertainty analysis (i.e. related to parameter uncertainty and boundary condition assumptions) to provide a plausible range of model outcomes to support decision makers and better characterize risk to the resource and environmental values.

In relation to the success target of a recovering LTA, there are two aspects that warrant further consideration (see Section 2.6.1 for more detail):

1. Recovery of regional scale hydrogeological function – a long-term aspirational target where the balance between recharge and discharge result in a new dynamic equilibrium (metrics may include continued monitoring of recovering trends and assessment of vertical hydraulic gradients)
2. Recovery of local scale hydrogeological function – the recovering LTA and aquitard hydraulic heads provide hydraulic support for the overlying shallow groundwater system (i.e. LTA recovering heads support local flow systems to allow shallow alluvial success targets and environmental objectives to be met)

2.4.2 Quaternary Aquifer

Baseline condition (pre-impact)

No known water level data exists to verify the baseline condition (pre-impact) of the Quaternary Aquifer (QA) in Big Swamp. However, inferences can be made as to the likely water level within the QA based on other known aspects of the swamp pre-impact. These being:

- Pre-existing water levels within the LTA and aquitard which demonstrate artesian conditions and upward hydraulic gradients between the LTA and above HSUs
- The known Acid Sulfate Soils (ASS) horizon
- Predicted vegetation assemblages based on historical satellite imagery
- Water quality data from Boundary Creek

Based on the ASS and water quality information and data, it is likely the groundwater levels within the QA were at least at or above the level of the ASS horizon. These data indicate non-acidic conditions were present in Boundary Creek prior to the drawdown events of the LTA in the late nineties (Barwon Water, 2020). Thus, the ASS horizon had not been exposed to oxygen and was likely permanently saturated.

As mentioned in Section 2.4.1, water levels measured from the LTA demonstrate there to be a stable upward hydraulic gradient between the LTA and overlying HSUs which provide upward or horizontal fluxes to support the shallower groundwater system (i.e. the QA). The presence of this hydraulic gradient would also have provided additional leakage during drier periods to the QA resulting in more sustained groundwater levels with little variation to the system.

Current condition (post-impact)

Water level data has been analysed for 18 monitoring wells for records dating back to June 2019 to assess the current condition of groundwater levels within the Quaternary Aquifer (QA) shallow alluvial sediments. A map of the monitoring bore locations within Big Swamp is presented in Figure 2.

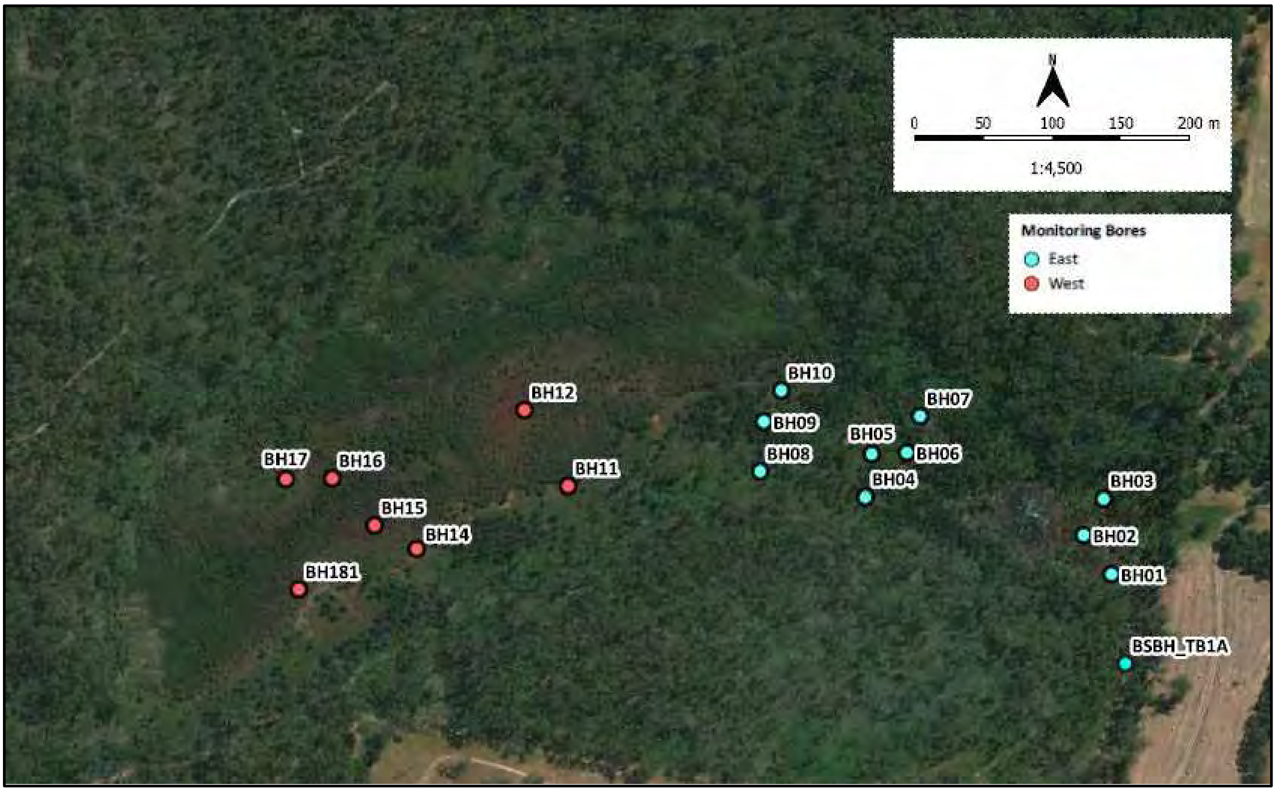

Figure 2 Big Swamp alluvial monitoring bore locality plan

Geographically, the monitoring bores can be classified by two groups: eastern monitoring bores (BSBH_TB1A, BH1 to BH10) of lower elevation ranging between 142 m and 144.5 m AHD, and western monitoring bores (BH11 to BH18) of higher elevation ranging between 147 m and 148.5 m AHD. Hydrographs of the eastern and western monitoring bores in comparison to rainfall from Pennyroyal (BOM station no. 90061) and Big Swamp stream flow (upstream gauge data) are presented in Figure 3 and Figure 4 respectively.

Analysis of stream gauge data (Big Swamp US gauge no. 233275) suggests this to be the predominant driver of groundwater levels within Big Swamp, where periods of high streamflow correspond with sustained and elevated groundwater levels and periods of low streamflow correspond with lower and decreasing groundwater levels. Groundwater levels are also sensitive to rainfall noted by sharp small increases in water levels during rain events which occur simultaneously with increases in stream flow through Big Swamp.

Fluctuation of groundwater levels 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. The smallest fluctuations of groundwater levels occur within monitoring bores BH04 and BH08 which are positioned in the south-east of Big Swamp near the existing fire trench. Water level fluctuation at these bores is around 0.75 m and is less responsive to changes in streamflow than all other bores monitored in the swamp indicating monitoring bores BH04 and BH08 are receiving sustained recharge to the QA. The explanation of this is unknown but may be a combination of material the bores are screened in and location of bores with respect to areas of current inundation.

Further analysis of the groundwater monitoring data suggests majority of the eastern monitoring bores (BH1, BH2, BH3, BH4, BH5, BH7) are artesian (positively pressured) for part of the period of record during instances of elevated streamflow. Conversely, the western monitoring bores (apart from BH15) are behaving as an unconfined system with water levels remaining below the ground surface over the entire period of record. Due to the higher topographic elevations to the west of Big Swamp, it is likely periods of high streamflow are increasing positive head pressures downstream in the east of the swamp and creating artesian flow at a number of eastern monitoring bores.

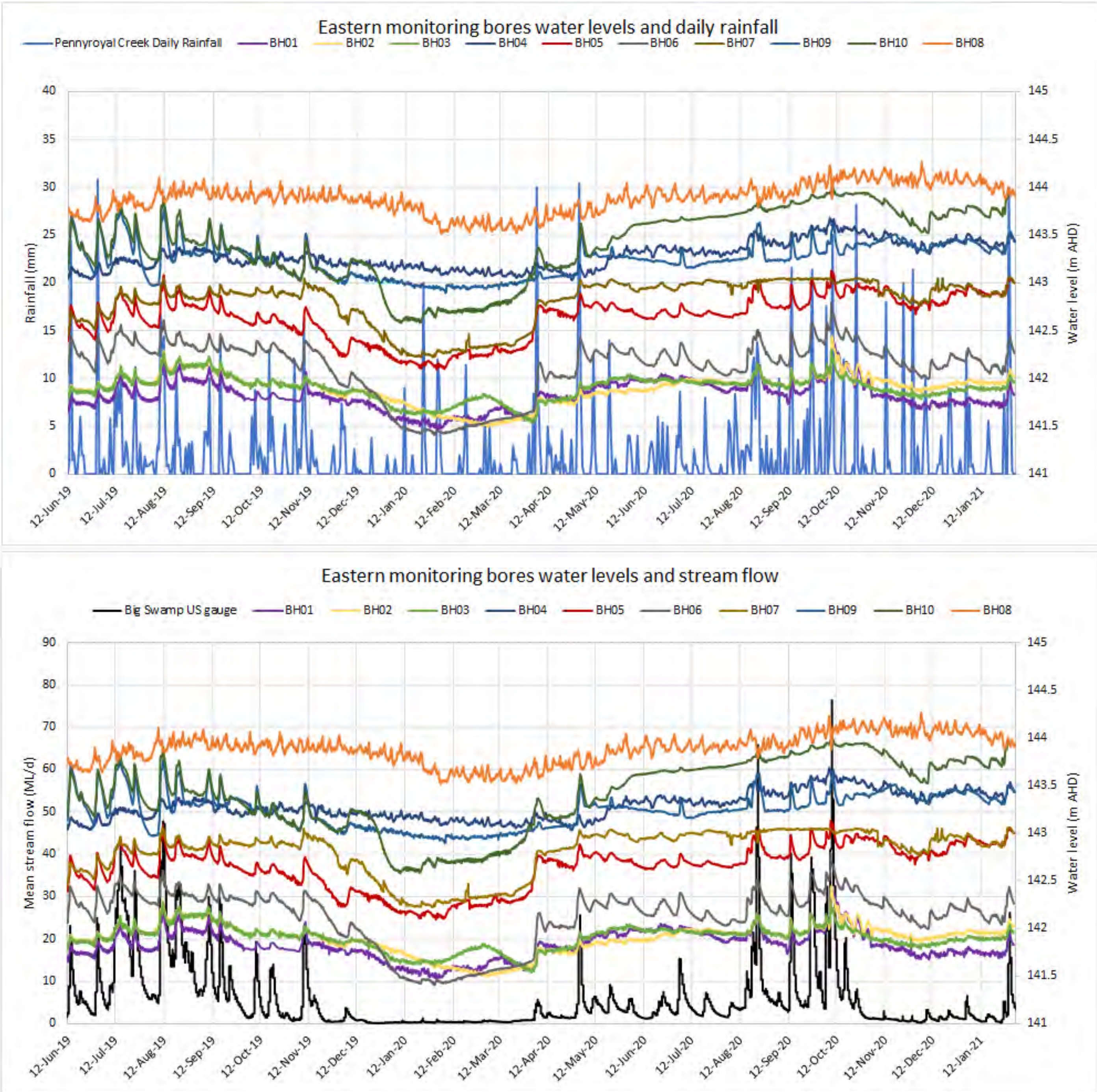

Figure 3 **Eastern monitoring bores**

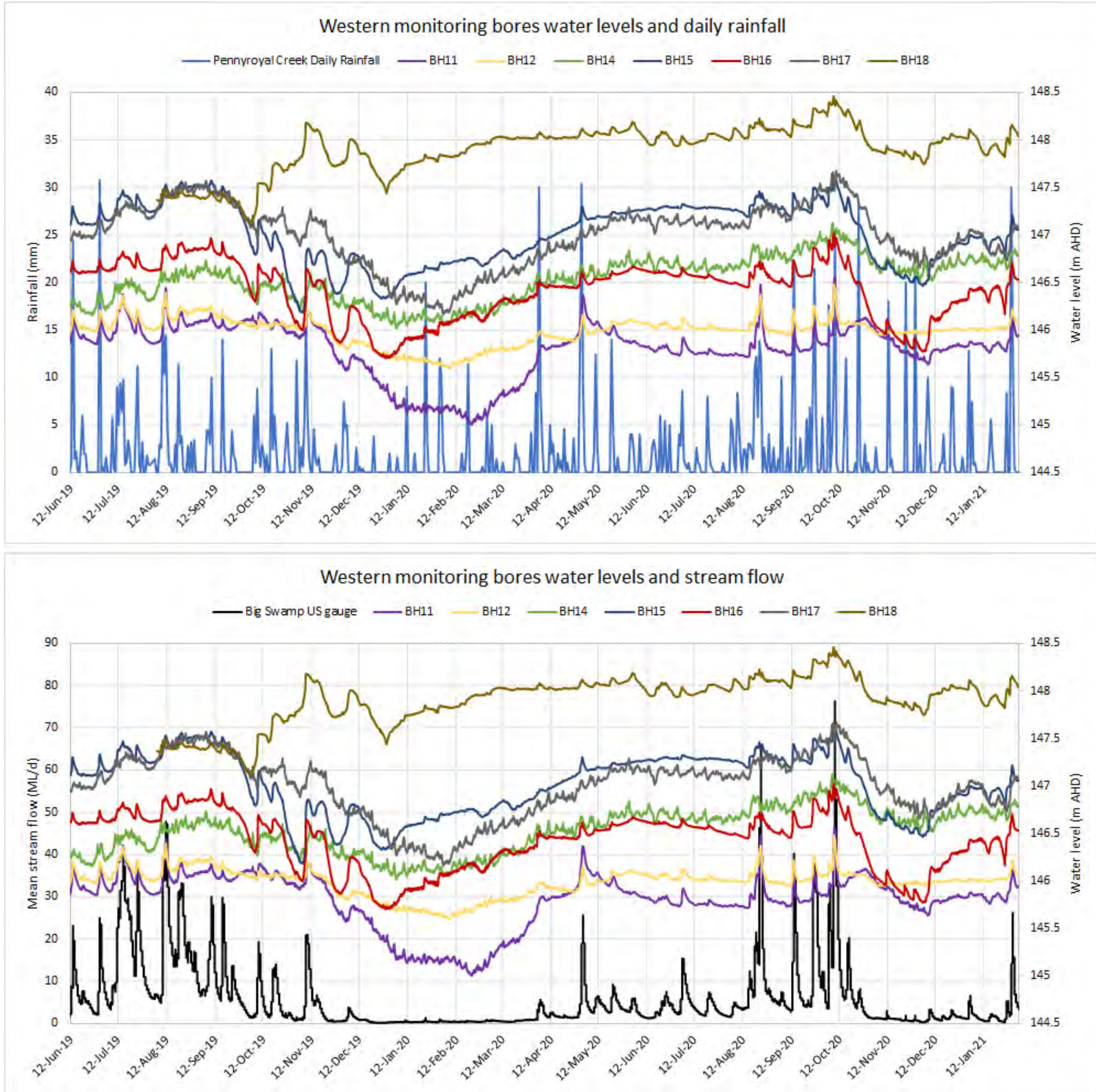

Figure 4 **Western monitoring bores**

Individual hydrographs for each of the monitoring bores (BH-1 to BH-18) showing groundwater levels (measured between 2019 and 2020) with relation to ground surface and success target water levels are presented in Appendix A.

Table 3 provides a summary of the current (2019 to 2020) monitoring bore water levels in meeting the water level targets. It is understood that these target water levels are designed to minimise the amount of sulfate available for oxidation at each bore, based on the concentration of sulfate recorded in soil cores collected during drilling (GHD, 2021). From the observed monitoring data, the following can be concluded:

- All eastern monitoring wells (excluding BH8) currently meet the success targets for either the whole period of record or partially (i.e. both exceed and fall below the water level target)
- Half of the western monitoring bores (BH11, BH12, BH15) currently meet the success targets for either the whole period of record or partially
- Monitoring bores which only partially meet their water level target (BH6, BH11, BH12) exceed their targets during periods of increased and sustained streamflow (i.e. flows generally greater than around 5 ML/d) and fall short of the target in all other instances. The exception to this is BH15 which only exceeds the target water level when stream flows are sustained at greater than 10 ML/d
- The monitoring bore water level targets are unlikely to be met within the west of Big Swamp without further remediation action

Table 3 Current status (2019 to 2020) of monitoring bore water levels against targets

Monitoring bore ID	Location	Water level target [1] (m bgl) [2] [m AHD]	Target met (Y/N/Partially)
BH1	East	0.7 [141.2]	Y
BH2		1.2 [140.5]	Y
BH3		1.6 [140.1]	Y
BH4		0.6 [142.8]	Y
BH5		1 [142.1]	Y
BH6		1 [141.9]	Partially
BH7		0.4 [142.1]	Y
BH8		0.4 [144.2]	N
BH9		1.5 [142.9]	Y
BH10		2 [142.3]	Y
BH11	West	1.5 [145.6]	Partially
BH12		1.2 [146.0]	Partially
BH14		0.15 [147.5]	N
BH15		0.2 [147.2]	N
BH16		-	-
BH17		-	-
BH19		0.2 [148.5]	N

Notes: 1. Targets as presented by GHD (2021)
2. Meters below ground level
- Denotes no target set
'Partially' denotes target met on occasion over the period of record, however, not consistently

2.4.3 Hydrology

Baseline condition (pre-impact)

Monitoring of streamflow through Boundary Creek at Yeodene has been ongoing since 1979. Historical flows in Boundary Creek measured at Yeodene creek gauge (233288A) are presented in Figure 5.

Due to a reduction in groundwater discharge and subsequent decreases in streamflow in Boundary Creek, the creek has been supplemented (when triggered by licence conditions) with discharge from McDonalds Dam since 2002 (Jacobs, 2018). Prior to this time, streamflow through Boundary Creek averaged around 10.6 ML/d at Yeodene with cessation of flows rarely occurring circa 1999. Furthermore, no alterations to the swamp hydrology existed by means of diversion of water from Boundary Creek at this point in time.

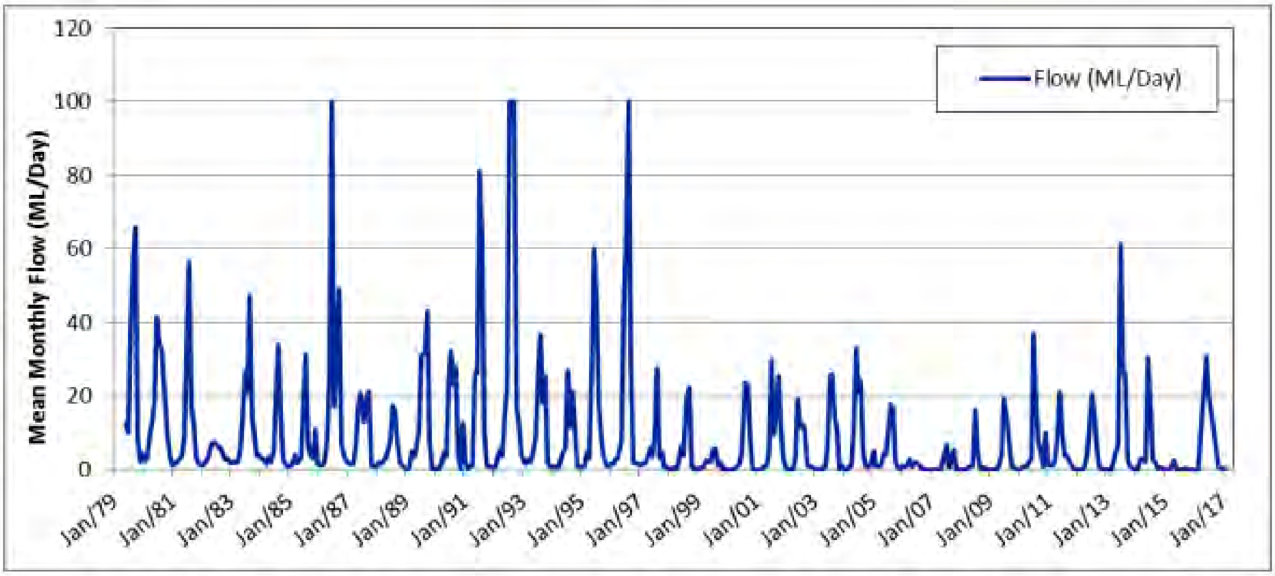

Figure 5 Average monthly flow in Boundary Creek at Yeodene stream gauge (233288A) (Jacobs, 2018a)

Current condition (post-impact)

Following a fire event at Big Swamp in 2010, major alterations to the hydrology of the swamp were made by construction of a fire trench to prevent the fire spreading. Alteration of the swamp hydrology coupled with the drying of Big Swamp has had significant impacts on the water quantity flowing from the swamp including:

- A reduction in average streamflow through Boundary Creek at Yeodene by around 3.4 ML/d from around 10.6 ML/d circa 2002 to around 6 ML/d post 2002
- Increased duration and frequency of flow cessation through Boundary Creek at Yeodene

In 2019, two additional stream gauges, Big Swamp upstream (US) gauge (233275A) and Big Swamp downstream (DS) gauge (233276A) were installed to assist in the measurement of streamflow through the swamp. A hydrograph of this streamflow data including mean hourly stream data from the Yeodene gauge 233228A) between April 2019 and June 2021 is presented in Figure 6.

The data suggests streamflow at Yeodene is generally greater than the Big Swamp US and DS flows, indicating the stream is likely gaining from downstream or areas outside of Big Swamp. Little variation of streamflow is seen US and DS of the swamp, though the US flows are generally higher over the period of record. Barwon Water (2020) indicated the difference in average monthly flows between the US and DS gauges varied up to around 0.24 ML/d between June 2019 and October 2019, however, had a net change of <0.1 ML/d overall. This suggests the groundwater exchange in the swamp (as either inflow or seepage) is minimal during this period. During wetter periods of higher streamflow, however, a greater variance between the US and DS gauges is observed and is likely attributed to greater groundwater exchange (recharge) to the QA and LTA.

During the dry period of 2019-2020 a supplementary flow of 2 ML/d was released from McDonalds Dam, however, even with the added flows the Yeodene stream gauge (233228A) recorded no flow for a period, indicating 2 ML/d of supplementary flow is insufficient in maintaining a flow of greater than 0.5 ML/d at Yeodene during dry low flow periods.

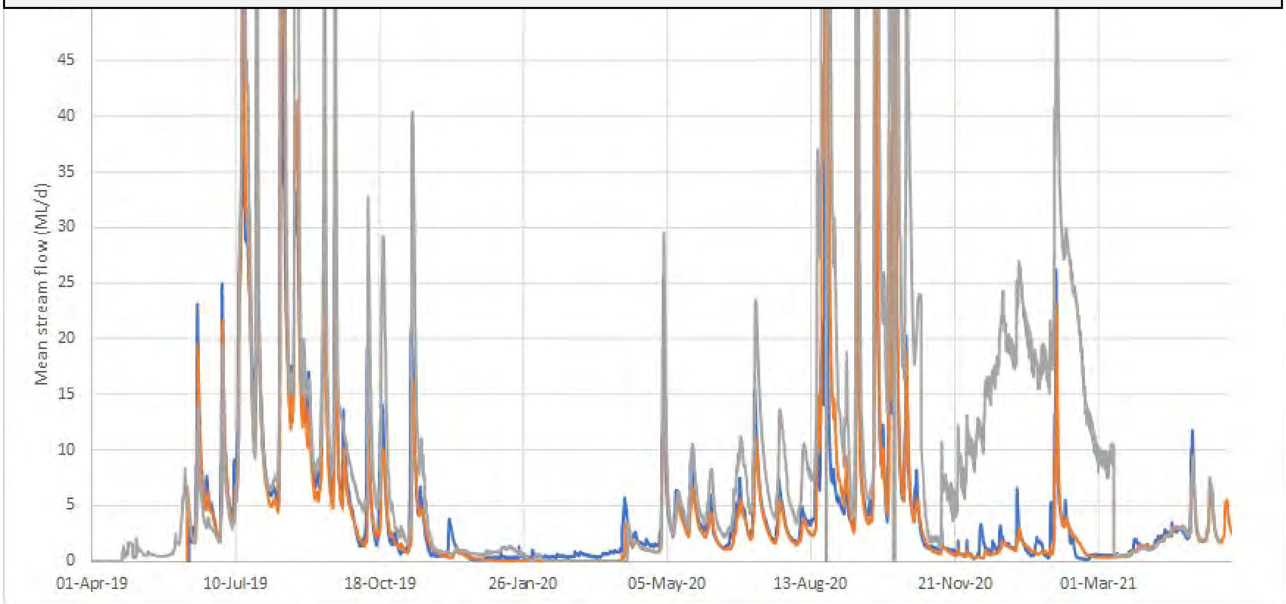

Figure 6 **Boundary Creek mean streamflow**

The modelled inundation and surface water flows at Big Swamp for wet and dry periods is presented in Figure 7. The modelling indicates a significant difference in surface water flow and ponding depth between August (wet period) and January (dry period) which is characterised by predominantly channelised flow during the dry period and extensive ponding over the western and eastern swamp areas during the wet period.

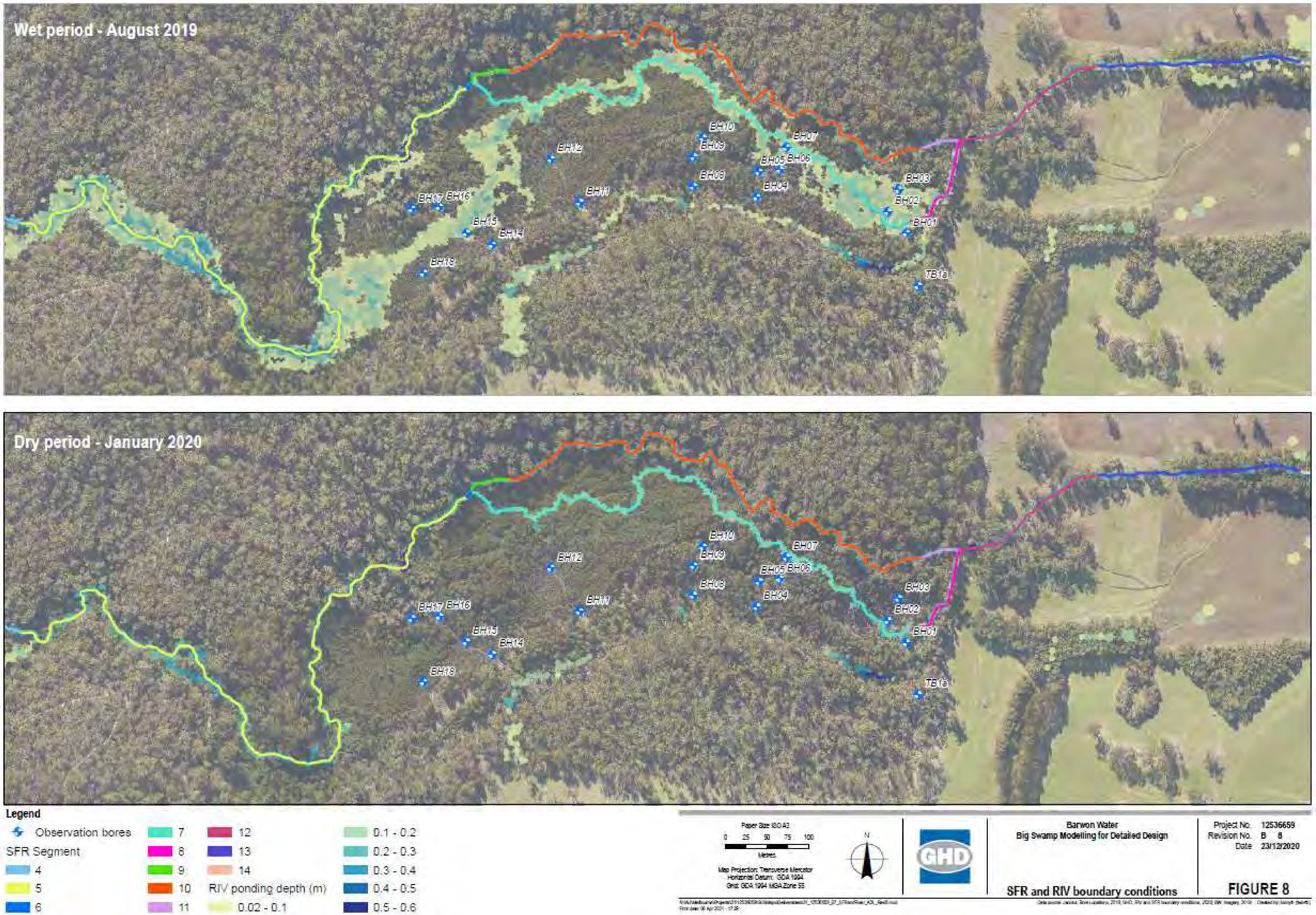

Figure 7 Surface water flows for wet and dry periods at Big Swamp

2.4.4 Eco-hydrology

EVCs and past assessments

According to the State wide Pre–1750 EVC coverage, Yeodene Swamp comprises two broad Ecological Vegetation Classes (EVCs), namely: Swampy Riparian Woodland (EVC 083) along the Boundary Gully drainage line and Lowland Forest (EVC 016) on the adjoining gentle sedimentary terrain.

Whatever the broader suitability of these groupings, at the local scale, EVCs are often unreliable and do not accurately reflect the nature and extent of vegetation patterns at the site scale. For instance, there is poor spatial correspondence between the 1:50,000 Stratigraphy layer valley bottom alluvium and the patterning of Swampy Riparian Woodland [associated with low energy streams of the foothills and plains] in the pre-1750 state-wide EVC reconstruction coverage.

Numerous studies (Glover 2014; Reidy 2019; ELA 2019; 2020) have more–or–less pointed out the inadequacy of the Pre–1750 EVC mapping coverage and have needed to develop their own finer–scale coverage for the purposes of their various investigations. ELA (2019; 2020), as a result developed its own 'new' EVC coverage. Reidy (2019) adopted an alternative approach based on vegetation structure, and dominant species lifeform and composition. This latter approach is effectively a lower–level of classification that makes sense at the site scale. If EVCs can be considered the highest level in the hierarchy of Australian vegetation classification typology (i.e. Formation level – encompassing lifeform, and crown cover and type), then floristic or community (and sub–community) level classification sit lower down with increasing resolution of structural and compositional complexity (Hnatiuk et al. 2009). The Reidy (2019) classification is useful, however, it is a coverage of extant vegetation based on current observations – post peat fires and the resulting ecosystem collapse of the local swamp ecosystem – and is not intended as a reconstruction.

So called 'Riparian Fern Scrub' is the heart of the swamp ecologically; prevalent across the most consistently saturated sections driven by saturated soils, surface inundation as well as ground water discharge. This vegetation type is classed as a permanent wetland or bog whereby inundation is "*constant, annual or less frequently but before wetland dries [or] constant waterlogging, inundation mostly superficial*." The duration of waterlogging is > 6 months and duration of inundation is between <1 month to 1–6 months. In addition, water depth is very shallow <30 cm and salinity levels fresh 0–3,000 mg/L (Frood and Papas 2016).

The ecohydrology of this system is also strongly driven by the area's complex hydrogeology as explained in this excerpt from ELA (2019):

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

Pre–disturbance benchmark vegetation reconstruction

In order to determine the level (and processes) of historic change at the swamp it is necessary to undertake a benchmark reconstruction, albeit of a limited nature due to project constraints. Both community data (Atlas of Living Australia) and aerial photography (Historic Photomaps curated by DELWP) are available going back to the 1980's and 1940's respectively. The need here, however, is not so much a pre–European reconstruction, but rather a benchmark that predates the 1997 bushfire that caused smouldering sub–surface fires from 1998 to 2010 (Glover 2014) made possible due to a combination of the Millennium drought plus earlier drainage and dam construction that has impacted local surface and groundwater hydrology. It is beyond the scope of this report to elaborate on the serious causes and consequences of the ecological collapse of this swamp as a result of the peat fires (see Glover 2014; Reidy 2019; ELA 2019).

The 1982 image was chosen as suitable for this benchmarking due to a combination of: (1) ready availability, (2) fine resolution scale and clear image with obvious patterns that could be interpretated at the site scale, and (3) immediately pre-dating the Millennium drought and the catastrophic fire. An appropriate study area was chosen that extended from the road reserve immediate east of the swamp (and directly south of Yeodene) west along Boundary Creek across the northern tip of Otway Forest Park until it crosses another road easement adjoining private land. This slightly extended region was chosen because it includes areas just upstream of the swamp that appear to have been of a similar nature prior to the drought/fire impacts and where some community data has been collected in the past. The image was georeferenced in ArcGIS and overlayed with relevant background spatial coverages (hydro, cadastre, contours, geology, DTM10m, Pre–1750 Ecological Vegetation Classes or EVCs sourced from www.data.vic.gov.au) for the purposes of interpretation and feature creation, map production and exporting to MS EXCEL for tabular presentation and simple analyses. Relevant layers were also obtained from previous studies and where data was not available, it was digitised from report maps and technical appendices.

The Chronosequence provided in ELA (2019) (1946, 1969, 1991, 2004, 2011, 2014, 2016) shows the clear contrast between the pre–disturbance period and the subsequent regrowth phase since ~2010 after the peat fire was extinguished. The catastrophic impact of the peat fire is clearly evident in the 2011 image (also available in Google Earth) showing a more–or–less collapsed ecosystem. The earlier images show a relatively undisturbed wetland dominated by vegetation described as Riparian Fern Scrub (ELA, 2019) with little or no Eucalypt/tree encroachment – except in the damp margins where canopy cover is quite open. The 1982 image is just after the construction of McDonald’s dam and the commencement of Barwon Downs aquifer groundwater extraction (ELA, 2019). From 1991, the imagery begins to show the gradual impacts of reductions in surface and groundwater levels with the taller shrubland showing apparent signs of dieback – perhaps the first obvious signs of hydrological dysfunction due to a combination of surface and groundwater extraction (which commenced ~ decade earlier; note also that Boundary Creek ceased to flow for the first time in 1990).

By 2004, there appears to be significant subsidence and bleaching of vegetation due to the slow smouldering peat fire that started in the east and gradually spread west presumably following wetness/drying gradients (ELA, 2019). The 2011 image shows the full extent of the then extinguished peat fire – showing soil subsidence, oxidation of naturally occurring acid sulphate soils (releasing acidic water downstream) and an incised gully that formed during the 2010/2012 La Nina driven floods – further exacerbating system ‘leakiness’ and hydrological dysfunction. The 2014 and 2016 images show a post–fire recovery sequence with the regeneration of shrubs onto non–saturated, fire–damaged soil.

The permanently waterlogged area is difficult to benchmark due to level of disturbance now in the swamp and the absence of pre–disturbance community data. However, as pointed out in ELA (2019) areas of saturated alluvial sediments occur shortly upstream. One such area has been mapped to the north of Boundary Creek in the 1982 coverage and which appears to have been sampled by Botanist Geoff Carr (Ecology Australia) first in 1993 and then again in 2008. The imagery clearly shows this area significantly encroached by taller shrubs and trees (presumably Swamp Gum *Eucalyptus ovata*) since around the period of Millenium drought. It is assumed this dramatic shift in structural dominance can only be attributable to a drying–out of the localised perched peat bog (aquifer) due to a combination of dam installation, groundwater extraction and the Millenium drought.

The 1982 vegetation pattern benchmark shows both the extent of the ‘wetland plain’ or peat wetland comprising Units 1 to 4. This coverage also implies a more accurate pre–disturbance groundwater surface with a gradient from at or very close to the surface for Unit 1 to deeper levels for Units 2 to 4 (up to 50 cm) – especially running from east to west (Figure 8; Table 4). In accordance with the State and Transition framework (Appendix 4), the modelled “historical” watertable depth is actually prior to the proposed barrier construction and after the peat fires and as such really represents the altered hydrology of the wetland following the peat fire (i.e. State 3: Homogenised/Simplified wetland) due to a combination of altered soils, gully erosion, and modified surface microtopography (amongst other things). The 1982 vegetation baseline is perhaps a better indication of the original structure of the water table surface prior to the fire. While it may not be possible to restore the swamp to this original structure, it nevertheless provides a more meaningful historical benchmark than after the devastating fire.

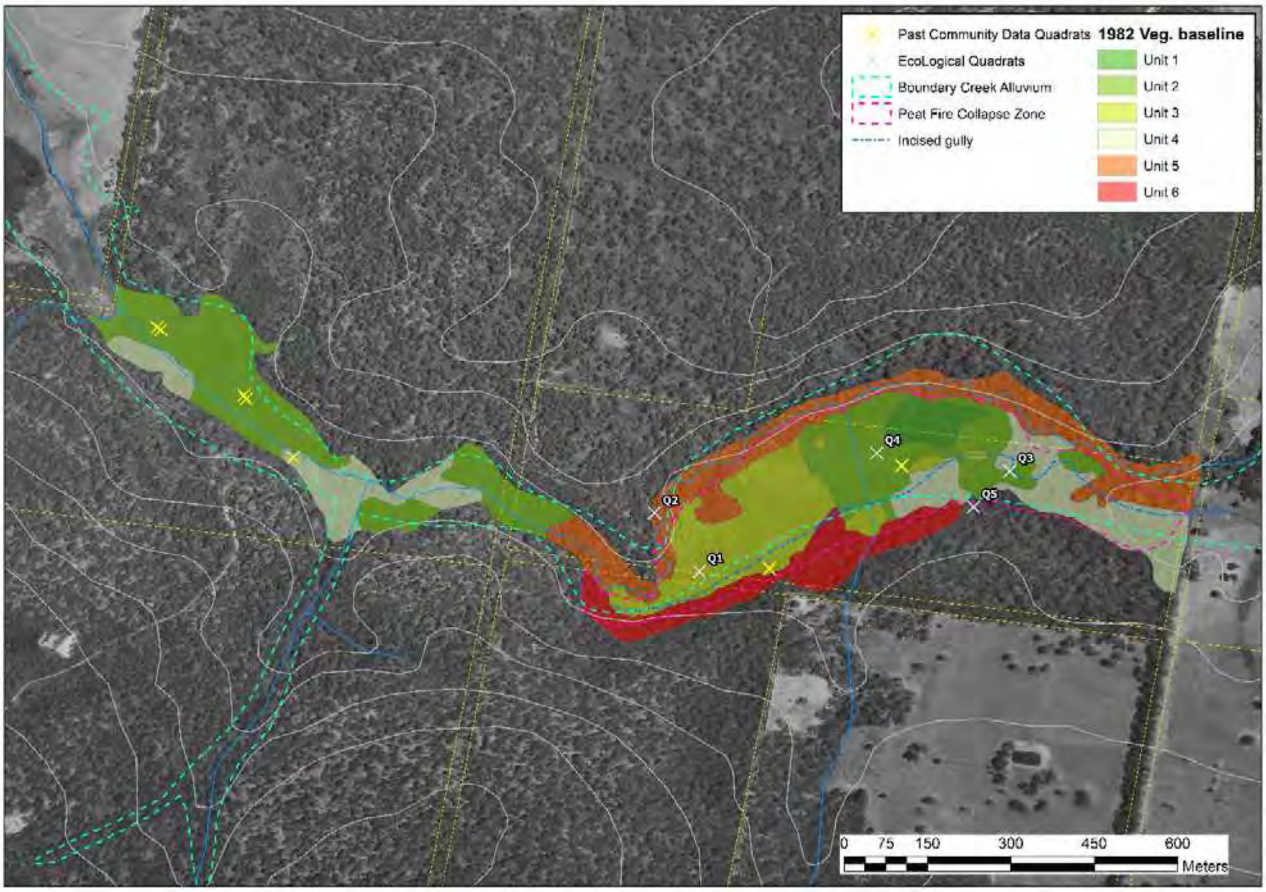

Figure 8 1982 image and pre–disturbance vegetation benchmarking patterning

Table 4 1982 benchmark reference vegetation units

	Unit 1	*Unit 2*	*Unit 3*	*Unit 4*	*Unit 5*	*Unit 6*
Soil	Peat weLTAnd	Peat weLTAnd	Peat weLTAnd	Drainage line tall shrubland	Drainage line Woodland	Damp margins Woodland/Forest
Hydrology	Permanently waterlogged; shallow inundation	Permanently waterlogged; shallow inundation	Semi-permanently waterlogged	Seasonal shallow inundation linked to stream flows	Seasonal shallow inundation linked to stream flows	Some seasonal moisture from surface or groundwater associated with the main swamp
GW depth	Shallow	Less shallow	Less shallow	Shallow or less shallow	Shallow or less shallow	Deeper due to local marginally elevated terrain
Drainage	Saturated alluvial deposits overlying an aquitard	Saturated alluvial deposits overlying an aquitard	Semi-saturated alluvial deposits overlying thinned aquitard	relatively well drained aquitard thinned or absent	Well drained aquitard thinned/inclined or absent	Well drained aquitard thinned/inclined or absent
Trees	No	No	No	Some emergent eucalypts; Swamp Gum, Manna Gum, same Blackwood	Dominated by open canopy eucalypts; Brookers Gum, Swamp Gum, Manna Gum, Blackwood	Dominated by a canopy eucalypts; Messmate, Narrow Leaf Peppermint, Manna Gum, some Swamp

	Unit 1	*Unit 2*	*Unit 3*	*Unit 4*	*Unit 5*	*Unit 6*
Tall Shrubs	No	Scented Paperbark; some Woolly Tea-tree, Coprosma quadrifida	Dense Woolly Tea-tree, Scented Paperbark	Dense Woolly Tea-tree, Scented Paperbark, Coprosma quadrifida	Pomaderris aspera, Leptospermum continentale, Gynatrix pulchella, Melaleuca squarrosa, Coprosma quadrifida, Olearia lirata	Gum and Blackwood Banksia marginata, Leptospermum continentale, Acacia verticillata, Bursaria spinosa
Ground	Sedges, Rushes, Ferns, Forbs	Sedges, Rushes, Ferns, Forbs	Sedges, Rushes, Forbs and some Ferns	Sedges, Rushes, Forbs and some Ferns	Sedges, Rushes, Forbs and some Ferns comprising a	Shrubs, Sedges, Grasses and Forbs
Floristics	Mesic specialists	Mesic specialists	Mesic specialists with some mesic generalists	Mesic specialists with some mesic generalists	Mix of mesic specialists and some generalists	Mix of some mesic generalists and xeric species
Distribution	Only thought to have occurred on the eastern end of the swamp, but may have occurred upstream as part of localised perched aquifer.	Once common in swamp and also likely occurred upstream as part of localised perched aquifer.	Mostly in the west of swamp but also likely upstream on the margins of localised perched aquifer.	Immediately upstream of the swamp in drainage line and on southern/eastern margin of swamp	Northern margin of swamp and immediately upstream	Mostly to south of swamp but likely common elsewhere along the margins of Boundary Creek
EVC (ELA)	High diversity Low/open Riparian Fern Scrub	High diversity Riparian Fern Scrub	High diversity Riparian Fern Scrub	High diversity Swampy Riparian Woodland and/or Damp Sands Herb-rich Woodland	High diversity Swampy Riparian Woodland	High diversity Damp Sands Herb-rich Woodland (or Lowland Forest?)

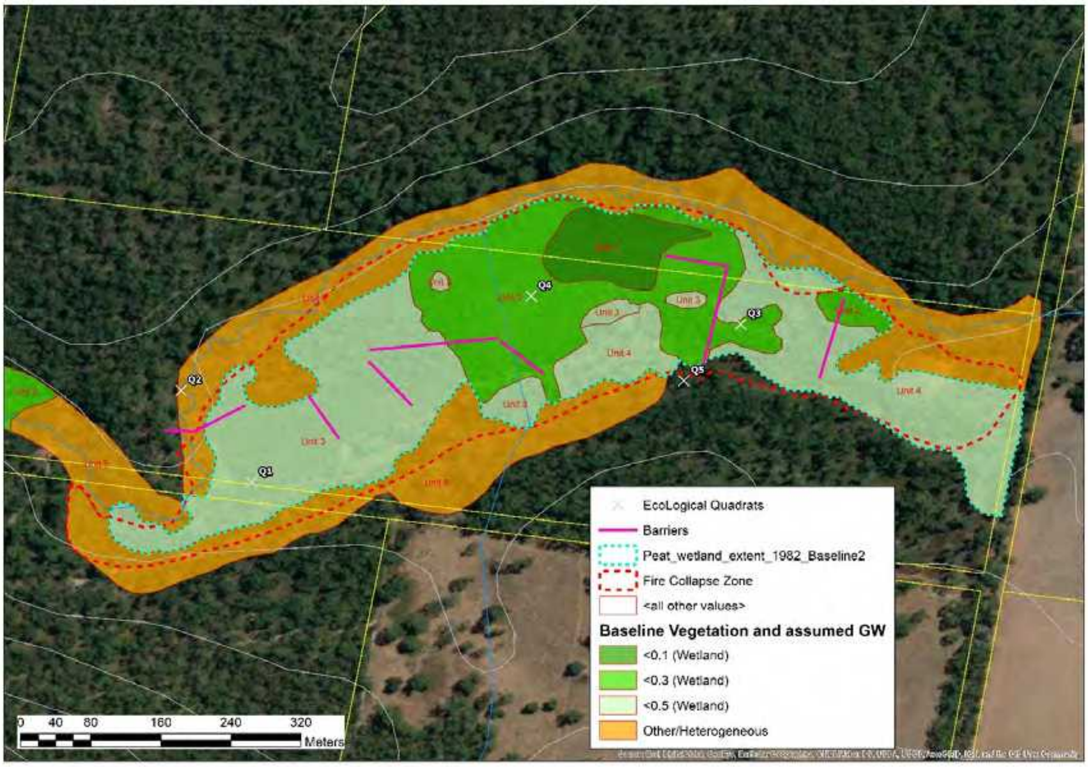

Figure 9 **1982 Baseline vegetation pattern and presumed groundwater depths**

Functional dynamics (State and Transition model) and Current condition (post-impact)

While it is acknowledged that the profound damage caused at the swamp can't be reversed, the remediation plan aims to change the wetting/drying regime in the swamp (from seasonal drying to permanently wet) by managing surface flows to maintain year–round waterlogging within the top metre of the 'swamp plain' (ELA, 2019). In practice, it is proposed this will be achieved by installing a limited number of low hydraulic barriers through strategic sections of the swamp in order to block the deeper channels that have formed in the 'swamp plain' and distribute flows across the broader area (ELA, 2019). It was part of the ELA (2019) project brief to begin assessing the likely impact of such measures on the existing vegetation diversity and condition.

Assessment of condition has previously been based on VQA (Vegetation Quality Assessment) and IWC (Index of Wetland Condition) methodologies even though it has been acknowledged that "*the VQA is not an accurate method for assessing wetland vegetation due to the paucity of wetland EVC benchmarks and absence of a method for assessing altered wetland processes [and] the IWC is not applicable to terrestrial vegetation*" (ELA, 2019). These are largely bureaucratic and statutory rating systems that have little utility for understanding dynamics and function (i.e. used for allocating regional funding, off–setting and decision–making around vegetation clearing etc.).

A State and Transition model is more ecologically meaningful and useful for restoration because it is more explicitly based on ecosystem function and dynamics. For instance, such a model developed for the floodplain vegetation dynamics in the Macquarie Marshes in NSW shows four key vegetation states (only the first being non–flood dependent): (1) Terrestrial; (2) Floodplain; (3) Semi–permanent wetland; and (4) River Red Gum (Bino *et al.* 2015). Transitions were possible between all four depending on shifts in flood frequency, distance to stream and fire frequency. Although the Yeodene Swamp is a very different system on one level, functionally there are similarities. Hydrological gradients and the conceptualisation of a similar model would have utility for planning remediation.

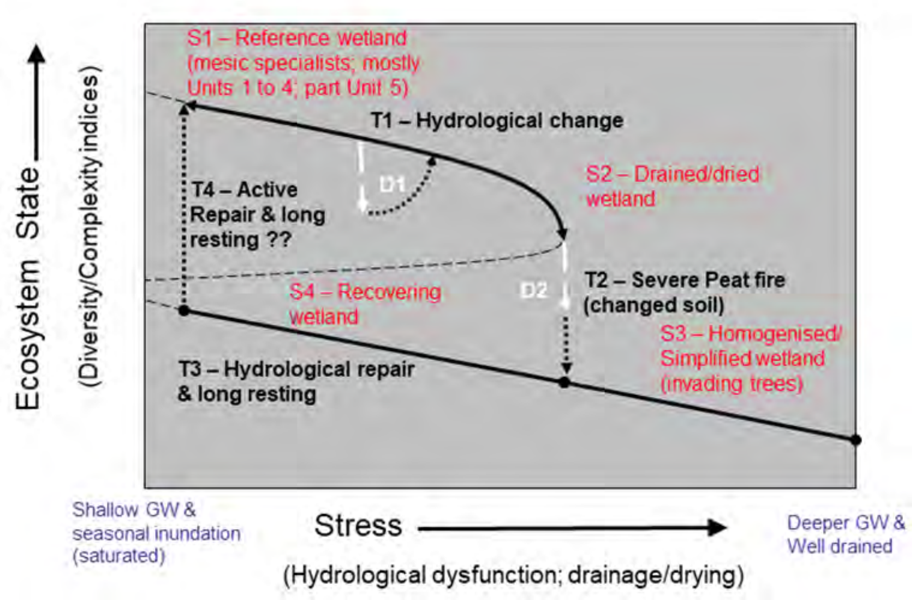

Figure 10 Putative State and Transition model for Yeodene Swamp.

At Yeodene Swamp the six units described earlier support different (albeit somewhat overlapping) vegetation in their natural state (i.e prior to dam, groundwater extraction, Millennium drought and fires) driven by a gradient of water logging/inundation from mesic specialists with restricted extent to more mesic generalists with a broad distribution even into more xeric (terrestrial) environments (Table 1, Figures 1, 2).

It is assumed that in pre–European times any transitions were largely driven by gradual shifts in hydrology (constrained by ecohydrological factors) and that the complex remained largely a fire refugial area (i.e. fire impacted surrounding terrestrial habitat but likely 'skipped over' the saturated and damp, valley bottom). In the post–European era, the onset of hydrological change plus fire has served to drive rapid transitions between these states plus homogenise and simplify vegetation structure and patterning towards generalist (esp. trees) and ruderal (disturbance–adapted species) including many exotics (Figure 10). The putative State and Transition conceptual model shows four primary states that are broadly applicable to Units 1 to 4 and in parts of Unit 5 (and possibly Unit 6 – at least to some degree). These states are: (1) S1 – reference wetland (mostly comprising mesic specialists), (2) S2 – Drained/dried wetland (assumed state in late 1990's and early 2000's prior to the onset of the peat fire, due to Millenium drought, groundwater extraction and modification of surface flows), (3) S3 – Homogenised/ Simplified wetland with low diversity and invading trees, and (4) S4 – Recovering wetland with relatively minor improvements in complexity and diversity following hydrological repair (albeit partial) and some resting time.

Four key transitions are posited: (1) T1 – hydrological change resulting from various natural and human 'disturbances', (2) T2 – Severe Peat fire that effectively destroyed the peat 'sponge' which previously served to absorb and regulate wetland hydrology, (3) T3 – Hydrological repair based on strategic impoundment of surface flows using proposed weirs/bunds and a period of resting (say decades), and (4) T4 – a hypothetical trajectory of significant restoration based in additional active adaptive management interventions plus a longer period of resting (say many decades). In addition, the model depicts two hypothetical disturbances, D1 and D2 – of more–or–less equal severity – such as a wildfire, which in the first case results in little or no peat loss and a quick rebound more–or–less back to its former state in a short time frame (an indicator of higher resilience), while the second case results in a fundamental simplification in the state of the system (low diversity, bracken, tree and weed invasion). Importantly, in this latter case, while the system can make some recovery with hydrological repair and resting time, this is now limited due to the transformation/destruction of the peat 'sponge' and the loss of mesic specialists with limited/little capacity for passive recolonisation. Only with further improvements in hydrology and active reintroductions of "missing" species will ecosystem condition significantly improve (in any meaningful timeframe) back towards reference condition.

Thus in the wake of the fires, very little regeneration of in situ diversity has occurred, but rather rapid invasion of a limited number of generalist and/or ruderal native species and exotics better adapted to the conditions prevailing in the wake of the fire. Such natives include: Swamp Gum *Eucalyptus ovata*, Bracken *Pteridium esculentum subsp. esculentum*, Heath Teatree *Leptospermum myrsinoides*, Weeping Grass *Microlaena stipoides var. stipoides*, Prickly Moses *Acacia verticillata*, Forest Wire–grass *Tetrarrhena juncea*, Red–fruit Saw–sedge *Gahnia sieberiana*, Groundsels *Senecio spp*. While the various weeds include: Fog Grass **Holcus lanatus*, Sweet Vernal Grass **Anthoxanthum odoratum*, Cat's Ear **Hypochaeris radicata*, Blackberries **Rubus spp*. Sow Thistle **Sonchus oleraceus*, Clevers **Galium aparine*, Spear Thistle **Cirsium vulgare*, Annual Meadow–grass **Poa annua*. Mesic specialists like Scented Paperbark *Melaleuca squarrosa*, Tall Sedge *Carex appressa*, Bat's Wing Fern *Histiopteris incisa*, Tall Rush *Juncus procerus* are present, but regeneration is limited and that of much of the associated original flora (e.g. other mesic specialist shrubs, sedges, rushes, ferns and forbs in particular) is minimal or completely absent.

Although many of these species are herbaceous ruderals that will diminish in time, it is the absence of the diversity of these putative original mesic specialists that will ensure there will be the potential for limited long–term recovery. A simplified, depauperate and more weedy vegetation will likely predominate across much of the swamp from now on unless there is intervention to improve ecosystem function (namely hydrology and plant recruitment). For example, in 2019, Quadrat 4 comprised just five species (in decreasing abundance): Austral Bracken *Pteridium esculentum subsp. esculentum*, Prickly Tea–tree *Leptospermum continentale*, Scented Paperbark *Melaleuca squarrosa*, Cat's Ear **Hypochaeris radicata* and Swamp Gum *Eucalyptus ovata* (ELA, 2020). Unless there is functional improvement, it is very likely much of the originally diverse swamp will be more–or–less locked into this highly simplified and depauperate state (Table 5 and see Appendix 4).

Assessment of the available data identified some 60 putative mesic specialists that would have been quite restricted and often quite abundant within the saturated peat swamp, but (with some exceptions) rare or absent from surrounding drier environments (Tables 1, Table 6 and Appendix 5). All of the rare or threatened species recorded for the Yeodene Swamp area in the past fall into this group of plants.

Table 5 Summary of mesic specialists recorded from saturated wetland/bogs at Yeodene Swamp or immediate vicinity since 1993 (various sources incl. Atlas of Living Australia and ELA 2019)

Row Labels	Count of Spp.
Forb	16
Ground fern	9
Aquatic herb	6
Rush	5
Sedge	5
Small Sedge	5
Shrub	3
Tussock Grass	3
Tall Shrub	2
Twig Rush	2
Geophyte	1
Rope Rush	1
Tree fern	1
Tree	1
Grand Total	**60**

Notes: Most diverse lifeforms include: Forbs, Ground/Tree Ferns, Aquatic Herbs, Rushes and Sedges. The distinctive taller shrubs Woolly Tea–tree Leptospermum lanigerum and Scented Paperbark Melaleuca squarrosa are often abundant and form thickets.

Table 6 Putative mesic specialists recorded from saturated wetland/bogs at Yeodene Swamp or immediate vicinity since 1993 (various sources incl Atlas of Living Australia and ELA 2019)

Freq.[1]	Name	Lifeform	Comments
EcoL	Alternanthera denticulata	Forb	
EcoL	Baumea arthrophylla	Twig Rush	
2	Baumea tetragona	Twig Rush	
1	Blechnum minus	Ground fern	
4	Blechnum nudum	Ground fern	
3	Blechnum wattsii	Ground fern	
1	Bossiaea cordigera	Shrub	Rare in Victoria
1	Cardamine tenuifolia	Forb	Poorly known in Vic
5	Carex appressa	Sedge	
1	Carex fascicularis	Sedge	
EcoL	Carex gaudichaudiana	Sedge	
EcoL	Centipeda cunninghamii	Forb	
5	Coprosma quadrifida	Shrub	
1	Crassula helmsii	Aquatic herb	
1	Cycnogeton procerum	Aquatic herb	
EcoL	Cyperus gunnii subsp. gunnii	Sedge	
1	Cyperus lucidus	Sedge	
2	Dicksonia antarctica	Tree fern	
EcoL	Empodisma minus	Rope Rush	

Freq.[1]	Name	Lifeform	Comments
EcoL	Eucalyptus brookeriana	Tree	Rare in Victoria
1	Gleichenia dicarpa	Ground fern	
3	Gleichenia microphylla	Ground fern	
1	Glyceria australis	Tussock Grass	
1	Gonocarpus micranthus	Forb	
5	Gratiola peruviana	Forb	
1	Gratiola pubescens	Forb	
3	Histiopteris incisa	Ground fern	
EcoL	Hydrocotyle muscosa	Forb	
4	Hydrocotyle pterocarpa	Forb	
1	Hypericum japonicum	Forb	
EcoL	Hypolepis rugosula	Ground fern	
1	Isolepis cernua	Small Sedge	
EcoL	Isolepis fluitans	Small Sedge	
3	Isolepis inundata	Small Sedge	
EcoL	Juncus amabilis	Rush	
1	Juncus pallidus	Rush	
2	Juncus pauciflorus	Rush	
1	Juncus planifolius	Rush	
1	Juncus sarophorus	Rush	
EcoL	Lachnagrostis filiformis	Tussock Grass	
5	Leptospermum lanigerum	Tall Shrub	
EcoL	Leptostigma reptans	Forb	
1	Lobelia anceps	Forb	
1	Lobelia beaugleholei	Forb	Rare in Victoria
1	Lobelia pedunculata	Forb	
EcoL	Lycopus australis	Forb	
4	Melaleuca squarrosa	Tall Shrub	
EcoL	Monotoca glauca	Shrub	Rare in Victoria
EcoL	Montia australasica	Forb	
1	Myriophyllum amphibium	Aquatic herb	
EcoL	Ottelia ovalifolia subsp. ovalifolia	Aquatic herb	
EcoL	Persicaria decipiens	Forb	
EcoL	Poa labillardierei	Tussock Grass	
3	Polystichum proliferum	Ground fern	
1	Pterostylis lustra	Geophtye	Victoria: endangered (e); listed in Flora and Fauna Guarantee Act 1988
EcoL	Ranunculus amphitrichus	Aquatic herb	
2	Schoenus maschalinus	Small Sedge	
EcoL	Todea barbara	Ground fern	
1	Triglochin striata	Aquatic herb	

Notes: 1. Number of records

2.4.5 Summary of conceptualisation

Table 7 provides a summary of the information supporting the conceptualisation and whether there is adequate information to support the problem statements and predict the trajectory of the success targets. Cross sections (West to East) across the swamp for baseline (pre-impact), post fire (2011) and current conditions of the swamp are presented in Figure 11, Figure 12 and Figure 13 respectively.

Based on the conceptualised knowledge of the area, the following can be said:

- There is adequate information to support the conceptualisation of Big Swamp so that the problem statements can be justified and trajectory of success targets be predicted
- There is an absence of baseline water level data for the QA, however, the presence of other information and data (i.e. LTA water levels, soil logging, Boundary Creek water quality and vegetation assemblages) supporting the swamp are sufficient to determine the likely baseline water levels within the QA
- There is a lack of data supporting the saturation of the surface soil of the wetland. Consideration should be made to utilise a combination of hand-held EM surveys, site observations, and/or remote sensing data to monitor soil saturation and use these data to calibrate the predictions made by modelling
- The most robust datasets in terms of historical records are LTA water levels, streamflow (Yeodene stream gauge) and Boundary Creek water quality

Table 7 Summary of information supporting conceptualisation

Success target	Change to system	Problem statement	Adequate information to support problem statement (Y/N)	Adequate information to predict the trajectory of success target? (Y/N)
1. Recovery trend for groundwater levels in the LTA	Decreased water levels in the LTA and increased fluctuation in the water table surface (changes in soil saturation)	Groundwater abstractions coupled with drier climatic conditions (i.e. reduced recharge) have led to the decrease in water levels within the LTA	Y	Y
2. No further encroachment of terrestrial woodland into the swamp plain	Severe impacts on soil properties, surface microtopography, channel incision, wetland vegetation destruction and drying of perched aquifer has lead to a collapse of the original wetland into a simplified/homogenised state (S3) dominated by a handful of invasive natives (woody) and exotics	System now locked into a permanently degraded state due to this combination of impacts and will not likely recover unless there is intervention to restore hydrology (to the extent possible) and remove invasive plants to encourage wetland regeneration	Y	Y
3. No encroachment of Lowland Forest dominant species into areas of Damp Forest	To the extent that the drying of the swamp and fire encroached into areas of fringing damp vegetation (Unit 6), there has also likely been a similar mass (albeit) patchy recruitment of Swamp Gum (and possibly other eucalypts) in this vegetation unit, that similarly could have the effect of driving canopy closure.	This so called 'canopy thickening' process could serve to drive further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance) and will not recover unless there is intervention to restore hydrology (to the extent possible) and (where appropriate) manipulate canopy structure to encourage understorey regeneration	Y	Y
4. No loss of structural or floristic diversity along the main channel and western end of the swamp	To the extent that the drying of the swamp and fire has also encroached into areas of fringing Drainage line Woodland vegetation (Unit 5), it is likely there has also been impacts of 'canopy thickening' and a drying out of the wettest sections that support some mesic specialists	These impacts could drive even further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance) and will not recover unless there is intervention to restore hydrology (to the extent possible) and (where appropriate) manipulate canopy structure to encourage understorey regeneration - especially those patches of mesic specialists	Y	Y
5. Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges	Severe impacts on soil properties, surface microtopography, channel incision, wetland vegetation destruction and drying of perched aquifer has lead to a collapse of the original wetland into a simplified/homogenised state (S3) dominated by a handful of invasive natives (woody) and exotics and little or no regeneration of the original diversity of mesic specialists	System now locked into a permanently degraded state due to this combination of impacts and will not likely recover unless there is intervention firstly to restore hydrology (to the extent possible - modelling suggest significant changes c.f. 1982 baseline), secondly to create a suitable ground level micro-environment (for seed/propagule dispersal and recruitment of mesic specialists), and thirdly actively reintroduce these wetland species should initial 'passive' strategies prove ineffective	Y	Y
6. Maintain monitoring bore water levels at individual bores above target water levels	Decreased water levels within the QA	Groundwater abstractions, swamp fires coupled with drier climatic conditions have led to a decrease in water levels within the QA at Big Swamp	Y	Y
7. At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years	- A reduction in average streamflow through Boundary Creek at Yeodene by around 3.4 ML/d from a flow of 10.6 ML/d circa 2002 to around 6 ML/d post 2002 - Increased duration and frequency of flow cessation through Boundary Creek at Yeodene	Depressurisation of the LTA coupled with drier climatic conditions has led to decreased water levels within the QA which in turn has decreased average streamflow in Boundary Creek due to less water being gained from the QA	Y	Y
8. Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	A sharp decrease in average pH from Boundary Creek decreasing from a median of 6.5 circa 1990 to a median of 3.8 post 2000	Groundwater abstractions coupled with drier climatic conditions has led to drawdown of water levels in the QA and exposure of ASS to oxygen leading to the generation of acid rock drainage and a decrease in the pH of Boundary Creek	Y	Y

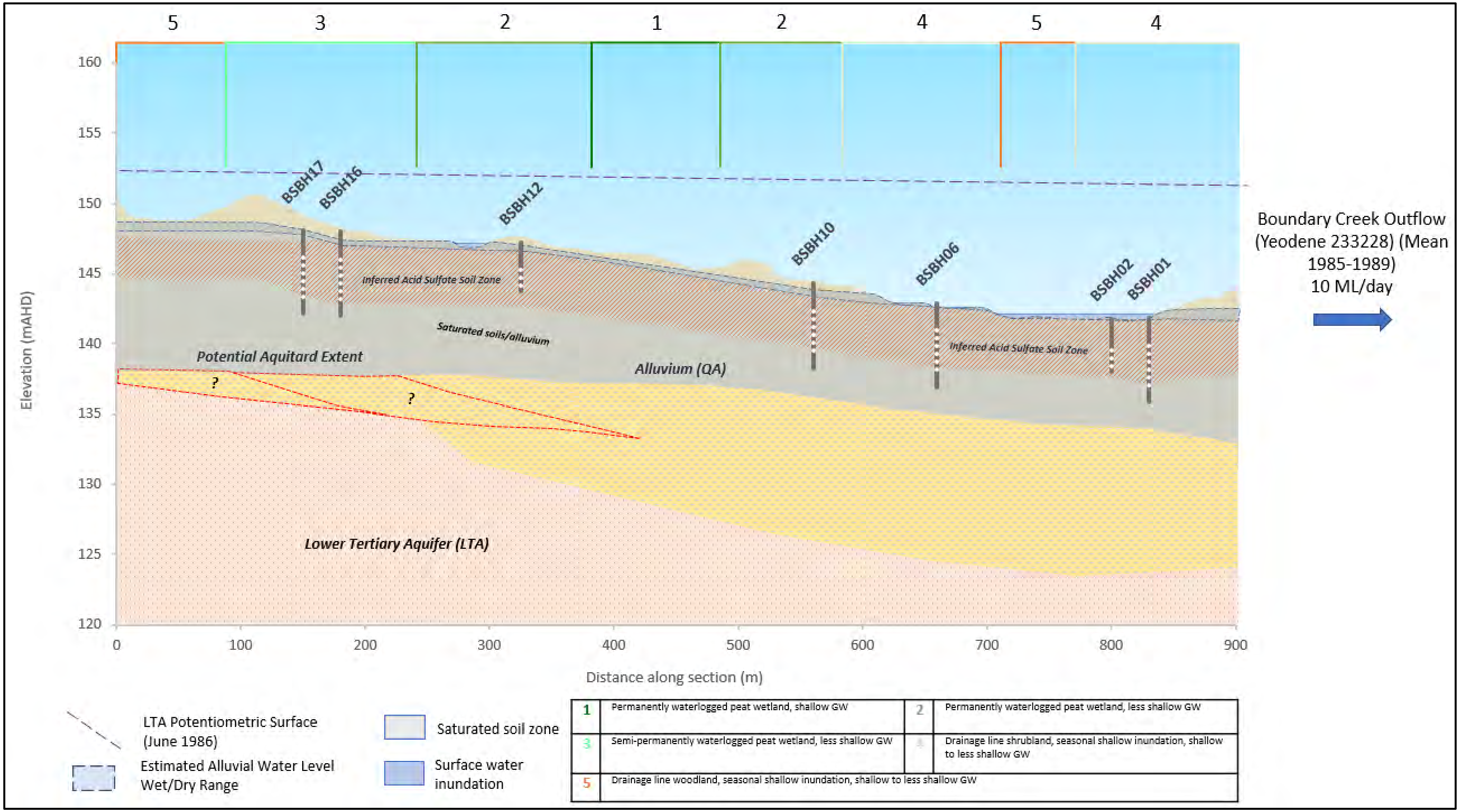

Figure 11 **Baseline (pre-impact) conceptual cross section of Big Swamp**

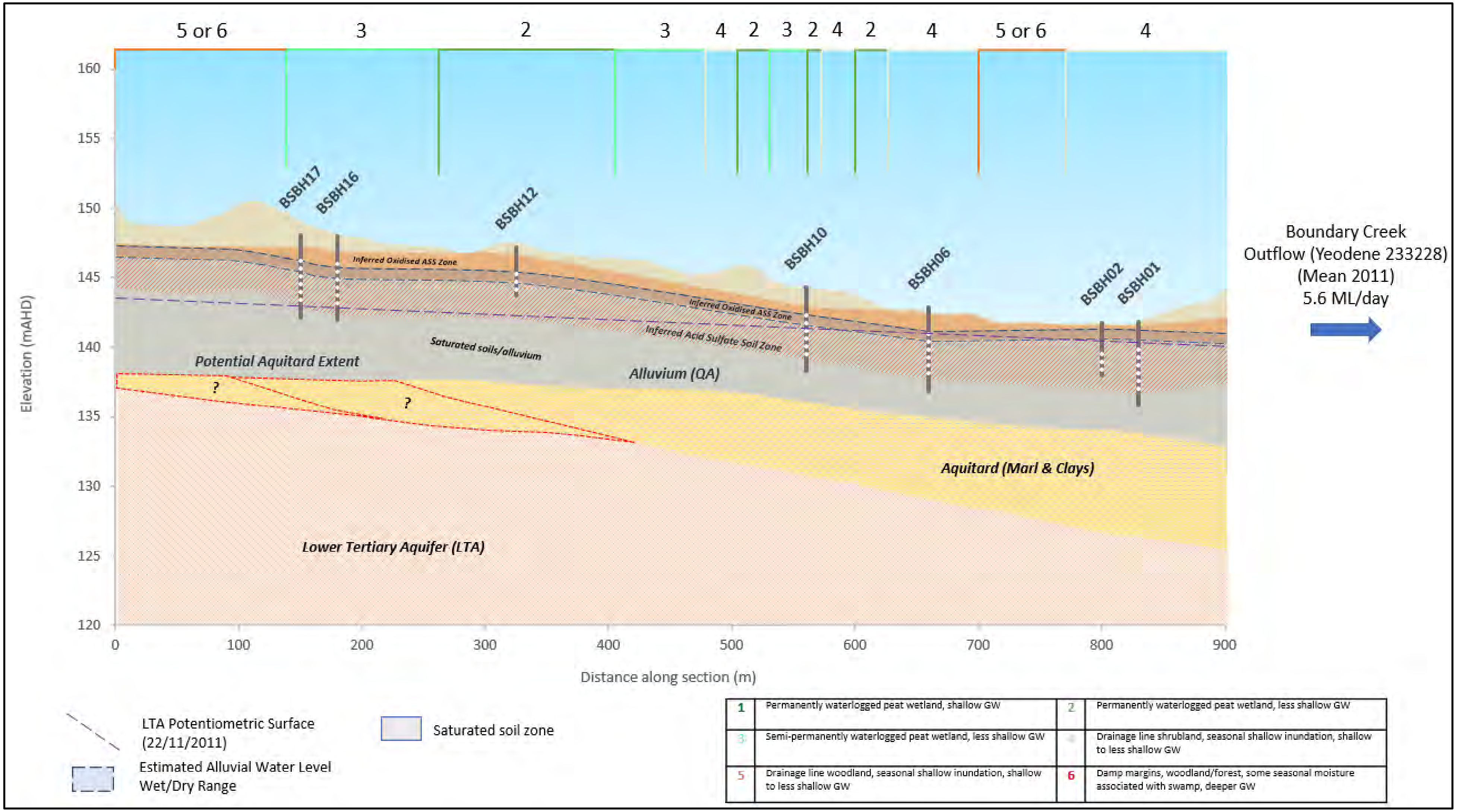

Figure 12 **Post fire event (2011) conceptual cross section of Big Swamp**

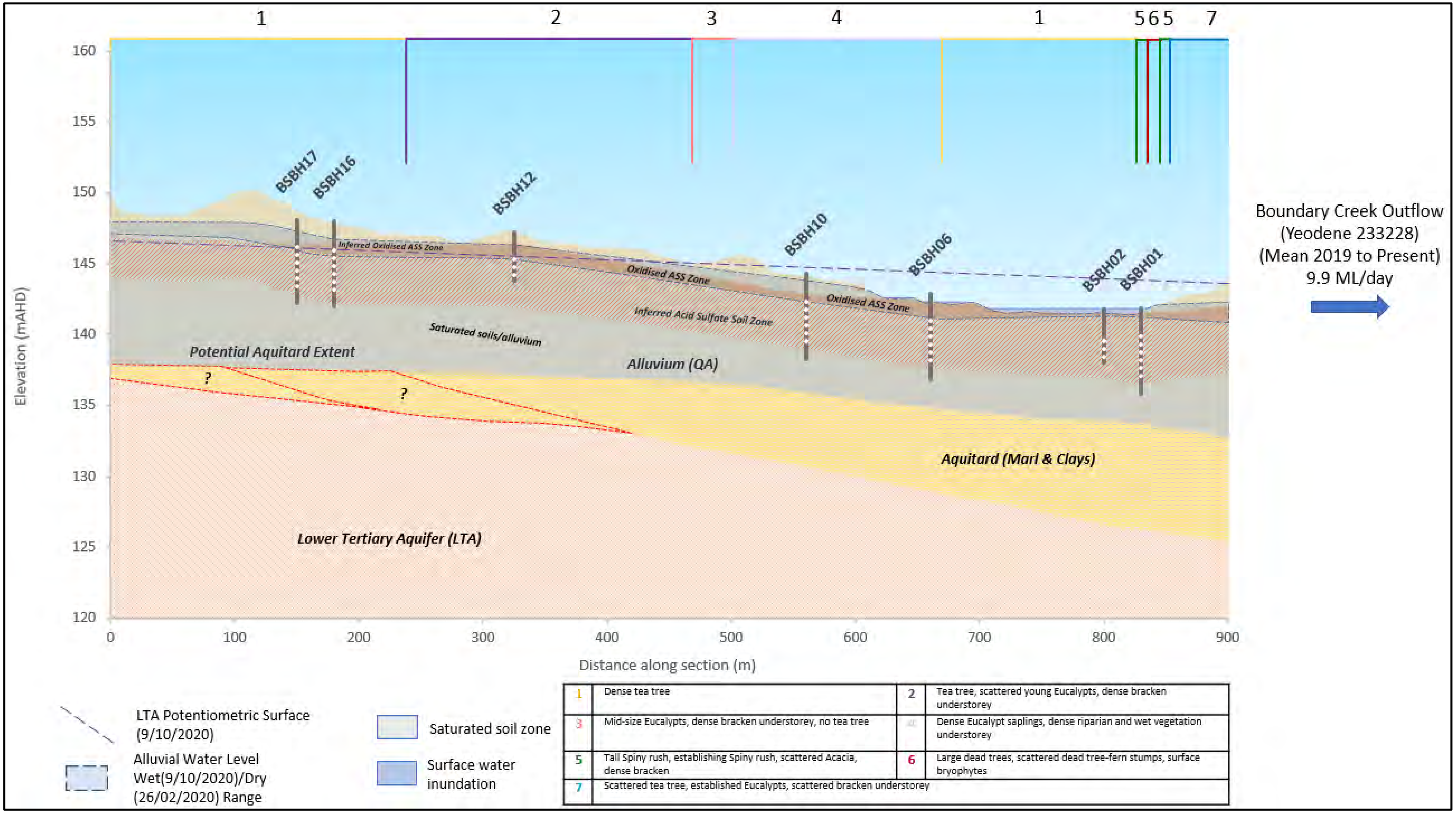

Figure 13 Current (post-impact 2019/2020) conceptual cross section of Big Swamp

2.5 Step 2 – Control measure (remediation strategy) evaluation

2.5.1 Lower Tertiary Aquifer

No formal control measures have been proposed specifically in relation to the LTA recovery success targets. However, the controlled releases from McDonald's Dam, should be considered a form of passive managed aquifer recharge (although not necessarily through design). Where Boundary Creek water levels are higher than the adjacent/underlying LTA hydraulic heads, infiltration through the creek bed will recharge the LTA. These river losses are likely one of the main drivers of the increasing hydraulic head trends in LTA bores downstream of the dam (e.g. 109128, 109130, 109131), which show a seasonal response to higher river flows.

An additional control measure is the ongoing surface water and groundwater monitoring across the study area, as this enables the continued hydrogeological analysis and evaluation required to assess the success targets. Evaluation of the existing targets and recommendations for further refinement are provided in Section 2.6.1.

2.5.2 Quaternary Aquifer

The control measures which relate to the QA's success target are presented in Table 8.

Table 8 QA success target control measures

Control measure	Success target
Construction of hydraulic barriers	Maintain monitoring bore water levels at individual bores above target water levels
Infilling of the existing fire trenches and agricultural drain	
Ongoing data collection	

GHD have recently completed integrated groundwater-surface water modelling to inform the effect remediation (via delivery of supplementary flow, construction of hydraulic barriers and infilling of trenches and drains) will have on water levels within the QA (GHD, 2021).

Hydrographs of the QA monitoring bores showing the modelled water levels in response to the implementation of barriers and a supplementary streamflow of 4.4 ML/d are presented in Figure 14 and Figure 15. The range of seasonal variability in groundwater levels across the swamp for current and remedial conditions are presented in Figure 16. This figure also highlights the effect of the remediation system on the seasonal variability of groundwater levels, where areas of negative change represent areas where seasonal variability has reduced, and areas of positive change indicate areas of increased seasonal variability.

The modelling suggests:

- Implementation of barriers and infilling of trenches and drains are effective in raising groundwater levels within the monitoring bores with predicted heads at or above the target groundwater levels over the period modelled. The exception is BH18, where computed heads are consistently lower than the target level by around 0.3 m
- Where ponding is maintained, the QA become fully saturated and groundwater levels become equilibrated with the pond level
- For all wells, implementation of hydraulic barriers decreases the variability (i.e. fluctuation in groundwater levels) in the monitoring bores by up to around 1 metre.
- There is potential for groundwater levels at BH08 to fall below the target level around 30% of the period modelled with water levels residing above the target level 60 to 70% of the modelled period

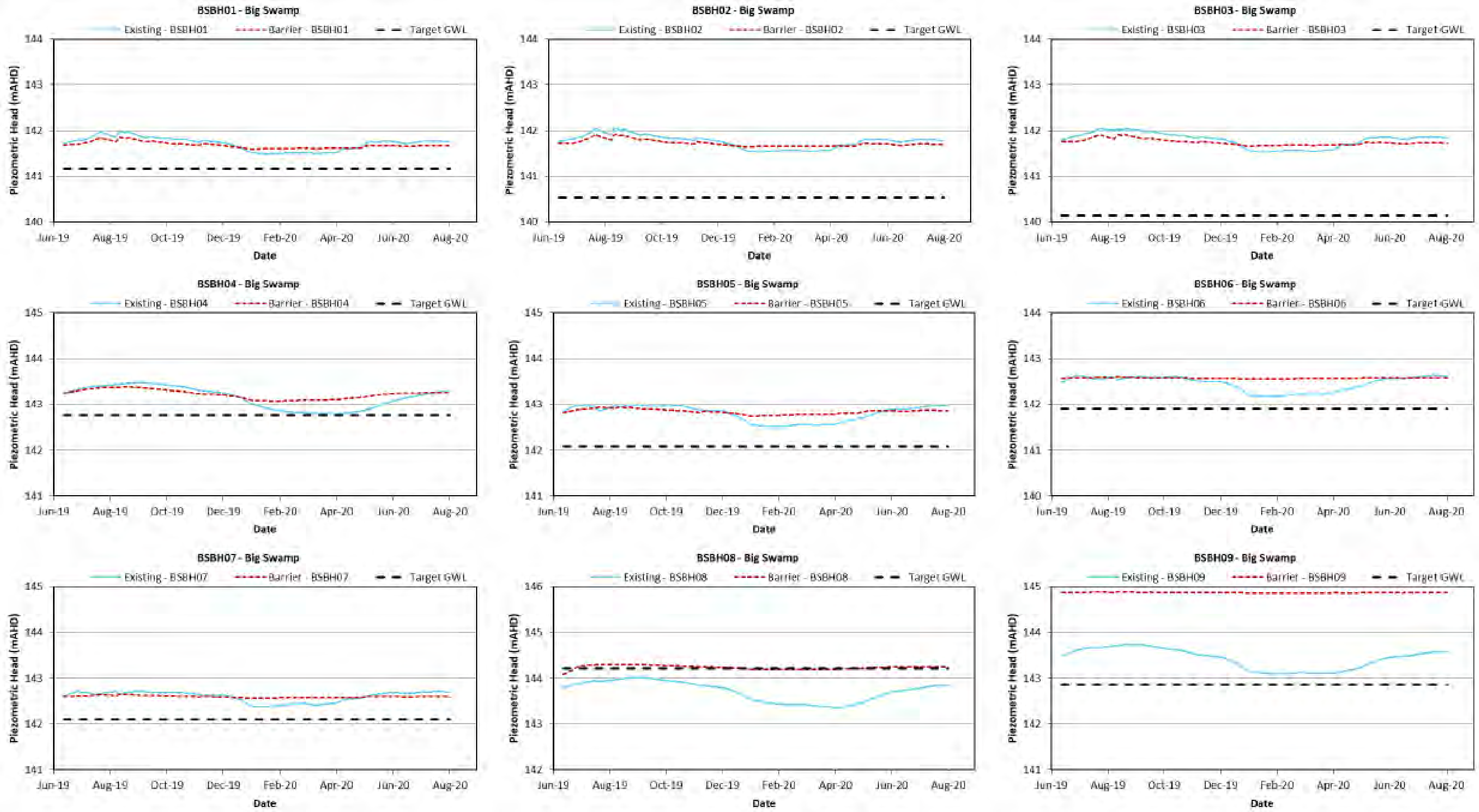

Figure 14 Predicted bore hydrographs (remedial) at 4.4 ML/d supplementary streamflow – BH01 to BH09 (GHD, 2021)

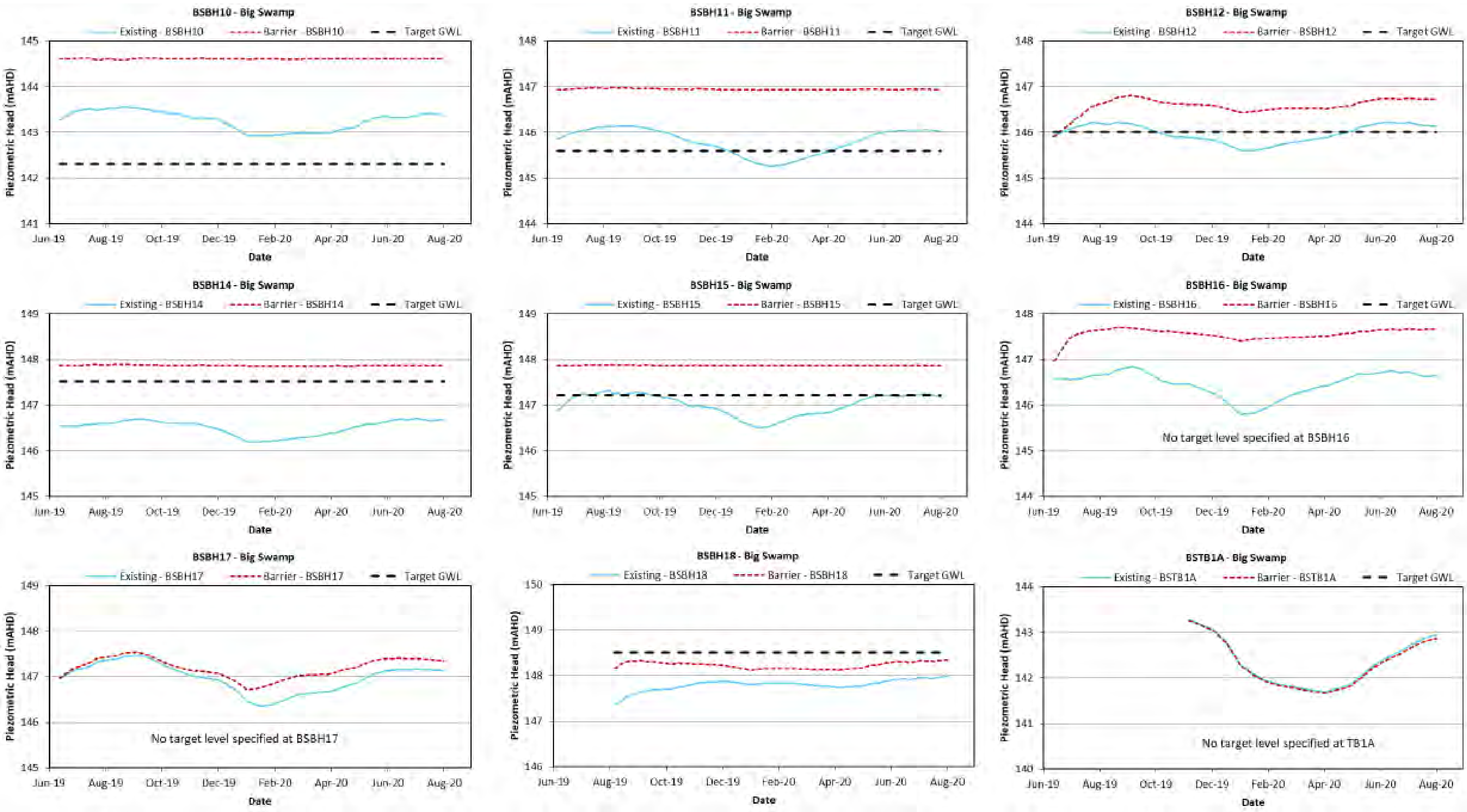

Figure 15 **Predicted bore hydrographs (remedial) at 4.4 ML/d supplementary streamflow – BH10 to BSBH_TB1A (GHD, 2021)**

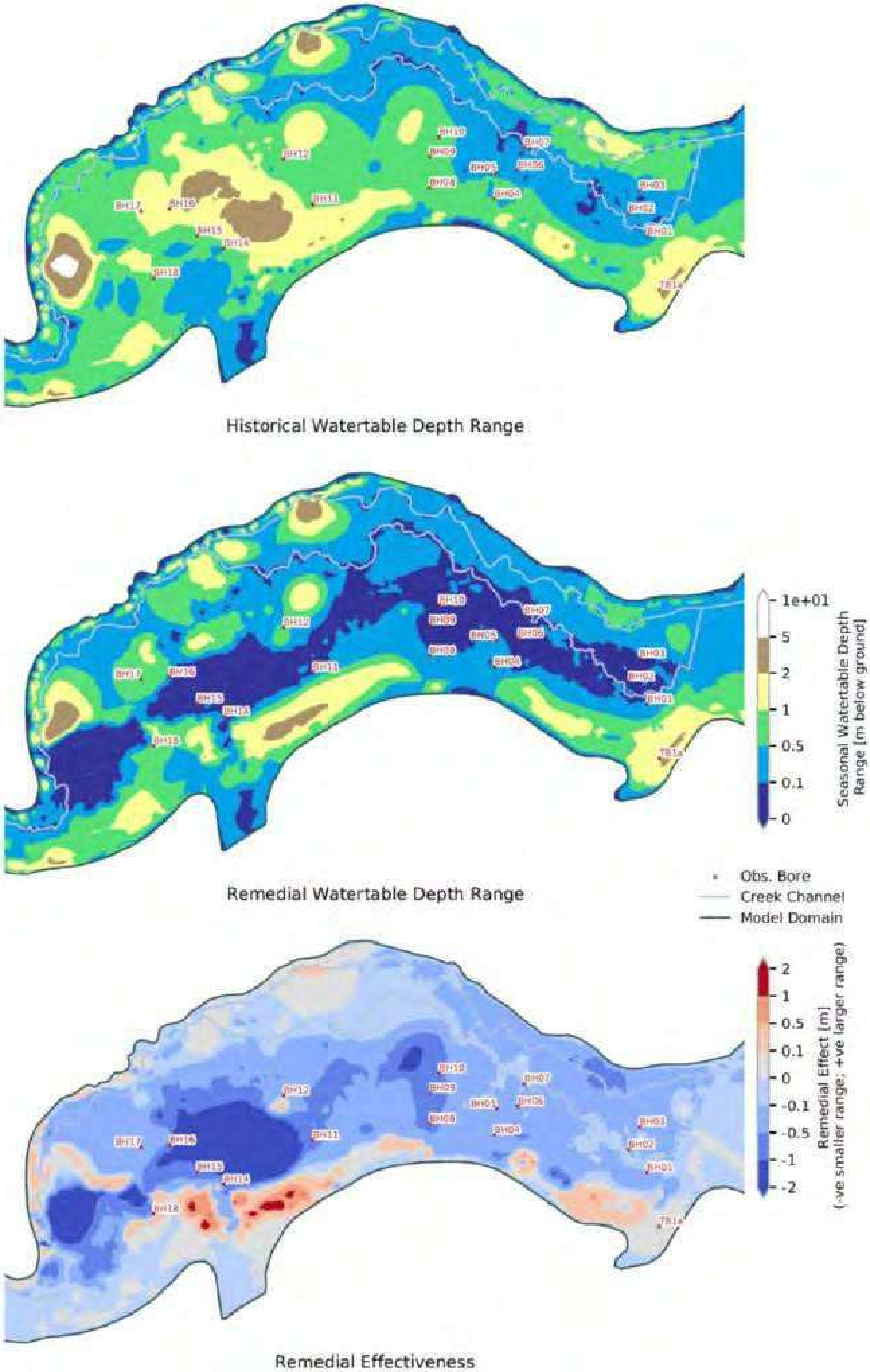

Figure 16 Modelled seasonal water table range and remedial effect (GHD, 2021)

- The hydraulic barriers and associated redistribution of flow has the potential to lower the water table (by <0.5 m) along Boundary Creek under wet or typical climatic conditions due to the diversion of water through the swamp
- A possibility for the groundwater level to fall along the southern boundary of Big Swamp, due to the infilling of the fire trench, resulting in a decrease to the water table of between 0.5 to 1 m
- The extent and depth of flooding is not sensitive to differing supplementary flows (50:50 flow split at barrier 1) meaning the hydraulic barriers generally have the same effect on groundwater levels whether streamflow is low or high

In terms of the effectiveness of the control measures, the following can be concluded:

- Construction of hydraulic barriers is effective in both increasing the groundwater levels in the Swamps west and reducing the variability in water levels across all monitoring bores
- Infilling the fire trenches and agricultural drains diverts greater water flows over the swamp area, however, reduces water levels in the southern and northern portions of the swamp.
- Ongoing data collection of QA water levels will assist in measuring the trajectory of the QA condition in meeting the success targets

2.5.3 Hydrology

The control measures which relate to the hydrology success targets are presented in Table 9.

Table 9 Hydrology success target control measures

Control measure	Success target
Construction of hydraulic barriers	At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years
Continued delivery of supplementary flow of >0.5 ML/d at Yeodene stream gauge	
Infilling of the existing fire trenches and agricultural drain	
Ongoing data collection	

Figure 17 presents the predicted flow at Yeodene stream gauge for a number of supplementary flow scenarios with hydraulic barriers implemented (GHD, 2021). The modelling suggests:

- The maximum available supplementary flow available is around 4.4 ML/d assuming supplementary flow is required for 114 days of the year and the volume available per year for discharge is 500 ML
- Almost all of this supplementary flow would be required to meet the success target of 0.5 ML/d at Yeodene stream gauge with the target generally being met with flow between 4 to 4.4 ML/d
- Flow at Yeodene stream gauge would be greater than 0.5 ML/d for 90% of the 14-month simulation period
- It may be possible to divert additional water to Boundary Creek or achieve the 0.5 ML/d flow target with less supplementary flow by adjusting the flow split at barrier 1
- The implementation of barriers appears to reduce the magnitude of flows downstream of Boundary Creek in the wet period while only marginally decreasing the low flow during the dry period

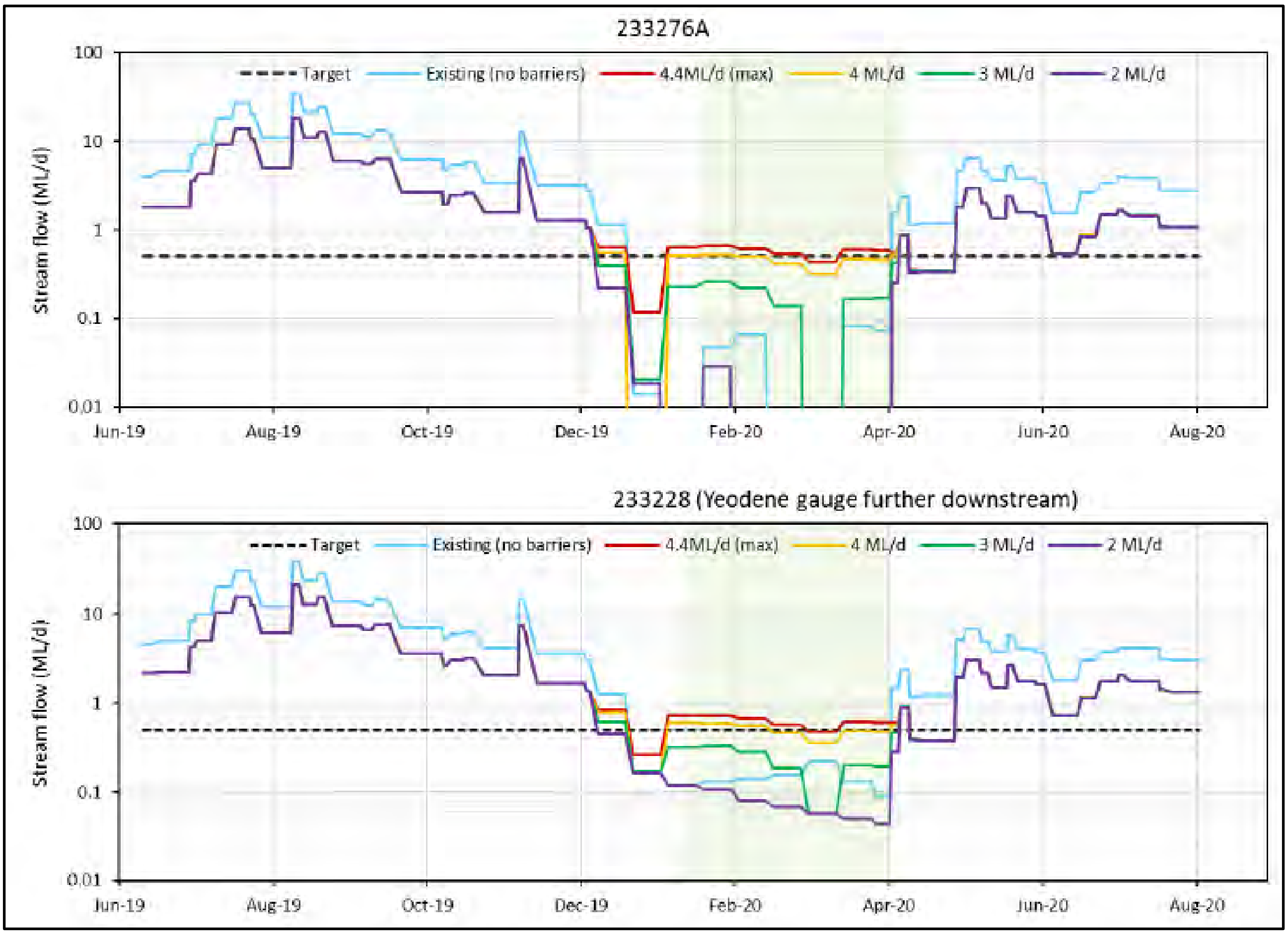

Figure 17 Predicted flow hydrographs at Big Swamp downstream gauges (GHD, 2021)

In terms of the effectiveness of the control measures, the following can be concluded:

- The addition of supplementary flow is effective in controlling the magnitude of streamflow within Boundary Creek, however, to maintain flows greater than 0.5 ML/d for 100% of the time at Yeodene stream gauge, flows greater than 4.4 ML/d (i.e. the maximum daily supplementary flow from McDonalds Dam) that was modelled would need to be released during the dry period
- The implementation of hydraulic barriers in the swamp has a small effect on the streamflow within Boundary Creek where greater supplementary flow is required to maintain the same amount of streamflow through Boundary Creek than without the use of barriers
- It is unknown what the effect of infilling existing fire trenches and agricultural drains alone will have on changing the magnitude of flows at the Yeodene stream gauge
- Ongoing data collection of Boundary Creek streamflow will be vital in measuring the trajectory of the hydrology conditions in meeting the success target

2.5.4 Eco-hydrology

A projected vegetation pattern has been modelled from a combination of the groundwater surface and above ground inundation/ponding depths expected following the construction of a series of strategically placed barriers (Table 10). The modelled remediation vegetation pattern (Figure 18) shows areas within the margins of the original peat wetland that are not likely to support wetland vegetation in the future due to excessively deep ponding (i.e. >0.3 m) and where the water table depth is greater than 0.5 m.

Table 10 Comparison of the estimated extent of the most saturated peat wetland types in (a) 1982 (pre-impact benchmark) ~38% and (b) under the proposed remediation ~22%

(a)

	Area (ha)	*%*
Unit 1	0.87	7%
Unit 2	3.75	31%
Unit 3	4.39	36%
Unit 4	3.22	26%
Grand Total	12.24	100%

(b)

	Desc.	*Area (ha)*	*%*
1	<0.3 inundation	1.50	12%
2	<0.1 GW	1.25	10%
3	<0.5 GW	3.87	32%
9	Dry soils	3.57	29%
99	Deep ponding	2.02	17%
	Grand Total	12.21	100%

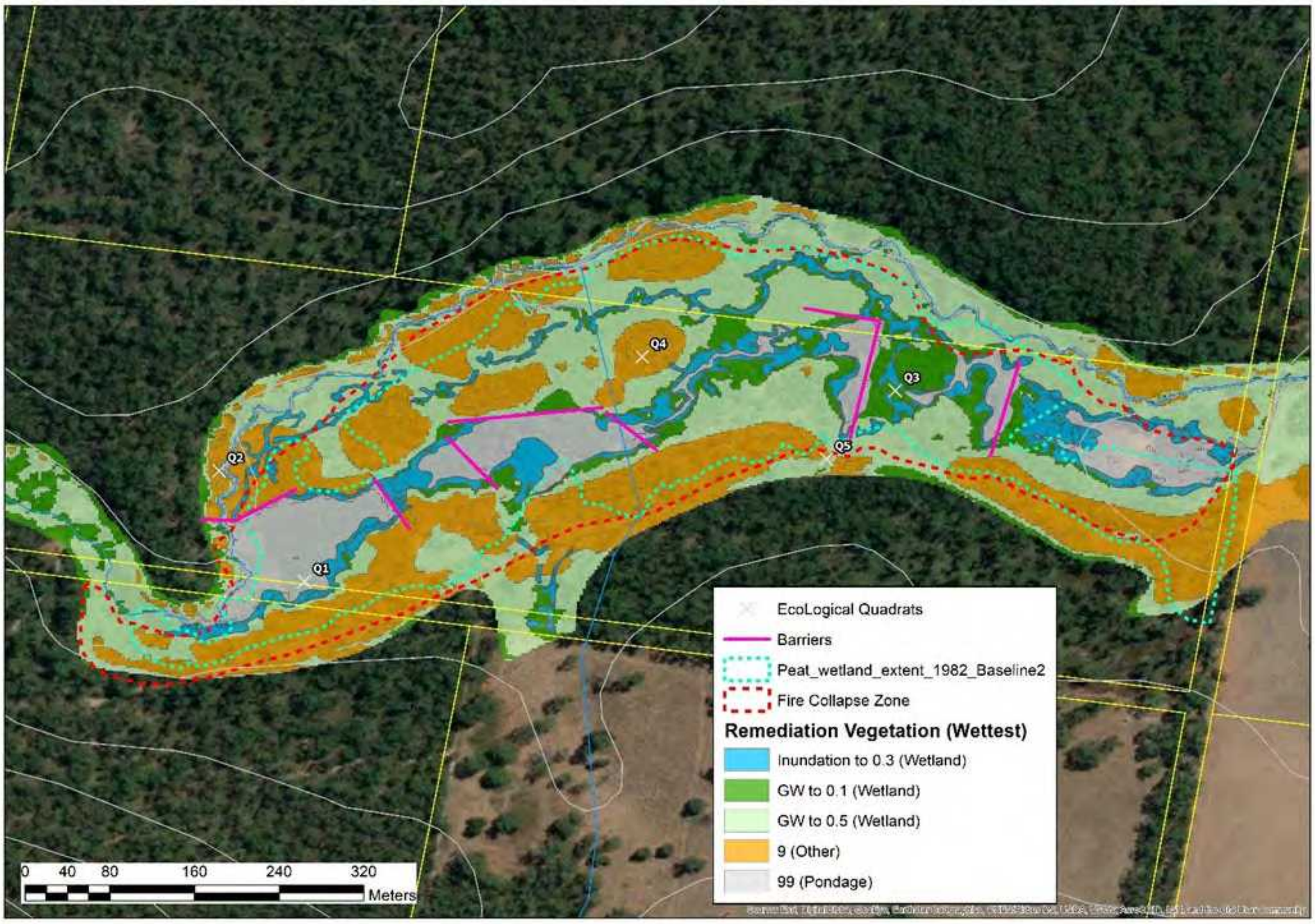

Figure 18 Modelled remediated vegetation pattern (based on inundation extent for wettest period)

2.5.5 Summary of control measure effectiveness

Table 11 presents a summary of the control measures (remedial strategies) effectiveness. The summary includes an assessment of the linkages between the control measures and the success targets as well as detailing the suitability of the control measures in achieving the Success Targets. From the assessment of the control measures the following can be concluded:

- All the control measures are considered suitable to achieve the success targets
- For every success target to be realised, all control measures will need to be implemented, i.e. construction of hydraulic barriers alone will not improve the condition of the swamp and is dependent on receiving supplementary flows, infilling of fire trenches/ agricultural drains as well as preventing the encroachment of dry vegetation species to the swamp
- Barriers reduce peak Boundary Creek flows at Yeodene stream gauge and prolongs periods of low to no flow during the dry period
- There is likely an adverse effect cause to the ecohydrology success targets by implementation of the hydraulic barriers due to the level of inundation in the swamp (i.e. more than 30cm fop prolonged periods of time). This may prevent some mesic specialist from establishing.
- Based on the interdependencies there is a sequence in which the success targets will be reached, therefore, the timing of reaching success targets needs to be considered appropriately and in accordance with each success targets influence on others (e.g. ecohydrology success targets cannot occur until the full effectiveness of inundation from the barriers is obtained)

A cross section (West to East) across the swamp predicting the remedial environment (approximately 10 years' time) is presented in Figure 19.

Table 11 Control measure 'score card'

Control measure	Effect on success target								Control measure suitable? (Y/N)
	Recovery trend for groundwater levels in the LTA	No further encroachment of terrestrial woodland into swamp plan	No encroachment of Lowland Forest dominant species into areas of Damp Forest	No loss of structural or floristic diversity along the main channel and western end of the swamp.	Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges	Maintain monitoring bore water levels at individual bores above target water levels	At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	
1. Continued delivery of supplementary flow in Reach 3 of Boundary Creek of >0.5 ML/d at Yeodene stream gauge	May provide increased recovery trend due to recharge of LTA from supplementary flow	Encroachment of invasive natives and exotics has already occurred, and their continued dominance will not be impacted (by this control measure)	Encroachment of invasive natives and exotics has already occurred and their continued dominance will not be impacted (by this control measure)	This supplementary flow will assist in maintaining wetland vegetation in the main channel but will require additional measures to be achieved	Flow through Boundary Creek and swamp required to maintain swamp vegetation such as ferns and sedges, although additional measures will be needed	Current supplementary flows assist in maintaining majority of eastern monitoring bores above success targets.	Surface water modelling indicates increases to supplementary flow is effective in increasing the flow at Yeodene stream gauge, however, flows greater than the maximum daily allowance may need to be released in order to meet the success target 100% of the time	Potential to indirectly reduce the pH downstream of Big Swamp through increased 'wetting' of the QA and reduction in the amount of ASS exposed	Yes, control measure considered vital in providing flow to inundate swamp
2. Construction of hydraulic barriers	Potentially may increase recharge to underlying HSUs from increased inundation	Encroachment of invasive natives and exotics has already occurred and the barriers will be only partly effective in reversing this process	Encroachment of invasive natives and exotics has already occurred and their continued dominance will likely not be impacted (by this control measure)	The barriers will have minimal impact on this target	Encroachment of invasive natives and exotics has already occurred and the barriers will be only partly effective in reversing this process	Maintains all monitoring bore water levels above target water levels except BH18 and reduces the variability in water levels across all monitoring bores	Reduces peak Boundary Creek flows at Yeodene stream gauge and prolongs periods of low to no flow during the dry period	Inundation of the swamp will lead to increased water levels within the QA and decreased variability in water levels preventing the exposure of ASS and acidification of the water downstream of Big Swamp	Yes, control measure may require additional refinement to allow for water levels within BH18 to rise above current water level target
3. Infilling of existing fire trenches and agricultural drain	N/A	Encroachment of invasive natives and exotics has already occurred and their continued dominance will not be impacted (by this control measure)	Encroachment of invasive natives and exotics has already occurred, and their continued dominance will not be impacted (by this control measure)	The infilling will have minimal impact on this target	The infilling will have minimal impact on this target	Increases water level flow through the swamp increasing ponding and thereby water levels within the QA, however, reduces water levels within the southern and northern portions of the swamp. Note the effect of this control measure alone, i.e. without barriers is unknown	Likely reduces the flow of water through the channels and Boundary Creek as a result of greater water flows being diverted through the swamp area and losing to the QA	Potential to indirectly reduce the pH downstream of Big Swamp through increased 'wetting' of the QA and reduction in the amount of ASS exposed. However, this is not supported by modelling.	Yes, necessary to prevent further erosion and channelisation in big swamp while providing greater flow of water though the swamp.
4. Prevention of encroachment of dry vegetation classes	N/A	Will reverse the encroachment process (esp. trees and larger shrubs)	Will reverse the encroachment (canopy densification) process (esp. trees and larger shrubs)	May partly contribute to maintaining diversity in this area	May partly contribute to increasing diversity (ferns and sedges)	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further may assist in preventing further decline in QA water levels	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further leaving additional water within the Swamp system which may induce groundwater gaining to Boundary Creek	Prevention of further dry vegetation classes will likely prevent evapotranspiration from rising further may assist in preventing further decline in QA water levels and thereby less exposure of ASS	Yes, control measure considered vital to prevent further decline in swamp terrestrial ecology
5. Ongoing data collection to inform the adaptive monitoring approach	No direct effect, however, considered crucial in measuring the success of the target and the effectiveness of other control measures in changing the eco-hydrological environment								Yes
6. Additional data collection and testing to inform the feasibility of the other contingency options	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Suitable as a contingency measure, however, does not provide any effect on current success targets

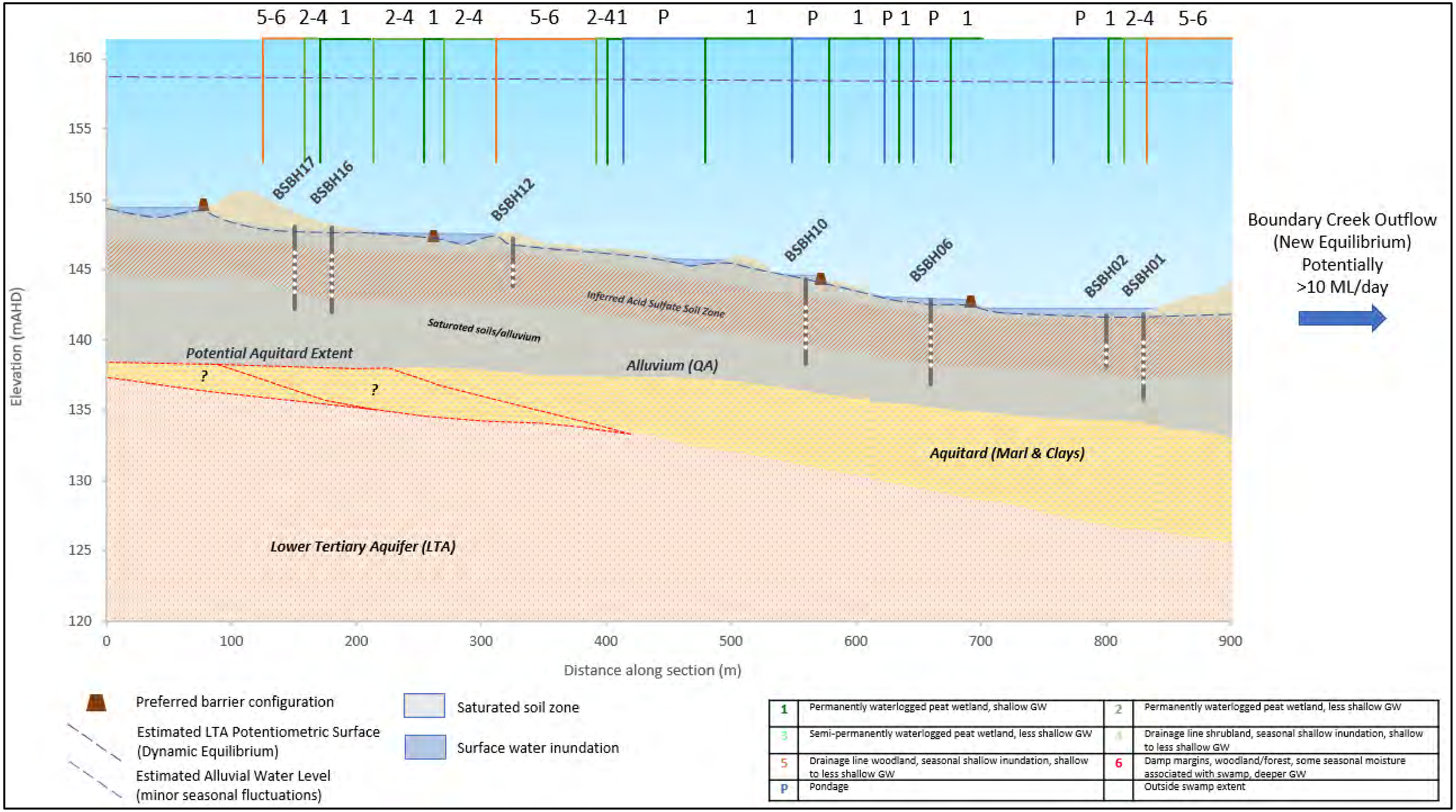

Figure 19 **Remedial (post remediation 2031) conceptual cross section of Big Swamp**

2.6 Step 3 – Success target evaluation

2.6.1 Lower Tertiary Aquifer

As previously defined, the success target relating to the LTA is:

- Groundwater level recovery trend (Lower Tertiary Aquifer – LTA)

The existing LTA success target of recovering trends is considered an appropriate aspirational target for the regional scale hydrogeological function of the LTA as a groundwater resource.

A current investigation is underway to identify the environmental values of shallow groundwater systems across the study area. The outcomes of this work will likely enable more specificity to be achieved in relation to the role of the recovering LTA in supporting shallow groundwater systems.

Evaluation of the hydrogeological function of the LTA and aquitard hydraulic heads in achieving Big Swamp alluvial aquifer success targets warrants further attention. A selection of shallow LTA bores in the vicinity Big Swamp are shown in Figure 20, where LTA bores adjacent to the losing section of Boundary Creek are showing rising trends as they receive seasonal recharge while also being supported by regional recovering LTA trends (i.e. 109113, 109132). These bores are not yet artesian but if the recent linear trend is cautiously extended, such conditions may occur in the next 10–20 years. Prior to this, the LTA hydraulic heads may reach a level that is higher than the variable Boundary Creek stage between Mcdonald's Dam and Big Swamp, which would then support greater surface water contributions to shallow groundwater system within Big Swamp. This may then further aide in the rehabilitation of the site independently of proposed barriers intended to manipulate shallow surface water – groundwater exchange.

However, on a smaller scale, the hydrogeological function of the LTA is also tied to supporting the environmental values of Big Swamp (riparian and aquatic), and an additional Success Target is proposed. The newly drilled nested site at the eastern end of Big Swamp shows LTA heads (TB1c) above those of the alluvium (TB1a) and aquitard (TB1b) observation bores. The LTA heads show a slight rising trend while the alluvium and aquitard heads show more seasonal variability, likely in response to a combination of rainfall and creek flow patterns. At this location there is an upward hydraulic gradient from the LTA towards the alluvium and aquitard. The LTA bores to the north and west appear to have higher hydraulic heads than this nested site, while bore 109112 is only slightly higher than TB1c with a similar trend. The continued recovery of these and other nearby LTA bores are expected to aid in the recovery of Big Swamp alluvial groundwater levels and so could be indirectly tied to their success targets.

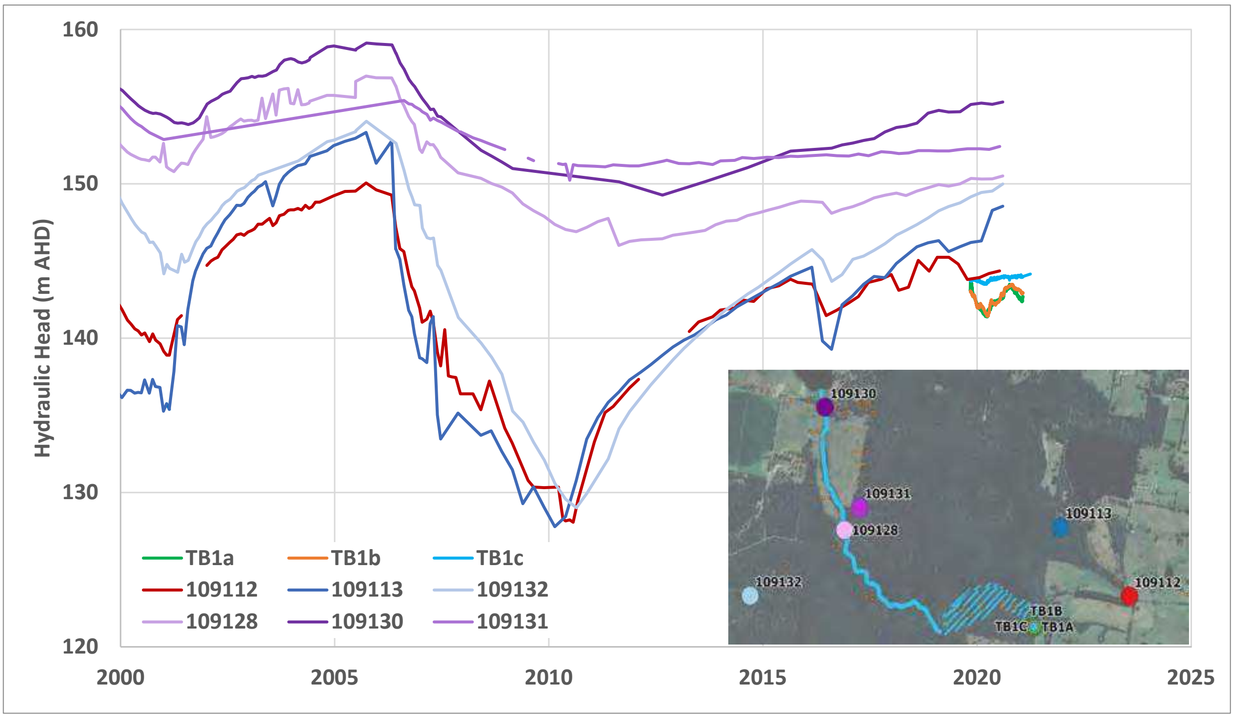

Figure 20 Selected hydrographs in the vicinity of Big Swamp

2.6.2 Quaternary Aquifer

As previously defined, the success target relating to the QA is:

- Maintain monitoring bore water levels at individual bores above target water levels

It is understood the success targets of the monitoring bores have been defined with regard to the ASS horizon with the bore network and lithology thought to be representative of the swamp geology. The control measure (i.e. implementation of hydraulic barriers) has proven an effective remediation strategy for increasing water levels above the water level targets, thereby saturating the ASS horizon and preventing further oxidation and acid generation within the swamp.

The current monitoring network allows for successful and straight forward monitoring of the success target which can be managed on a continual and automated basis via pressure transducer data loggers (PTDLs). The current monitoring data, however, suggests that, BH18 responds differently to the remaining bores in Big Swamp which currently is not understood. To assist in increasing the understanding of the geology within the swamp and whether the success targets chosen are representative of the system, the following recommendations are made:

- Undertake an analysis of the monitoring bore construction and logging to determine if the well responses are related to the lithology or well construction

2.6.3 Hydrology

As previously defined, the success target relating to hydrology is:

- At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years

Based on discussions with Barwon Water, it is understood the hydrology success target has been devised with the intent of maintaining ‘adequate’ flows which are measurable across the Yeodene stream gauge, with very low flows (<0.5 ML/day) difficult to measure accurately without a v-notch weir. Surface water modelling undertaken by GHD (2021), indicates the control measure (i.e. continued delivery of supplementary flow to Reach 3 of Boundary Creek) is effective in increasing the flow at the Yeodene stream gauge especially during dry periods, however, was limited by the total volume of supplementary flow (500 mL/year) used for the modelling. Capping supplementary flow at 500 ML/year results in the hydrology success target being met for 90% of the modelled period of record, with streamflow falling below 0.5 ML/d for 10% of the time during dry periods. Therefore, although the success target aligns with the expected eco-hydrological changes, adjustments may be required to the management of barrier's and flows to maintain flows in order to meet the success target 100% of the time.

Monitoring of the hydrology success target, similar to the measurement of monitoring bores, can be managed on a continual and automated basis. With the addition of the two Big Swamp stream gauges (233275A and 233276A) in 2019, further monitoring to the Yeodene stream gauge can now be made and greater assessment of the water being lost to the swamp or gained via recharge to Boundary Creek. Therefore, no issues or gaps exist regarding the measurement of this success target.

From this assessment it is clear that other success targets occur concurrently, for example, the removal of vegetation such as *eucalypt* species has a positive impact on the swamp water consumption and therefore, the hydrology, with gains of water to the system expected possible as a result of *eucalypt* removal. Similarly, the trapping of water from hydraulic barriers on the swamp have a positive impact in reducing the exposure of ASS and thereby the acid generated within the swamp. With these observations noted, the following revisions to the hydrology success target is recommended:

- Revisit the success target based on continued monitoring data once other success targets have been realised

2.6.4 Eco-hydrology

As previously defined, the success targets relating to eco-hydrology are:

- No further encroachment of terrestrial woodland into the swamp plain
- No encroachment of Lowland Forest dominant species into areas of Damp Forest
- No loss of structural or floristic diversity along the main channel and western end of the swamp
- Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges

While the diagnosis of the ecological collapse at Big Swamp and the proposed remediation chain (Figure 5-1 in ELA 2019) is well described, and the current success targets are a broad elaboration of the long–term remediation goal for the swamp, there is a risk the current success targets will be difficult to achieve and/or interpret the effectiveness of control measures effect on reaching the target.

The introduction to the remediation strategy makes the point that wetlands are well known to be highly resilient and can quickly recover with the restoration of hydrological function (ELA, 2019). For instance, ephemeral wetlands on the Victorian Volcanic Plains long drained for pastoralism and cropping can recover reasonably quickly if a plug is put back in the bottom and sufficient inflows continue. As pointed out in the State and Transition model presented here the resilience of the system will very much depend on current state and context. Wetland vegetation in S2 is likely to rebound quickly once hydrology is restored whereas wetland vegetation in S3 may take much longer and require additional interventions.

a. Terrestrial vegetation encroachment halted or reversed (onto 'swamp plain' – Units 1 to 4);

This target explicitly relates to the invasion of plants into the 'swamp plain' from surrounding mostly terrestrial environments as a result of the combination of hydrological dysfunction and the peat fire. The most conspicuous example is the mass episodic regeneration of Swamp Gum triggered by a brief 'window' of ideal conditions; a coincidence of: (1) the drying out of the soil, (2) removal of above ground biomass and the creation of an ash bed, and (3) the onset of flooding rains during the 2010/2012 La Nina. This change was of course accompanied by a number of other significant shifts that has served to push much of the original wetland into a significantly poorer condition (S3 Homogenised/Simplified wetland; Figure 10) characterised by the loss of mesic specialists, and the invasion of exotic plants and other native generalists/ruderals such as Austral Bracken. Maturation of this post disturbance cohort of eucalypt regrowth will likely result in canopy closure, driving further decline in condition (e.g. complete loss of any residual mesic specialists). While it is unlikely further encroachment will happen (future fires notwithstanding), this rare event could nevertheless have a lasting impact on the swamp if not rectified with a number of interventions. Thus, it is critical this episodic cohort of Swamp Gum (and any other tree species) is removed to assist with transitioning.

This target is considered appropriate, as long as the following actions are implemented:

- Active removal of trees (mostly Swamp Gum regrowth) from across the 'swamp plain' (Units 1 to 4) (cutting, removal and poising as needs be) irrespective of rehydration extent, the coverage of large trees across the site should be close to zero as possible. It is important to note that mass tree recruitment was linked to conditions immediately following fire (ash bed and generally dry soil surface), this is unlikely to happen again on any significant scale as long as soils not exposed.

b. No encroachment of Lowland Forest dominant species into areas of Damp Forest;

To the extent that the drying of the swamp and fire encroached into areas of fringing damp vegetation (Unit 6), there has also likely been a similar mass (albeit) patchy recruitment of Swamp Gum (and possibly other eucalypts) in this vegetation unit, that similarly could have the effect of driving canopy closure. The canopy thickening process could also serve to drive further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance).

This target is considered appropriate, as long as the following actions are implemented:

- Active monitoring of canopy cover and as required thinning of trees from Unit 6 (Damp margins Woodland/Forest with mostly Swamp Gum regrowth) to encourage understorey recovery and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery, maintaining percent cover of canopy at 10 to 30%).

c. No loss of structural or floristic diversity along the main channel and western end of the swamp;

To the extent that the drying of the swamp and fire has also encroached into areas of fringing Drainage line Woodland vegetation (Unit 5), it is possible there have also been impacts of 'canopy thickening' and a drying out of the wettest sections that support some mesic specialists – driving further decline in the state of this vegetation unit (at least those sections directly impacted by the fire and associated soil disturbance). Consequently, it is recommended canopy cover be monitored in these areas and where applicable canopy thinning be undertaken in a similar fashion to above AND also that those mesic specialists present in the wettest sections be monitored and a suitable remedial response implemented if declines detected.

This target is considered appropriate, as long as the following actions are implemented:

- Active monitoring of canopy cover and as required thinning of trees from Unit 5 (Drainage line Woodland with mostly Swamp Gum regrowth) to maintain understorey condition and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery, maintain %cover of canopy at 10 to 30%.
- Maintenance of adequate flows along the main channel currently supporting Unit 5 (Drainage line Woodland)
- Monitor the diversity and abundance of mesic specialist species in Unit 5 (e.g. Blechnum nudum, Todea Barbara, Carex fascicularis, Melaleuca squarrosa, Lobelia beaugleholei) and consider active recovery works if local populations are threatened. Other rare mesic specialist species within this system that could be considered for monitoring and active recovery works include: Cardamine tenuifolia, Eucalyptus brookeriana.
- If populations of the remaining rare or threatened species (Monotoca glauca, Bossiaea cordigera, Pterostylis lustra) recorded in similar habitat nearby are found within the swamp and associated section of Boundary Creek, these too could be considered for monitoring and active recovery works as appropriate.

d. Increased diversity of understorey species within the swamp plain, with a focus on ferns and sedges;

A staged functional progression in the condition of the swamp is proposed to facilitate the transition from S3 to S4 and ultimately someway back towards S1. As illustrated by the comparison between the putative 1982 benchmark water table and that under the remediation scenario (wettest year) (Figure 9 and Figure 18) the pattern of a future repaired wetland will differ from the original condition.

This target is considered appropriate, if the following monitoring and recommended actions are implemented;

- Firstly, it must be demonstrated with field observations that the construction of the weirs actually results in surface and groundwater conditions modelled. Rehydration of the soil profile across as much of the original swamp (Units 1 to 4) is possible using bunds/weirs to reinstate a water regime at the land surface and in the soil profile (root zone) that is consistent with that for 'Riparian Fern Scrub' (where rehydration involves waterlogging with fresh water for at least > 6 months and duration of inundation up to 6 months and water depth is very shallow <30 cm; Frood and Papas 2016). The rehydration extent should be at least ~50% as per Table 4 and Figure 10; Area of modelled GW within 0.1m leads to actual soil saturation based on field monitoring).
- Secondly, the ground level micro-environment will need to be suitable for allowing seed/propagule dispersal and recruitment of mesic specialists. Cut and remove shading trees and taller invasive shrubs possibly also slash bracken and dense lower vegetation to provide recruitment space and opportunity;
- And thirdly, there should be monitoring in pace to determine the level of the swamp species recruitment (both diversity and cover/abundance). If recruitment isn't occurring within a reasonable time frame, then a process of reintroduction should be commenced (again subject to success around the first two steps) – which in turn should be monitored to ensure success. At least within the rehydrated zones, active regeneration of as many mesic specialists, in as many of the most diverse lifeforms – Forbs, Ground/Tree Ferns, Aquatic Herbs, Rushes and Sedge) as possible, along with active reduction/removal of weeds and other native ruderals (including trees like Swamp Gum).

Section 3 Recommendations

3.1 Success Targets

To assist in increasing the conceptual understanding of Big Swamp and allow for the effective implementation and measurement of the success targets, the following recommendations have been made and are presented in Table 12.

Table 12 Recommended success targets and further work

Functional Group	Current success target	Recommended success target	Further Work Required
Lower Tertiary Aquifer	Recovery trend for groundwater levels in the LTA	Recovery of regional LTA hydraulic heads such that vertical hydraulic gradients between LTA and overlying HSUs reach stable hydraulic gradients (i.e. at nested observation bores to be identified) Recovering LTA hydraulic heads in vicinity of Big Swamp (i.e. BH01-PB, TB1c, 109113, 109132, 109131) to be higher and remain higher than the surface elevation of the swamp within 10 years. LTA bores immediately to the west of the swamp (109113, 109132, 109131) to have hydraulic heads greater than 150 mts (elevation of western edge of the swamp) and LTA bore TB1c, greater than 143 mts (elevation of the eastern edge of the swamp)	Continued monitoring of hydraulic heads to confirm recovering hydraulic head trends Identify locations of nested monitoring bores for comparison of vertical hydraulic gradients between LTA and overlying HSUs (at varying distances from the borefield to show spatial distribution of relative vertical hydraulic gradient stabilisation).
			Continued monitoring of LTA hydraulic heads further develop understanding of relationships between LTA, shallow groundwater systems and environmental values Detailed groundwater mass balance and revision of hydrogeological conceptualization of Big Swamp using multiple lines of evidence (i.e. first principles) to better establish context for role of LTA in supporting the shallow groundwater system and alluvial success targets, analysis may include: Comparison of LTA hydraulic heads in the vicinity of Big Swamp with shallower HSUs to better establish the 3-dimensional relationships between LTA recovery and the shallow groundwater system Evaluation of Boundary Creek losses (Reach 2) using multiple approaches to constrain differencing error between flow gauges (e.g. seasonal differential flow gauging with ~250 m spacing & development of flownets comparing LTA heads to creek stage) to better characterize the role of recovering LTA hydraulic heads on Boundary Creek flow into Big Swamp Development of multiple hydrostratigraphic cross-sections to represent spatial and temporal variability of shallow groundwater system
Quaternary Aquifer	Maintain monitoring bore water levels at individual bores above target water levels	No Change	Undergo analysis of geology at individual bores to determine the individual bore response to inundation and possible reconfiguration of the hydraulic barriers to increase the water level within BH18.
Ecohydrology	No further encroachment of terrestrial woodland into the swamp plain		**Establishment of new base of no mature terrestrial vegetation** Active removal of trees (mostly Swamp Gum regrowth) from across the 'swamp plain' (Units 1 to 4) (cutting, removal and poising as needs be) irrespective of rehydration extent (metric = cover of trees on swamp should be zero); Also mass tree recruitment likely episodic linked to conditions immediately following fire (ash bed and generally dry soil surface) – this is unlikely to happen again on any significant scale as long as soils not exposed.
			Establishment of hydrated swamp deposits Prevention of further encroachment by re hydrating the swamp, reducing the surface environmental suitability for woodland species encroachment
	No encroachment of Lowland Forest dominant species into areas of Damp Forest		**No encroachment of Lowland Forest dominant species into areas of Damp Forest through active monitoring of canopy cover and thinning of trees from Unit 6 as required** Active monitoring of canopy cover and as required thinning of trees from Unit 6 (Damp margins Woodland/Forest with mostly Swamp Gum regrowth) to encourage understorey recovery and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery (metric = maintain %cover of canopy at 10 to 30%)
			Establishment of suitable canopy cover and maintain suitable micro conditions
	No loss of structural or floristic diversity along the main channel and western end of the swamp		**Establishment of suitable canopy cover (monitoring of canopy cover and thinning of trees from Unit 5 as required** Active monitoring of canopy cover and as required thinning of trees from Unit 5 (Drainage line Woodland with mostly Swamp Gum regrowth) to maintain understorey condition and control key weeds such as Fog grass and Blackberries as required to facilitate this recovery (metric = maintain %cover of canopy at 10 to 30%)
			Maintenance of adequate flows currently supporting Unit 5 Maintenance of adequate flows along the main channel currently supporting Unit 5 (Drainage line Woodland) (define levels?? metric = Say 2 to 20 ML/Day)

Functional Group	Current success target	Recommended success target	Further Work Required
			Maintain the diversity and abundance of mesic specialist species in Unit 5 Monitor the diversity and abundance of mesic specialist species in Unit 5 (e.g. Blechnum nudum, Todea Barbara, Carex fascicularis, Melaleuca squarrosa, Lobelia beaugleholei) and consider active recovery works if local populations are threatened. Other rare mesic specialist species within this system that could be considered for monitoring and active recovery works include: Cardamine tenuifolia, Eucalyptus brookeriana. If populations of the remaining rare or threatened species (Monotoca glauca, Bossiaea cordigera, Pterostylis lustra) recorded in similar habitat nearby are found within the swamp and associated section of Boundary Creek, these too could be considered for monitoring and active recovery works as appropriate.
	Increase diversity of understory species within the swamp plain, with a focus on ferns and sedges		**Rehydration of the soil profile to reinstate water regime suitably consistent with needs of 'Riparian Fern Scrub' (after Frood and Papas 2016) – rehydration extent at least ~54% as per Table 4; Figure 10** Rehydration of the soil profile across as much of the original swamp (Units 1 to 4) is possible using strategically placed bunds/weirs to reinstate a water regime at the land surface and in the soil profile that is consistent with that for 'Riparian Fern Scrub' (where rehydration involves waterlogging with fresh water for at least > 6 months and duration of inundation up to 6 months and water depth is very shallow <30 cm; Frood and Papas 2016) (metric – rehydration extent at least ~50% as per Table 4; Figure 10; Area of modelled GW within 0.1m leads to actual soil saturation based on field monitoring).
			Manage micro-environment through removal of regrowth trees / larger shrubs and dense lower vegetation to provide recruitment space and opportunity, no soil disturbance Micro-environment: shading from trees and taller invasive shrubs; cut and remove regrowth trees (and larger shrubs); possibly also slash bracken and dense lower vegetation to provide recruitment space and opportunity.
			Active regeneration of mesic specialists within rehydrated zones to achieve combined cover of >50% At least within the rehydrated zones, active regeneration of as many mesic specialists (in as many of the most diverse lifeforms – Forbs, Ground/Tree Ferns, Aquatic Herbs, Rushes and Sedges) as possible (metric = diversity of mesic specialists lifeforms and species) aiming for a combined cover of >50% (metric = combined cover of mesic specialist lifeforms and species) and active reduction/removal of weeds and other native ruderals (including trees like Swamp Gum). If natural regeneration of at least some species in each lifeform category do not spontaneously regenerate, then measures should be taken to actively reintroduce them.
Hydrology	At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years	At least 0.5 ML/day flow maintained at Boundary Creek and Yeodene stream gauge maintained for a period of 2 years 90% of the time	Revisit the success target based on continued monitoring data once other success targets have been realised
Hydrochemistry	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	Annual median pH equal to or greater than 6.5* at Boundary Creek (stream gauge 233228) and Yeodene stream gauge maintained for a period of 2 years	Revisit the success target based on continued monitoring data once other success targets have been realised

3.2 Additional works

Monitoring and Evaluation Vegetation

The proposed success targets for vegetation are aligned with the predicted area of groundwater depth <50 cm, and how relevant species and inundation occurs within that zone (Figure 18). Monitoring transects need to be aligned with the zones of future depth to water table, as well as to transitional zones between existing vegetation units. It is recommended that a review of current location of transects occur to identify the most suitable locations that cover the areas where expected hydrological and species change coincide. In addition, it is possible to calibrate high resolution remote sensing data (i.e Sentinel 2, 5 metre resolution) to the current vegetation units (using field based transects), and use the time series capacity (every 5 days) to spatial map changes in eco-hydrogeological zones. The advantage of the remote sensing approach is that it provides a very efficient (time and cost) way of providing a time series measure of the success targets, that can be supported by annual field-based assessments. The outcome would be a direct linkage between changes in vegetation and changes in the sub soil saturation.

Monitoring and Evaluation Soil Saturation and soil carbon

The assessment of the eco-hydrogeology of the swamp has identified that a critical component of successful remediation is the establishment of a suitable root zone hydrology and soil characteristics. There is a lack of data that informs on the saturation of the surface soil of the wetland and how this may act to provide a suitable root zone environment for the establishment of mesic specialists. If a suitable root zone is not developed through the remediation actions, then success targets pertaining to specific vegetation may not occur, irrespective of all other success targets.

Consideration should be given to proposing a new success targets focused on

- Root zone conditions. It is fundamentally associated with the realisation of the modelled future depth water table and extent of surface inundation, as this process equates to a saturated root zone. What is unclear is how effective the modelled shallow water table zones, groundwater <50cm (Figure 18) are at saturating the root zone.
- Soil carbon accumulation. A feature of the pre-impacted swamp and a necessary requirement of the root zone environment for swamps species is a top soil that is high in organic matter (as opposed to surface organic trash). This organic matter is a component of peaty wetland soil structure and water holding capacity that especially mesic species require. As discussed, the fire event would have burnt and or removed this organic material, it is anticipated that the re hydration and establishment of preferred wetland species will to some degree begin the accumulation process of carbon.

A combination of hand-held EM surveys, site observations, soil sampling along set transect and/or remote sensing data to monitor soil saturation and soil carbon could be used to confirm soil saturation is occurring and that soil carbon is being accumulated. This data would also be effective in a semi calibration assessment of the model predictions.

Macro-invertebrate Success Target.

A measurable component of the health of a swamp are macroinvertebrates. However, it is understood that no baseline data for the swamp exist, with the possible exception of upstream and downstream monitoring, to evaluate the current condition and trajectory of the species.

It would be possible through literature review and or sampling similar swamps to determine a baseline species list and abundance, in line with the expected hydrology and vegetation of the swamp. Sampling bi-annually within the swamp could provide data on how effective remediation efforts are in enabling macro-invertebrate population to re-establish towards a defined local baseline.

It is therefore recommended that consideration be given to performing baseline studies to establish an expected trajectory of macro-invertebrates. Once this is established, metrics against species and abundance could be derived and used to set a Success Target.

Boundary Creek downstream of Big Swamp

It is acknowledged that the impact of groundwater pumping, millennium drought and acidification of the swamp will have had a negative impact on the values within the water way of Reach 2 of Boundary Creek. While no specific success targets for values within Boundary Creek are currently specified, existing success targets regarding the LTA, alluvial aquifer, pH and flows in Boundary Creek at the Yeodene gauge provide some measure of support for the values in the creek.

Site specific success targets for the creek at this stage are considered problematic, as the current condition of the creek is subject stressors that are not associated with the management of the swamp and the aquifers, for example, grazing, pugging and pollution from stock. Unless theses stressors are controlled and or managed, proposed actions or success targets will be difficult to achieve.

It is recommended that a waterway management plan is developed for the creek (noting this is outside the scope of this report) that aims to in general boost the resilience of the creek's values, by controlling erosion, stock access and weeds. Once this is in place, consideration can be given to whether additional onsite actions and or management is required and or appropriate.

Data collation and analyses

In addition to the recommendations that are related to specific targets, the ongoing monitoring and evaluation requires the development of two specific pieces of work. One is in regards to the water balance in the swamp and the second is in regards to effectively assessing the monitoring data and how these data relate to achieving the success targets. The works are:

1. Development of a wetland water budget. This will involve estimates of groundwater evapotranspiration, rainfall recharge, hyporheic exchange (i.e. bank storage scale), vertical and horizontal fluxes in/out of Big Swamp. This will provide an ongoing monitoring tool to assess the achievement of the success target. The water budget should be temporally developed in a format such that as new data is collected the overall shift in water in, outs and consumption within the wetland is determined at least bi-annual scale.
2. In addition, a graphical interface could be developed that shows the current tracking of success targets spatially and through time. This interface provides a single portal by which Barwon Water are able to review and present the outcomes of future monitoring of success targets. The interface may also provide a report card style assessment of how well success targets are tracking, providing a high-level risk appraisal regarding Barwon Waters requirements.

Section 4 References

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Casanova M.T. and Casanova A.J. 2016. Current and Future Risks of Cropping Wetlands in Victoria: Technical Report. Charophyte Services, DELWP.

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Jacobs (2018a). Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts. Prepared for Barwon Water. Project IS191000. Revision: Final, 22 August 2018.

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Theis CV (1940). The source of water derived from wells – Essential factors controlling the response of an aquifer to development, Civil Engineering, Vol. 10, 277-280

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Appendix A Hydrographs of alluvial sediments (2019-2021)

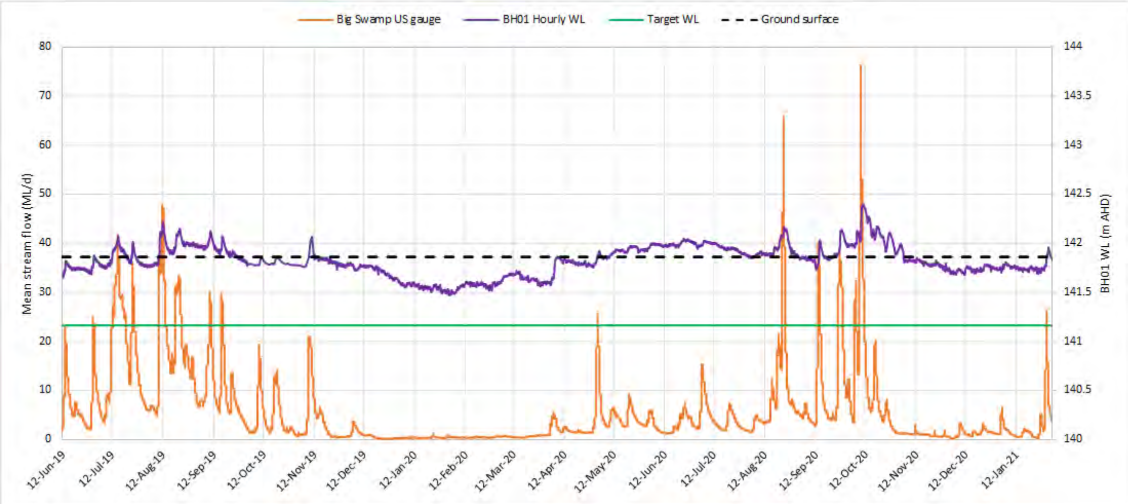

Figure A-1 BH-1 hydrograph vs streamflow

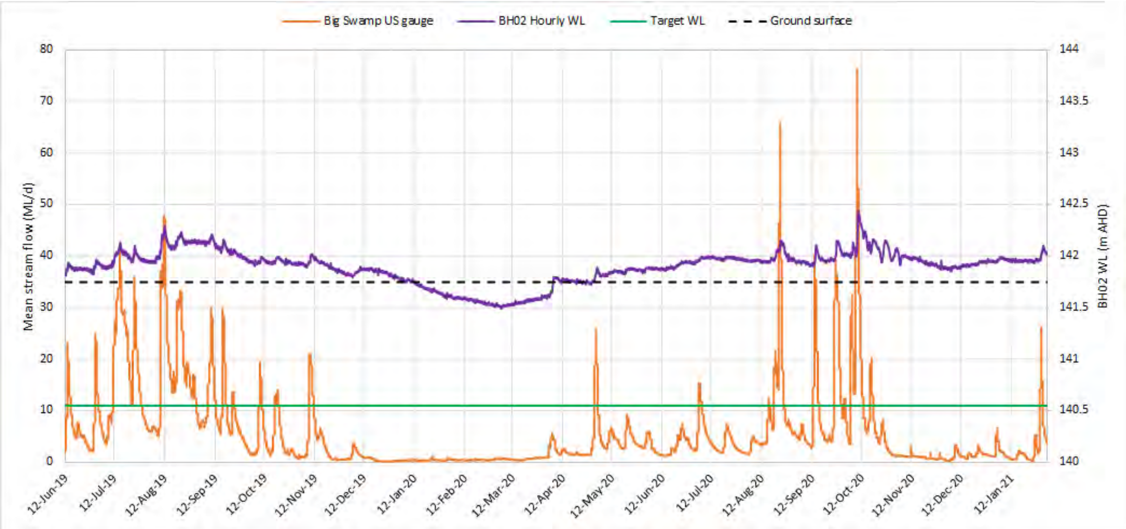

Figure A-2 BH-2 hydrograph vs streamflow

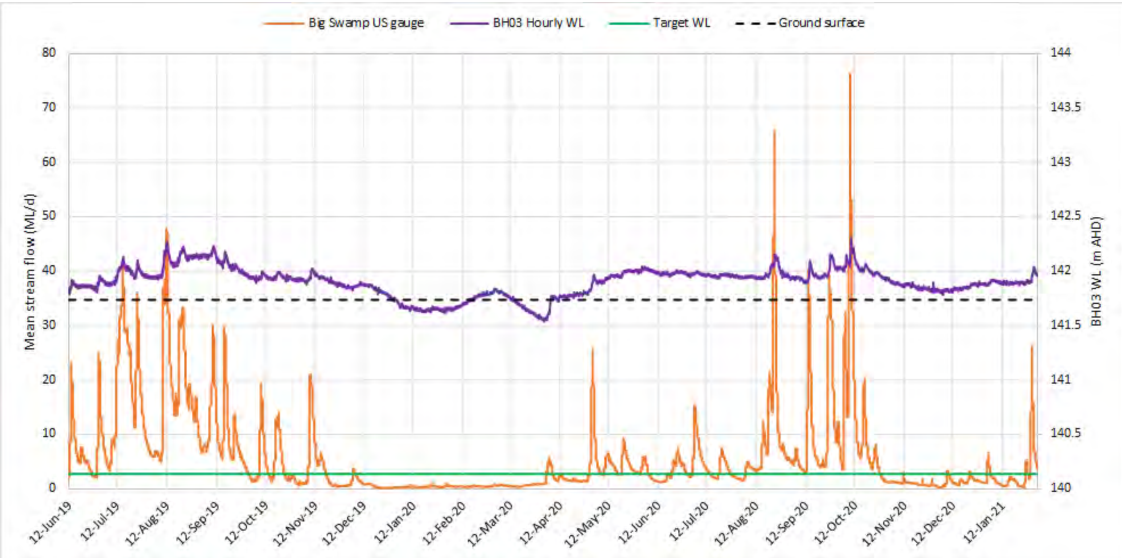

Figure A-3 BH-3 hydrograph vs streamflow

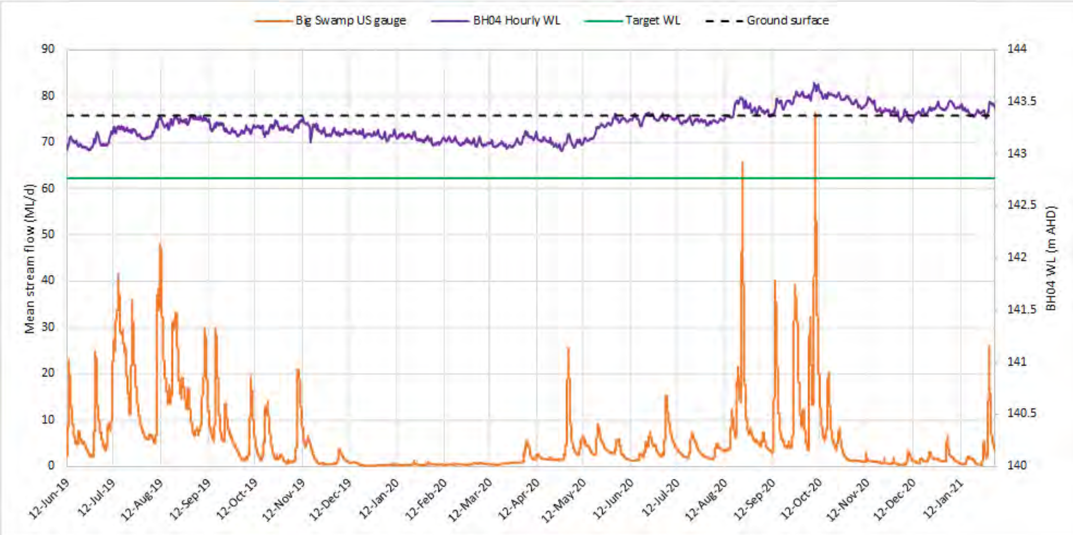

Figure A-4 BH-4 hydrograph vs streamflow

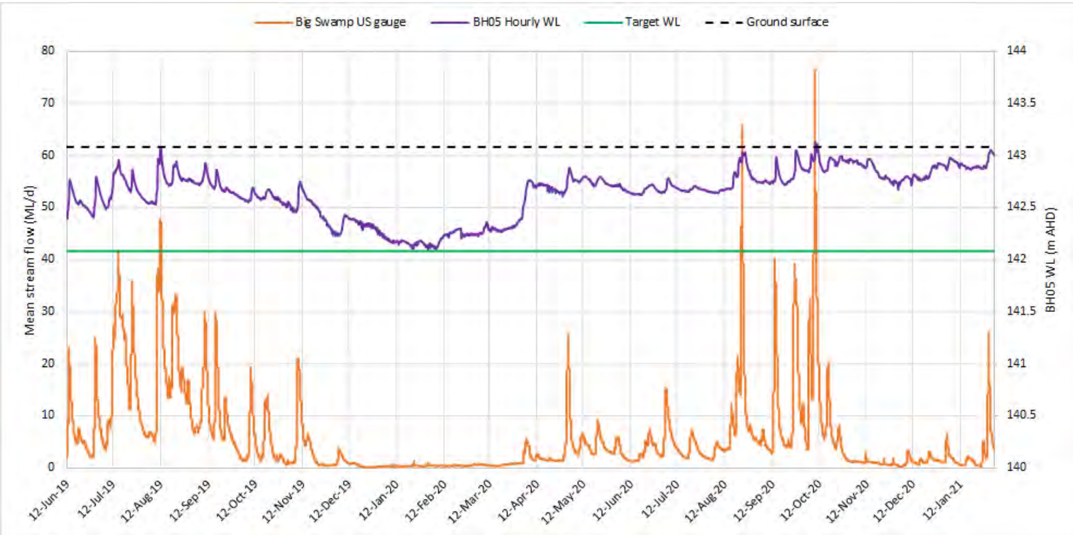

Figure A-5 BH-5 hydrograph vs streamflow

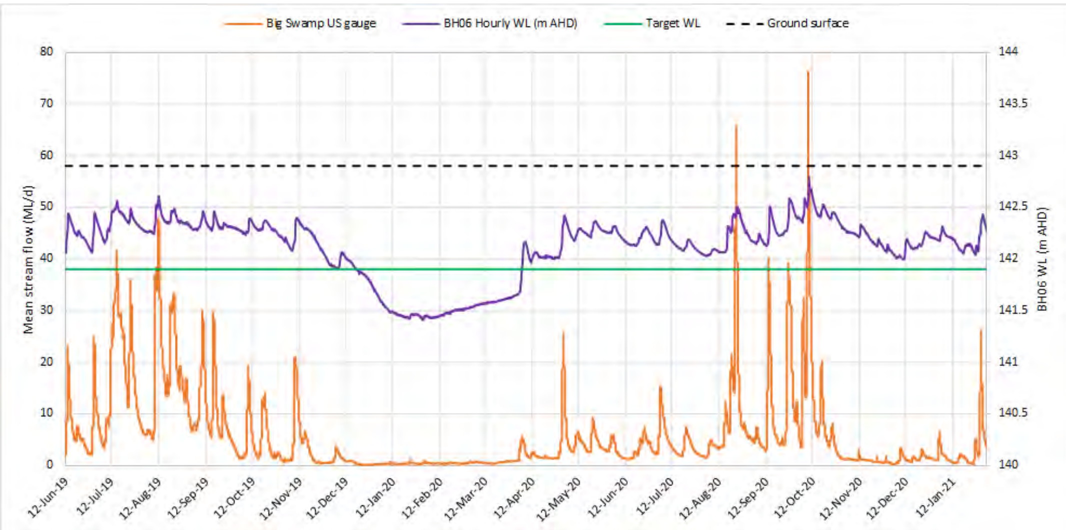

Figure A-6 BH-6 hydrograph vs streamflow

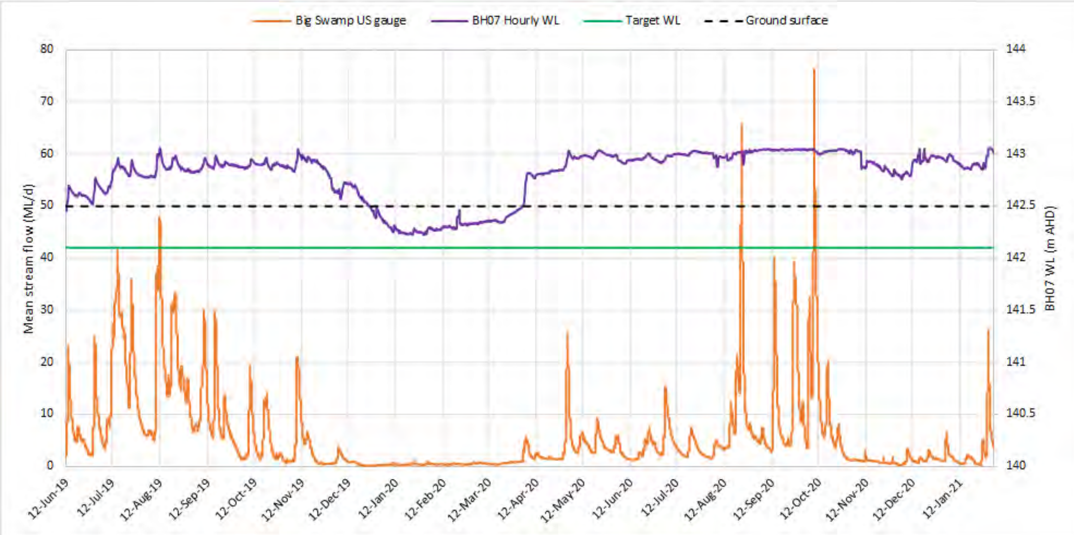

Figure A-7 BH-7 hydrograph vs streamflow

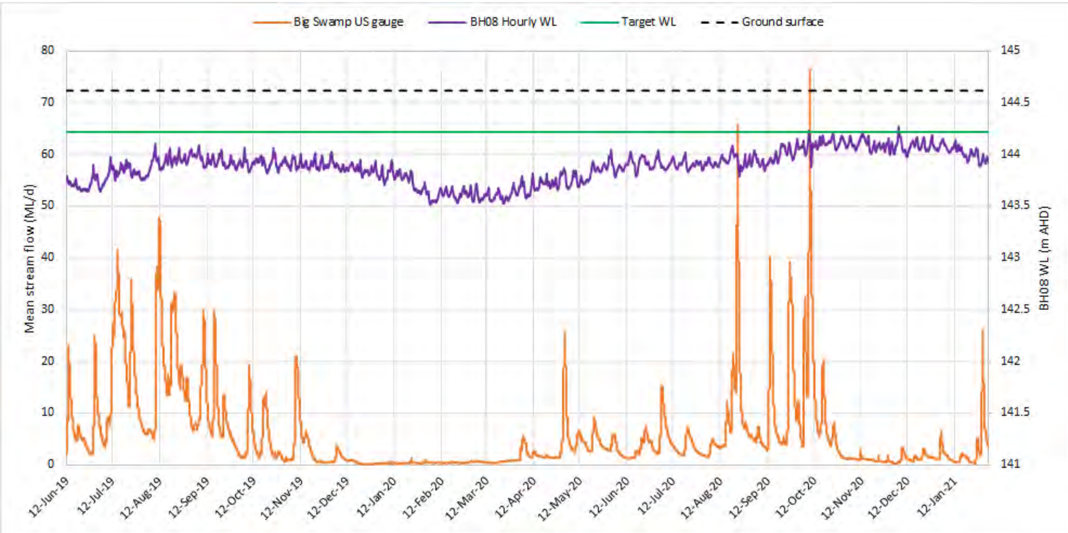

Figure A-8 BH-8 hydrograph vs streamflow

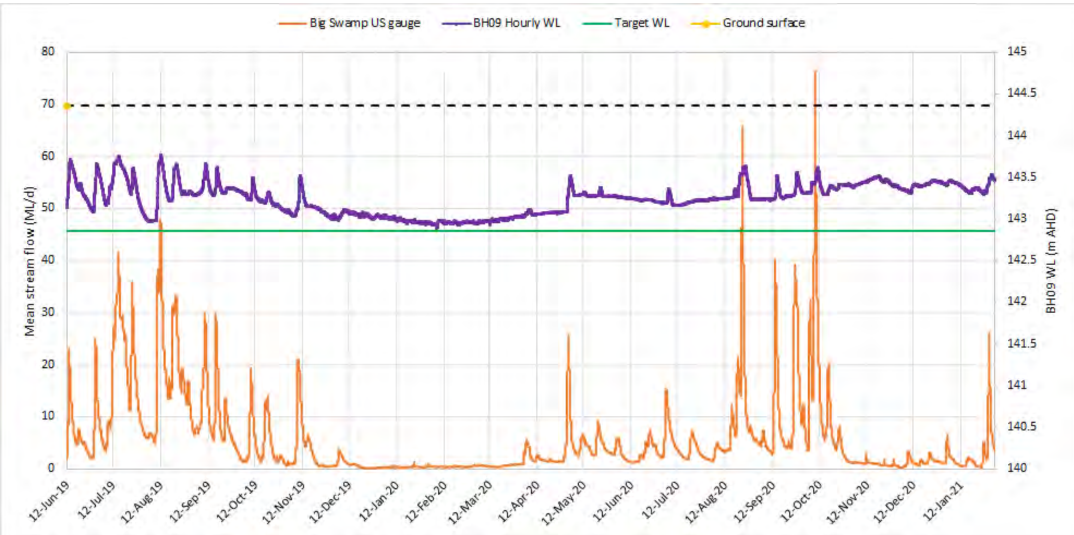

Figure A-9 BH-9 hydrograph vs streamflow

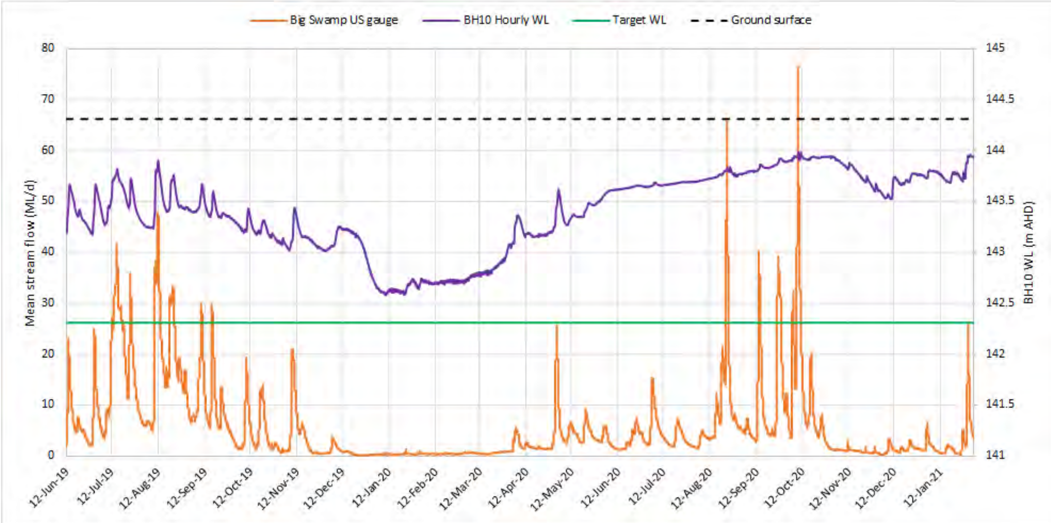

Figure A-10 BH-10 hydrograph vs streamflow

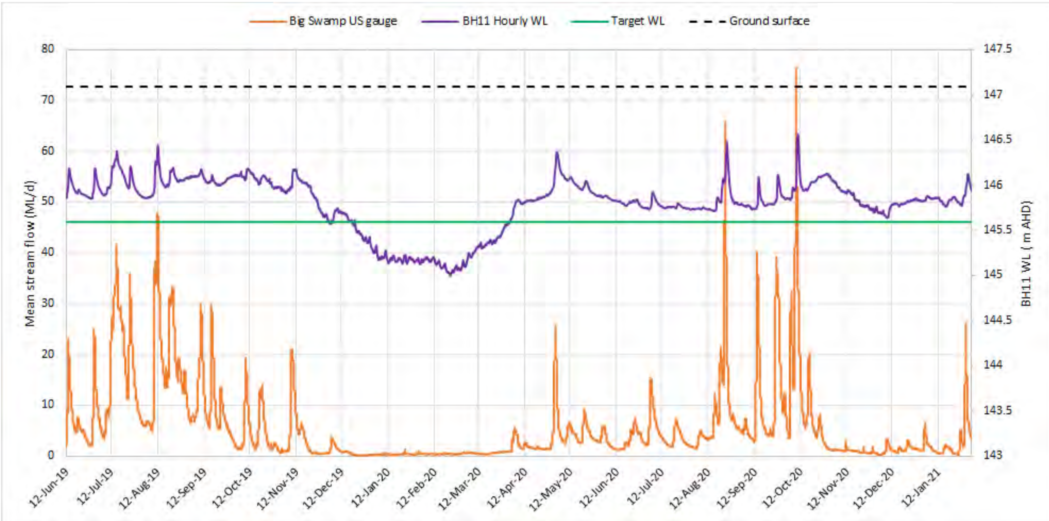

Figure A-11 BH-11 hydrograph vs streamflow

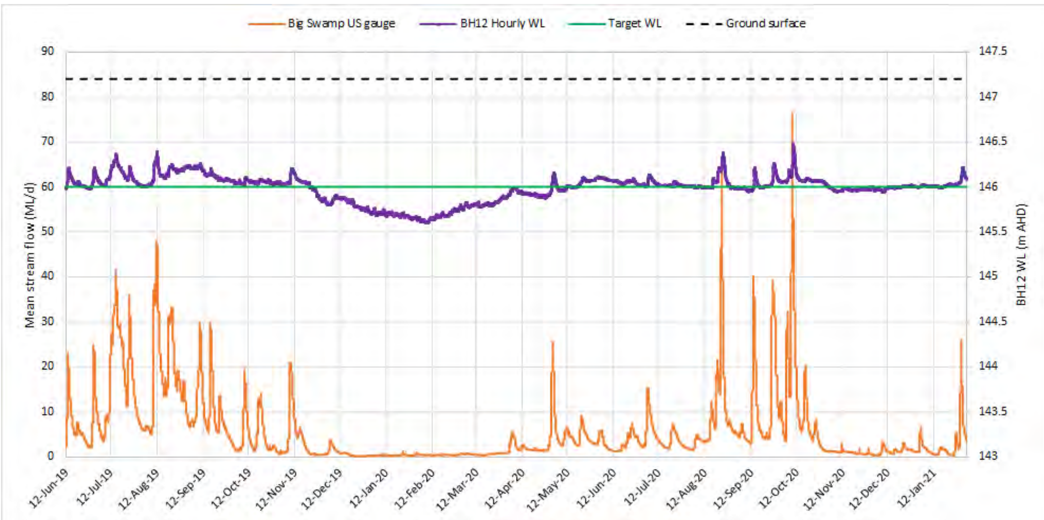

Figure A-12 BH-12 hydrograph vs streamflow

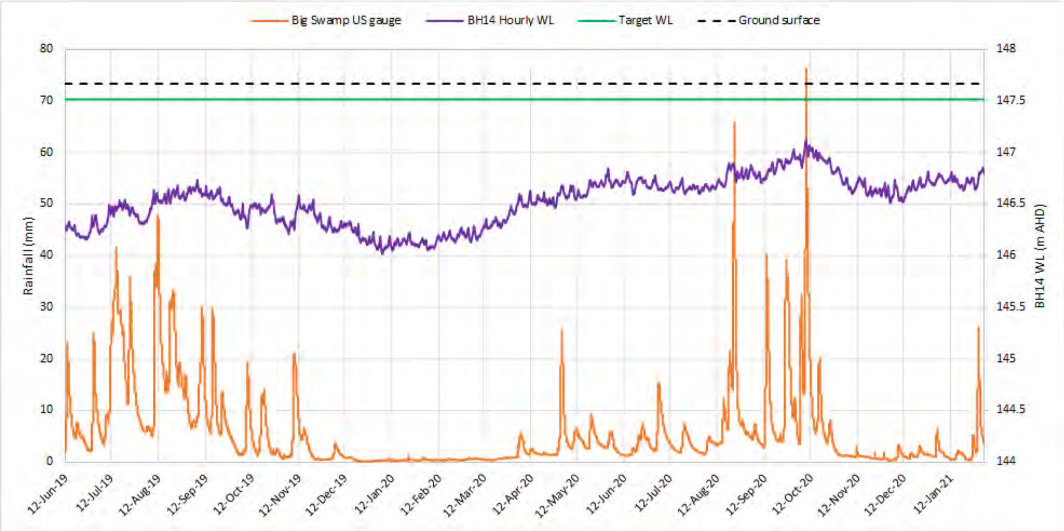

Figure A-13 BH-14 hydrograph vs streamflow

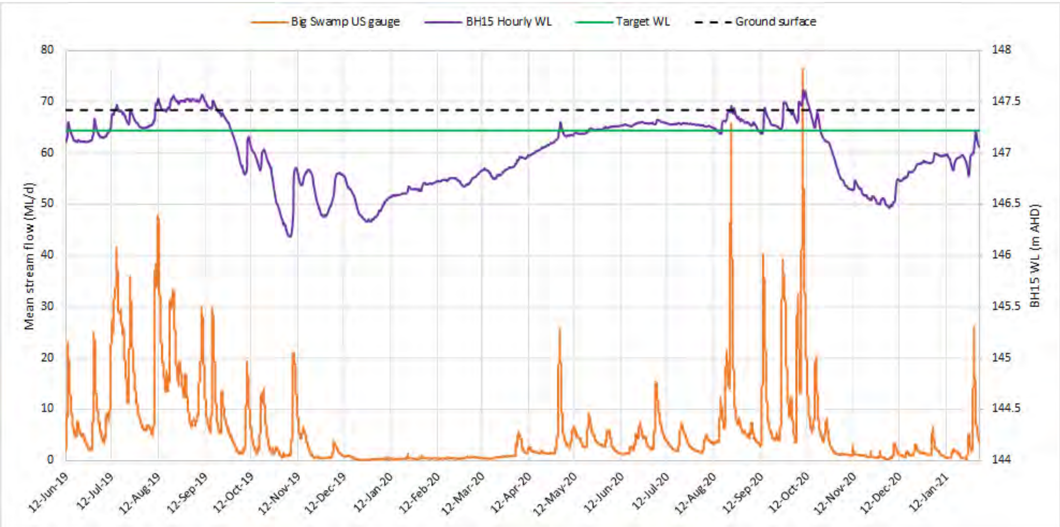

Figure A-14 BH-15 hydrograph vs streamflow

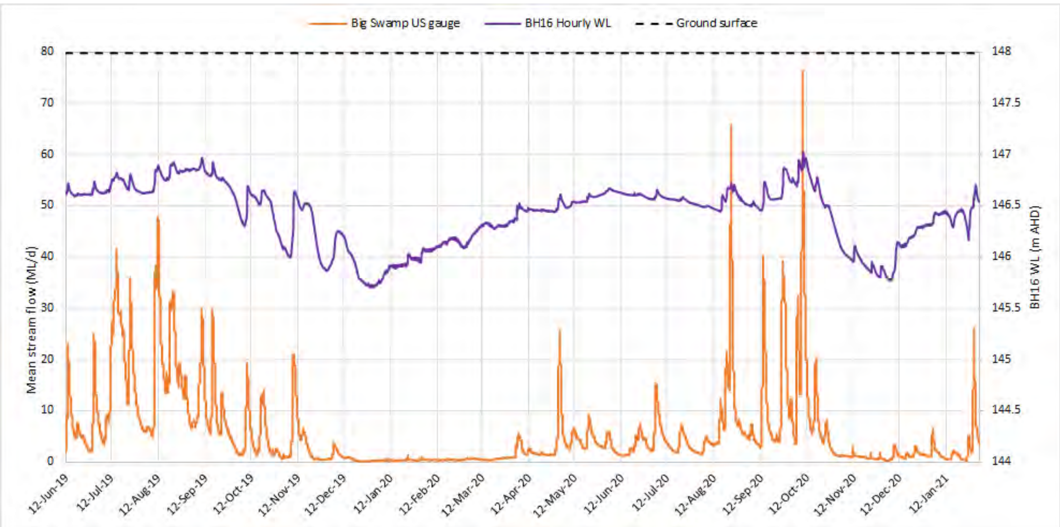

Figure A-15 BH-16 hydrograph vs streamflow

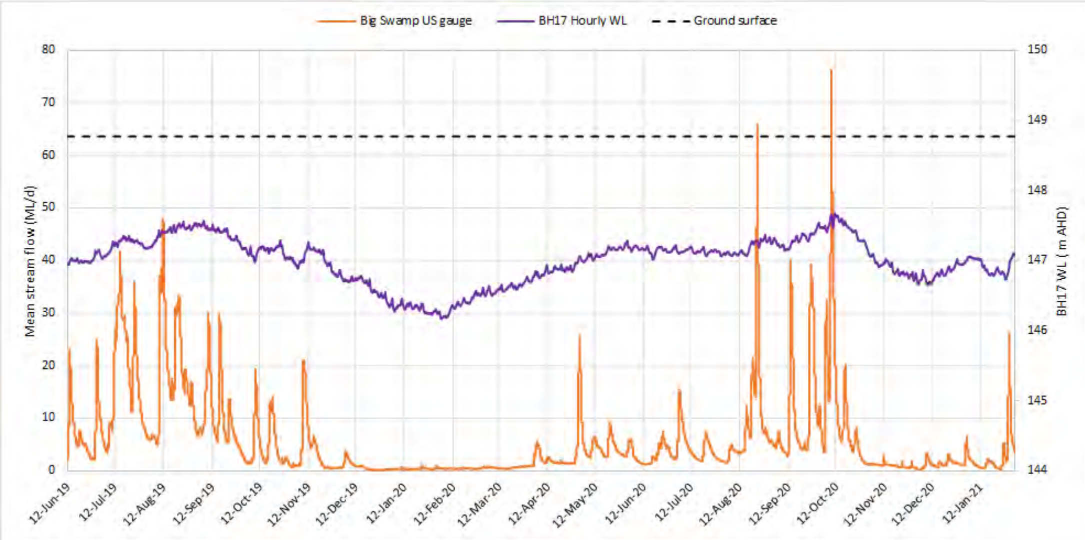

Figure A-16 BH-17 hydrograph vs streamflow

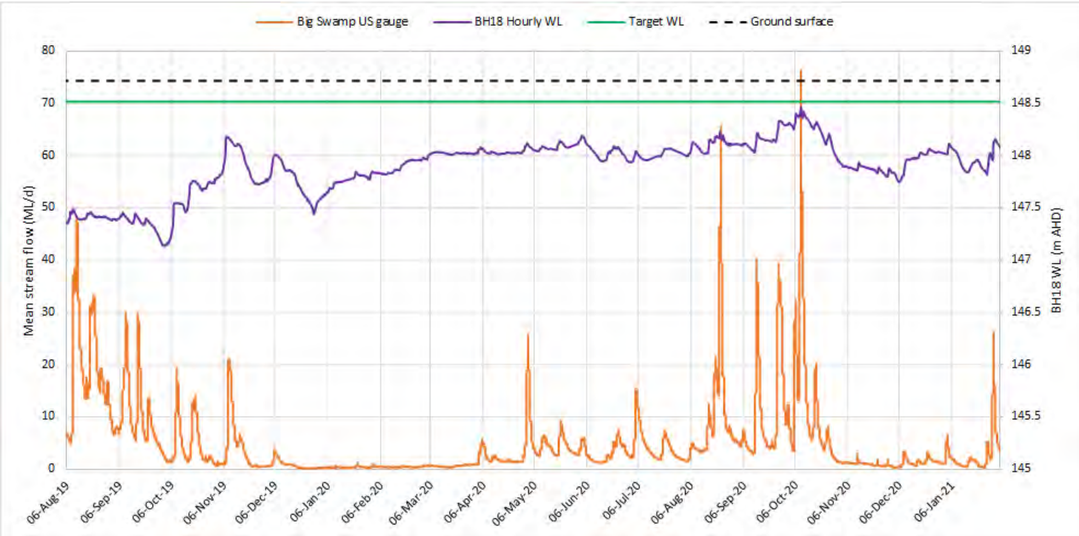

Figure A-17 BH-18 hydrograph vs streamflow

Appendix B Comment response table

<table>
<tr><td>ITRP Comment</td><td>Response</td><td>Relevant section</td></tr>
<tr><td>1a. The ITRP expect, and we believe there is a community expectation, that the endpoint of improvements will be a system that does resemble to some degree the pre-extraction state, at least in terms of its ecosystem function, although we concur that the ‘original state’ is unlikely to be achieved, given the post-colonisation environmental history and changing climates. Elsewhere in the REPP the more appropriate wording '...this is likely to be different to the original condition...' is used and that is recommended as a replacement to phrases using 'resemble' throughout the report.</td><td>The CDM report focuses on providing context that the re hydration of the swamp will provide a suitable environment for wetland assemblages that will resemble a functioning peaty wetland.</td><td>Section 2</td></tr>
<tr><td>1b. Best practice in restoration or remediation would include the concept of returning ecological functions to the system, not just assets (species or habitats) or the previous condition. The remediation and environmental protection plan is largely focused on a recovery of the system based on the improved ecological condition. Even then, there is very little definition of what aspects of condition were being sought, apart from references to the SEPP benchmarks.</td><td>The report has attempted to present more detail around what ecological condition represents. The expected end points of the remediation are contained with targets and actions that include.
Aim to re-instate groundwater pressures and levels for both the LTA and alluvium systems
Aim to re hydrate the swamp, through controlled inundation enabling groundwater levels to rise, saturating sediments and creating shallow inundation.
From the outputs of the gw/sw modelling the extent of likely vegetation units are proposed. Within each of these units’ specific species and recommendation are provided to assist recolonisation.
Recommendations and descriptions are provided around the importance of establishing suitable soil hydrology conditions, micro-climate requirements (sun light, organic matter) and depth and period of surface water inundation
All of these aspects are components of the condition of the wetland, and are focused on ecological functions that drive a resilient wetland system.</td><td></td></tr>
</table>

2a. unless the chosen 'relevant environmental quality indicators' in the SEPP are specified and the 'substantial and quantifiable impact' on each of these indicators is specified, the definition of "environmentally significant impact" remains vague. How do these (chosen indicators) relate to the success targets for remediation of Boundary Creek and Big Swamp listed in Table 6 (Items 7, 20 & 23)? Only one (the pH) refers to the SEPP. And how do they relate to the risk assessment in Section 5.3 (Item 31)? To be consistent with Principle 3, the Surrounding Environment Investigation should consider both High Value GDEs and the SEPP environmental quality indicators.	NA – This relates to the surrounding environment investigation and determining the environmental significance of impacts, as opposed to monitoring success of remediation and was therefore considered out of scope	
2c. The detail for the macroinvertebrate monitoring proposed is lacking within the REPP, and the frequency proposed, of every two years, is too infrequent. Standard best practice would have samples taken in spring and autumn each year (as a minimum) and possibly quarterly. The frequency of sampling is especially important as they remediation period is said to be 2 years (Section 5.2.4 Table 6 Page 47 & 48), so only monitoring every two years cannot actually detect the changes expected, and will likely miss seasonal variations, and it will not monitor the trajectory of improvement (or lack of improvement).	We acknowledge that at this stage, no direct monitoring macroinvertebrates within the swamp is occurring. In light of this we have added recommendations pertaining to the development of a baseline regarding macroinvertebrate species and abundance. Once the baseline is established, if appropriate, specific success targets can be developed.	Section 3

2d. There is a restricted list of environmental quality indicators in the SEPP which lists only WQ and macroinvertebrates. So, if the REPP just uses these environmental quality indicators, then the monitoring and assessment will be narrow and inadequate. However, in the actual implementation of the SEPP, there is call for a regional target setting process where environmental quality indicators are chosen for specific catchments, based on the issues for that catchment. In the Interim Regional Target Setting Project (Lloyd et al 2019), the identified environmental quality indicators of fish, flow regimes and macroinvertebrates, and in some systems (like this one) vegetation (including EVC mapping), should be included	CDM acknowledges that there are numerous metrics that can be used as indicators of environmental impact and condition. The outcome of the report is to increase the indicators to include; • Macroinvertebrates • Soil hydrology • Soil Carbon • Specific vegetation species • Flow regimes • pH In light of the actions providing in the report to ensure a positive trajectory of indicators that are related to success targets these are considered an appropriate coverage of indicators In relation to specific water quality parameters (i.e. DO) these are dependent in part on the ongoing modelling and understanding of the geochemistry of the swamp, and will also likely shift as the swamp transitions from a modified territorialised eucalypt dominated wetland, to a semi inundated mesic dominated wetland. Therefore, at this stage they are not considered completely appropriate until knowledge regarding the geochemistry and final implementation of remediation actions are undertaken. In addition, it is anticipated that the surrounding environment report will provide more context regarding catchment wide indicators that may be integrated into the remediation program at a later stage.	
4. Items 7, 20 & 23 Success Targets: The recommended SMART updates are missing from the proposed changes, and Table 6 of the REPP warrants refinement, including on specific targets and timing, as recommended in the ITRP review of February 2020. For example, the first success target of 'recovery trend for groundwater levels in the LTA' has already been achieved because levels are recovering, and yet success is indicated as well into the future.	More detail is provided around the definition of success for the LTA, both within the regional aquifer component and new success targets that are specific around the interaction of the LTA and the swamp.	Section 2.6 and 3

5a. the linear extrapolation of recovering groundwater levels at bore 109128 (REPP Figure 56, see below) at a relatively flat rate is not consistent with records of previous recovery around 1990 and 2002, nor the modelling.	Na	
5b. recovery predictions should be made using the regional groundwater model, and preferably at a bore with good calibration performance; however, bore 109128 was not assessed for calibration performance, and the nearby bore that was used for both calibration and recovery predictions is 109130 (Jacobs 2018, Figure 6.5; see below); but the model performance at this bore is poor, with Jacobs (2018) admitting that it 'under-predicts drawdown and recovery' by about 5m; bore 109129 is also close to bore 109128 and near 109130, but it is suitable as it shows good model performance.	Na	
5c. It is recommended that bores 109129 should be used to more reliably predict the trajectory for recovery of the unconfined LTA, until an improved model is developed and reliable recovery simulation results become available. Other review advice on the ongoing modelling task was provided to SRW by the ITRP in a document dated 18 December 2020.ITRP response to REPP revision (2020) 5/5	This bore is now part of the Success Targets for the LTA	Section 3.1

Additional feedback Item 7: Success Targets. As stated in the previous ITRP and SRW feedback and listed in the revised REPP (27 February 2020 amended version, feedback items 20 to 23) success targets need to be measurable, explicit, consistent and transparent. They should include additional targets such as water quality (using agreed EPA/DELWP regional targets), including pH, salinity, nutrients, DO and toxicants (key metals) and ecological targets (key vegetation species and EVCs, fish, invertebrates – specific targets to be developed). These would arise out of a vision for the remediation plan, and what is known to exist in the region, and those factors, species or communities, which are critical at structuring the ecological communities. The success targets need to be spatially referenced as well as these might apply to the Swamp, Boundary Creek, Barwon River and surrounding environments (which are dependent upon the aquifer).	As per above statements	