Surrounding Environment Investigation Report

Remediation and Environmental Protection Plan (REPP)

Submitted: 31 July 2023

Executive Summary

This report summarises the findings of two parallel technical investigations undertaken in accordance with Barwon Water's Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP), to determine whether Barwon Water's historical management of groundwater pumping activities within the Barwon Downs graben resulted in any other unintended environmentally significant adverse impacts, in addition to those already confirmed within the lower reaches of Boundary Creek.

A key element of this work was the development of a Conceptual Site Model that consolidates the abundance of work completed within the Barwon Downs graben since investigations commenced in 1974. This Conceptual Site Model was then used in conjunction with groundwater levels, surface water flows, surface water and groundwater extraction licences, land use change and climate related factors such as rainfall, to identify the potentially susceptible water features and apportion the likely influences on observed trends. While this also considered the outcomes from earlier work completed by Jacobs (2019), this work incorporated a multiple lines of evidence approach to test the underlying assumptions of the regional groundwater model and provide a comprehensive assessment of the existing data.

The outcomes of this work have identified hydraulic influences from Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield on Love Creek, Yahoo Creek and to a lesser extent in the Barwon River and Gellibrand River. With the exception of the upper reaches of Deans Marsh, Matthews and Pennyroyal Creeks, which remain unclear, groundwater pumping related influences have not been identified within any other areas of the broader environment. Despite the identification of groundwater pumping related influences, there is no evidence to suggest that these have resulted in any environmentally significant impacts (i.e., material harm to human health or the environment) within the broader environment.

This work has instead identified multiple contributing factors, with groundwater pumping related impacts equal to or in most cases below those that can be attributed to climate related influences on recharge/discharge and rainfall-runoff processes. In some cases, potential impacts from licenced surface water extraction activities, land use changes, and changes in recharge/discharge processes associated with the upper aquifer system have also been shown to have confounded the overarching impacts.

As such, with the exception of the further work identified in upper reaches of Deans Marsh, Matthews and Pennyroyal Creeks, in line with the requirements of the section 78 notice and the principles that underpin the REPP, no further work is required within the broader environment. The actions that have already been committed to as part of the Boundary Creek and Big Swamp Remediation Plan are considered to be the most appropriate course of action to facilitate recovery within the broader environment.

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Introduction

Background

As outlined in the Remediation and Environmental Protection Plan (REPP) (Barwon Water 2020 and Barwon Water 2023), the Surrounding Environment Investigation considers the whole extent of the Lower Tertiary Aquifer (480 km^2) and aims to determine whether the historical management of Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield resulted in any other unintended environmentally significant adverse impacts within the broader environment, in addition to those already confirmed within Big Swamp and the lower reaches of Boundary Creek.

The first step in this process involved the use of the regional groundwater model to identify the areas where groundwater pumping activities within the Lower Tertiary Aquifer may result in impacts to surface water features based on a systematic risk assessment framework (Jacobs, 2019). Given the uncertainties and limitations associated with the groundwater model, this work was also used to determine where further investigation(s) was required to fill the identified data gaps and provide sufficient data to 'ground truth' the findings of the systematic risk assessment.

The outcomes of this work identified the following eight areas outside of the Boundary Creek catchment, where further monitoring and/or investigation was required, as shown in Figure 1, to better inform the impact assessment:

- Barwon River (East branch)
- Barwon River (West branch)
- Barwon River (downstream of the confluence with Boundary Creek)
- Gellibrand River and associated groundwater dependent ecosystems
- Ten Mile Creek
- Yahoo Creek
- Groundwater dependent ecosystems west of the Barwon River (near Yeodene), and
- Groundwater dependent ecosystems east of the Barwon River (between Barwon Downs and Yeodene)

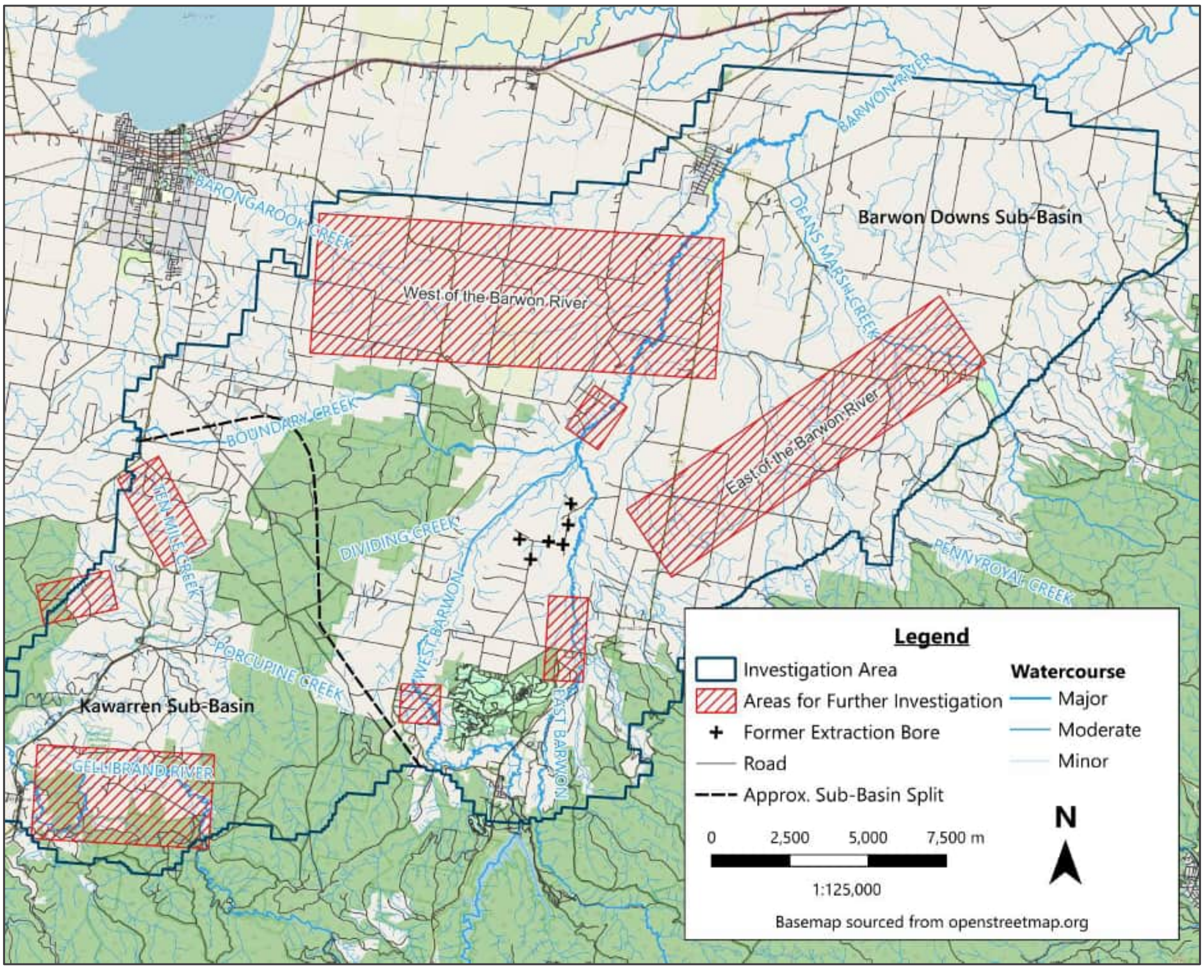

Figure 1 Areas identified for further investigation

Since 2019, Barwon Water has installed and/or re-instated an additional 24 groundwater monitoring bores as well as an additional five stream gauges to better understand the connectivity or otherwise between the Lower Tertiary Aquifer, overlying geological units and surface water features. The findings from this work have informed the hydrogeological assessments that underpin this report.

It is noted that the hydrogeological assessments that underpin this report did not consider the further investigation areas in isolation. Rather, these were considered as part of two broader parallel investigations that considered the two sub-basins within the Barwon Downs Graben (refer Figure 1), which are referred to as:

- The Barwon Downs Sub-Basin – where the Barwon Downs borefield extraction bores are located, and
- The Kawarren Sub-Basin

Objectives of the hydrogeological assessments

The objective of the hydrogeological assessments that underpin this this report were to:

- Develop a robust conceptual site model based on the current state of knowledge, which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and

- Use the conceptual site model to evaluate if Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield has resulted in any environmentally significant adverse impacts within the broader environment

Noting that these assessments considered the full extent of the Lower Tertiary Aquifer and were not just focused on the areas for further investigation to ensure the previous work did not exclude any potentially impacted areas outside of these areas.

Scope of work and methodology

The hydrogeological assessments were completed in general accordance with Environment Protection Authority (EPA) Victoria's Publication 668 – Hydrogeological Assessment (Groundwater Quality) Guidelines published in September 2006 and included the following scope of work:

- Review of existing reports and information
- Desktop review of publicly available information relating to the environmental setting, geology, hydrogeology, hydrology, rainfall including community gathered and climate, groundwater dependent ecosystems and acid sulfate soils
- Completion of a site inspection to ground truth the findings of the desktop review and interviews with knowledgeable landholders
- Development of a conceptual site model
- Identification of water features that are potentially susceptible to low flow impacts from grounding pumping activities within the Lower Tertiary Aquifer
- Apportionment of likely flow impact from historic groundwater pumping activities as opposed to other factors and identification of confirmed areas of impact
- Overview of changes and/or improvements since cessation of groundwater pumping activities, and
- Consultation with relevant stakeholders, including presenting and testing the assumptions in the conceptual site model and inclusion of feedback from the RRG nominated experts, and
- Preparation of two reports – provided in Appendix A and Appendix B of this report.

It is noted that due to the focus of previous work being on the Barwon Downs Sub-Basin, additional community engagement with local community members was completed as part of the Kawarren Sub-Basin hydrogeological assessment. This included engagement with Land and Water Resources Otway Catchment (LAWROC) and their appointed representatives during the scoping and delivery phase of the project.

What has informed this process?

Information sources

The Surrounding Environment Investigation has been informed by the following documents and information sources:

- W.J.R. Blake, 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area, Geological Survey of Victoria
- J. Leonard, R. Lakey, R. Blake, 1983, Hydrogeological investigation and assessment – Barwon Down Graben, Otway Basin, Victoria, Geological Survey of Victoria (unpublished)
- R. Lakey, 1983, Gellibrand Groundwater Investigation – Kawarren Pumping Test Report, Geological Survey of Victoria
- R. Lakey, J. Leonard, 1983, Gellibrand Groundwater Investigation – Stage II Report
- Geological Survey of Victoria, 1984, Department of Minerals and Energy Submission to Natural Resources and Environment Committee Inquiry into Water Resources Management
- Stanley, 1991, Preliminary Groundwater Resource Evaluation of the Kawarren Sub-region of the Barwon Downs Graben
- Preliminary Draft Regional Landcare Action Plan for the Corangamite Region, 1993
- HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area - Kawarren Groundwater Resource Evaluation
- G.W. Carr & A.M. Muir, 1994, Barwon Downs aquifer flora
- Witebsky et al., 1995, Groundwater development options and environmental impacts: Barwon Downs Graben south-western Victoria
- P. Dahlhaus, D. Heislers, P. Dyson, 2002, Groundwater flow systems of the Corangamite Catchment Management Authority Region
- B. Petrides & I. Cartwright, 2006, The hydrogeology and hydrogeochemistry of the Barwon Downs Graben aquifer, southwestern Victoria, Australia
- EAL 2011, Preliminary Inland Acid Sulfate Soil Assessment Report, prepared for LAWROC
- SKM, 2012, Newlingrook Groundwater Investigation, Gellibrand River Streambed and Baseflow Assessment
- M. Gardiner, 2013, Otway Water Book 21: An aquifer divide shift and Study of the EVF aquifers in the Gerangamete and Gellibrand Groundwater Management Areas
- F. Glover, 2014, Characterisation of acid sulfate soils in south-west Victoria, Australia
- Aquade Groundwater Services, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area
- Jacobs, 2015, Barwon Downs Vegetation Monitoring – Vegetation Monitoring Report
- M. Gardiner, 2015, Otway Water Book 28: The Western Front, Ten Mile Creek and Loves Creek Catchment

- Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/2016 - Recharge Rate Assessment
- Aquade Groundwater Services, 2017, Impacts of Barwon Downs extraction on groundwater and surface water in the Kawarren Area
- Jacobs, 2017, Barwon Downs Technical Works Program, Integration Report
- Jacobs, 2017, Barwon Downs Vegetation Survey 2016
- Jacobs, 2018, Barwon Downs Technical Works Program - Potential impacts and risks from future operation of the Barwon Downs Borefield
- Jacobs, 2018, Barwon Downs Hydrogeological Studies 2016-2017, Numerical Model Calibration and Historical Impacts
- Aquade Groundwater Services, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment
- Aquade Groundwater Services, 2019, Impacts of Barwon Downs Extraction on Groundwater and Surface water in the Kawarren Area, Part B (Update)
- Jacobs, 2019, Technical support for Section 78 Scope of Works - Historical Pumping Risk Assessment Method and Results
- GHD, 2021, Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design, Technical Modelling Report
- Barwon Water, 2020, Boundary Creek, Big Swamp and Surrounding Environment Remediation & Environmental Protection Plan (REPP)
- Austral Research and Consulting, 2022, Upper Barwon River Macroinvertebrate Sampling Report 2019-2022
- Barwon Water, 2022, Revised Interim Draft of the Boundary Creek, Big Swamp and Surrounding Environment Remediation & Environmental Protection Plan (REPP)
- CDM Smith, 2022, PRB Assessment
- Eco Logical Australia, 2022, Barwon Downs Vegetation Monitoring Report, - November 2020, prepared for Barwon Water
- Eco Logical Australia, 2022, Groundwater Dependent Ecosystem Survey of the Barwon Downs region, prepared for Barwon Water
- Jacobs, 2022, Otway Ranges surrounding areas hydrogeological investigation
- Jacobs, 2022, Surrounding Environment Bore Completion Report, Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan (REPP)
- BlueSphere, 2023, Hydrogeological Investigation of the Kawarren Sub-basin – Surrounding Environment Investigation
- BlueSphere, 2023, Hydrogeological Assessment of the Kawarren Sub-Basin – Surrounding Environment Investigation
- Nation Partners, 2023 (draft), Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Community gathered rainfall data was also used as part of this assessment.

Stakeholder engagement

In addition to the above information sources and interviews with local community members, a series of workshops was completed with the RRG nominated experts to test the assumptions and findings of the work. These workshops also aimed to confirm the work was technically sound and met the community's expectations. Feedback was also sought from the RRG nominated experts on the draft report. This feedback was considered and used to revise the report as required.

For the Kawarren Sub-Basin hydrogeological assessment, LAWROC representatives were also included in these workshops and invited to provide feedback on the draft report. Aquade Groundwater Services were also engaged to provide independent feedback on the Kawarren Sub-Basin hydrogeological assessment.

Barwon Water would like to acknowledge the valuable insights and feedback provided by the local community members and appointed experts during the course of this project.

Overview of the Conceptual Site Model (CSM)

The following provides a high-level summary of the Conceptual Site Model outlined in Appendix A and Appendix B. Further information regarding the hydrogeological setting for each of the sub-basins is also provided in these appendices, noting that only references outside of the current work have been provided, where relevant.

Hydrogeological setting

The Barwon Downs graben sits within the Otway Basin and is one of two main structural features in the north-eastern portion of the Port Campbell Embayment, alongside the Carlisle River Graben. The Barwon Downs graben consists of a deep sequence of Tertiary aged sediments deposited during major regressive and transgressive cycles (Lakey & Leonard, 1983). The Barwon Downs graben is bound by the Loves Creek / Barwon Monocline to the north-west and the Bambra Fault Zone to the south-east and is separated into two distinct sub-basins, the Barwon Downs Sub-Basin and the Kawarren Sub-Basin.

The Lower Tertiary Aquifer, which overlies the basement rock (Otway Group), is the primary aquifer within the Barwon Downs graben and extends to a depth of approximately 600 metres (m) below ground surface. While thicknesses vary throughout the graben, the Lower Tertiary Aquifer can be in excess of 400 m thick, but more typically is between 100 and 200 m thick. Over the vast majority of the graben, the Lower Tertiary Aquifer is overlain by very low permeability sediments associated with the Narrawaturk Marl. These sediments, which are up to 90 m thick in the Kawarren Sub-Basin and 200 m in the Barwon Downs Sub-Basin, retard groundwater flow and separate the Lower Tertiary Aquifer from the overlying sediments. Similarly, these sediments restrict recharge into the Lower Tertiary Aquifer, meaning the Lower Tertiary Aquifer recharges and discharges principally in areas where these sediments daylight, or outcrop at the surface. Noting that with the exception of the outcrops in Pennyroyal and Deans Marsh, the outcrops to the south-east of the Bambra Fault are disconnected from the two sub-basins.

Based on the current understanding, the Lower Tertiary Aquifer is primarily recharged via rainfall infiltration in the Barongarook High, that receives around 3,552 ML of recharge a year, compared to the 935 ML of recharge that is expected to occur via the outcrops in Pennyroyal and Deans Marsh. This then flows through the aquifer via two main recharge avenues termed the Yeodene Recharge Avenue (that flows into the Barwon Downs Sub-basin) and the Kawarren Recharge Avenue (that flows into the Kawarren Sub-basin). Noting that a component of the Yeodene Recharge Avenue also flows into the Kawarren Sub-basin via a narrow valley referred to as the Pipeline Restriction (Aquade Groundwater Services, 2017). A component of this recharge also discharges to local river systems that are directly underlain by the Lower Tertiary Aquifer. Based on a review of the available information, this is expected to occur within the upper reaches of Boundary Creek, Pennyroyal Creek, Deans Marsh Creek, Ten Mile Creek and Yahoo Creek. Accounting for these flow paths, the

Gellibrand River is considered to be a regional groundwater discharge feature of the Lower Tertiary Aquifer.

Identification of potentially susceptible water features

Based on the updated Conceptual Site Model presented in Appendix A and Appendix B, potentially susceptible water features have been characterised into two categories:

- Primary susceptible water features: Those that receive groundwater discharge from the Lower Tertiary Aquifer; and
- Secondary susceptible water features: Those that flow over another unit but are downstream of a Lower Tertiary Aquifer outcrop.

Surface water features that do not fall into either of these categories are not susceptible to potential impacts from Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield and have been excluded from this assessment. However, it is important to note that these are still susceptible to a range of other factors that may be important from a broader catchment management and/or local perspective.

Based on the current state of knowledge, the potential exists for groundwater pumping related influences to have occurred in the following areas:

- Barwon River (downstream of the confluence with Boundary Creek)
- Gellibrand River and associated groundwater dependent ecosystems
- Ten Mile Creek
- Yahoo Creek; and
- Groundwater dependent ecosystems east of the Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks). Noting that the potentially susceptible areas are upstream of those previously identified by Jacobs (2019).

Note: The potential for influence does not imply impact has occurred. This is explored in detail below.

Boundary Creek and Big Swamp have not been included in this assessment as impacts to these areas are well known, with a series of remedial actions already implemented as part of the Boundary Creek and Big Swamp Remediation Plan. Noting that Appendix B does provide some further discussion around the potential impacts from surface water extraction activities along Boundary Creek given these have not previously been considered in previous technical work.

This work has also revealed that the potential risks from groundwater pumping related influences identified by Jacobs (2019) at the following locations are expected to have been overestimated:

- Barwon River (East Branch)
- Barwon River (West Branch)
- West of the Barwon River

The revised risk ranking for these areas is now considered low. For the east and west branches of the Barwon River, this is due to the limited hydraulic connection across the Bambra Fault, while for the areas west of the Barwon River there is limited Lower Tertiary Aquifer outcrops in this area and elsewhere the Lower Tertiary Aquifer is confined with limited surface connectivity. This review also confirmed that Porcupine Creek does not receive groundwater discharge from the Lower Tertiary Aquifer and hence, the potential risks from groundwater pumping related influences on Porcupine Creek are also considered low.

Further information on the specific elements of the CSM can be found in Appendix A and Appendix B along with a series of cross sections.

Data gaps

It is important to note that the work completed to date has also identified a number of data gaps, particularly in relation to:

- The recharge and discharge relationships of the upper aquifer systems that underly the majority of the surface water features within the Barwon Downs graben and what changes occurred in these systems during the Millennium Drought. Particularly given the unconfined nature of these systems and the surface area of these outcrops – that exceed that of the Lower Tertiary Aquifer.
- The hydrogeology associated with the Lower Tertiary Aquifer outcrop in the north-eastern portion of the graben. Noting that if this is a recharge area, it is minor in comparison to the Barongarook High.
- The nature and extent of Lower Tertiary Aquifer sediments across the pipeline restriction. This underpins the estimates of throughflow and would be of importance for any future assessment of sustainability
- The significance of the hydraulic connection across the Colac Monocline, and
- The potential shift of the groundwater divide in the Barongarook High area.

While these are not expected to impact the outcomes of this work, they are integral to understanding the amount of water that could be taken from the Lower Tertiary Aquifer without impacting on the sustainability of the resource.

As Barwon Water no longer has a groundwater extraction licence and have committed to decommissioning the Barwon Downs extraction bores, understanding the sustainable yield is beyond the scope of this investigation and more broadly the section 78 notice.

Therefore, these data gaps will not be addressed as part of the REPP. That said, these will help inform water resource managers and other agencies in making future management decisions.

Impact assessment summary

The Barwon Downs borefield, which was installed in the Barwon Downs Sub-basin, periodically accessed groundwater from within the Lower Tertiary Aquifer. Over its lifetime, the Barwon Downs borefield was used to extract up to 119,000 ML of groundwater to supplement drinking water supplies during dry periods.

As a result of pumping, water levels within the Lower Tertiary Aquifer declined by up to 60 m in the vicinity of the borefield, with Lower Tertiary Aquifer outcrops experiencing declines of up to 4 m in the Kawarren Sub-basin and up to 22 m in the Barwon Downs Sub-basin. These declines, along with drought conditions, subsequently led to an alteration of the recharge and discharge relationships, ultimately leading to the potential for impacts to primary and secondary susceptible water features within the graben.

It is important to note that surface water features are fed by a range of sources and the proportion of groundwater discharge to total flows can vary both spatially and temporally. Because of this, groundwater contribution is at its highest during the dry season when there is less rainfall (i.e., low flow conditions). This is when the potential for groundwater pumping related impacts is at its highest. As such, this assessment focuses on this period to provide a worst-case estimate of potential impact.

In order to separate groundwater pumping-derived impacts on surface water features from those caused by other factors, a detailed review of groundwater levels, surface water flows, surface water and groundwater extraction licences, land use change and climate related factors was undertaken in line with the process outlined in Figure 2.

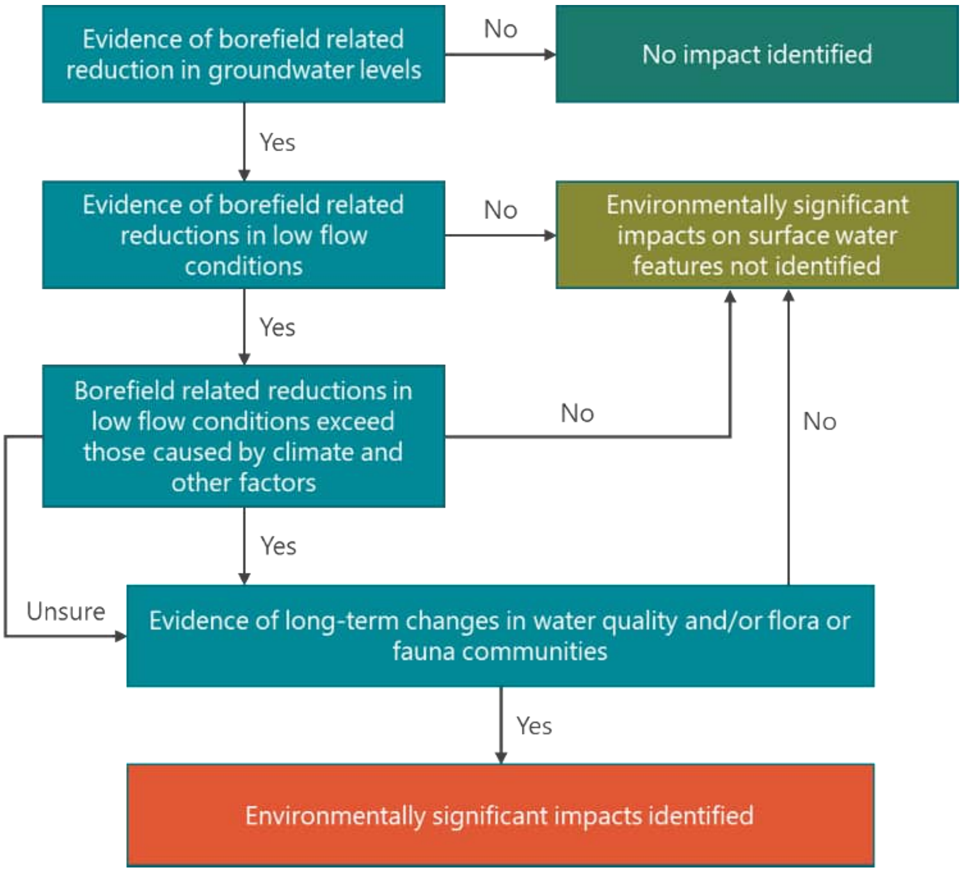

Figure 2 Impact assessment framework

The following provides a high-level summary of the impact assessment outlined in Appendix A and Appendix B. Further information regarding how these have been developed and the various inputs is provided in these appendices.

Apportionment of likely influences

The first step in the impact assessment focused on the apportionment of likely influences. While a summary of the impact assessment is provided below, more detail is available in Appendix A and Appendix B.

Climate related influences on recharge / discharge processes

During the Millennium Drought (1997-2009), rainfall deficits of between 33 to 88 mm/year and 66 to 148 mm/year were recorded in the Barwon Downs Sub-basin and Kawarren Sub-basin respectively. In Barongarook High, the rainfall deficits can be attributed to an approximate 7 per cent reduction in groundwater recharge. This resulted in a reduction in infiltration to the Lower Tertiary Aquifer, and subsequently the amount of groundwater discharge from the Lower Tertiary Aquifer (i.e., baseflow) into surface water features that are in direct hydraulic connection.

Refer to Table 1 for a summary of estimated climate-related influence from observed rainfall deficits, or to Appendix A and Appendix B for further information.

Climate related influences on streamflows

In addition to the recharge deficits outlined above, a Department of Environment, Land, Water and Planning (now Department of Energy, Environment and Climate Action) (2020) report indicates that the rainfall deficits experienced during the Millennium Drought have also led to a 20-40 per cent decline in annual streamflows. This is due to the shift in rainfall-runoff relationships driven by a general reduction in moisture within the landscape and potential changes in soil characteristics. These changes significantly influence low flow conditions and reduce the resilience of the system to other influences.

Surface water extraction

A review of the licenced surface water extraction volumes sourced from the Victorian Water Register (http://waterregister.vic.gov.au) revealed that there is the potential for influence associated with surface water extraction activities in the following surface water features:

- Barwon River (Middle Barwon River): 1,051.6 ML per year
- Gellibrand River (including tributaries): 1,065.9 ML per year
- Love Creek: 543.5 ML per year
- Matthews Creek: 47.3 ML per year
- Pennyroyal Creek: 211.1 ML per year
- Ten Mile Creek: 31.6 ML per year

While in many cases, these are not expected to significantly contribute to the observed reduction in baseflow, where present, the hydrogeological assessment has indicated that surface water extraction activities could play an important role in Love Creek where surface water extraction and the observed baseflow declines are within the same scale. Potential impacts, albeit to a lesser degree, have also been identified in the Barwon and Gellibrand Rivers, where these could in theory explain 30 per cent and 21-35 per cent of the observed baseflow reduction, respectively, as outlined in Table 1.

However, while possible, these influences cannot be confirmed without a detailed understanding of the location, actual extraction volumes and usage patterns throughout the period of interest. It is also noted that this does not account for any unlicenced extraction, or those with existing water rights, that may also access surface water during dry periods. Refer to Appendix A and Appendix B for further information.

Groundwater pumping related influences

Through a process of exclusion, the potential groundwater pumping related influence on potentially susceptible water features was calculated by subtracting climate related influences from the observed reduction in baseflow.

This baseflow reduction was then corrected based on the proportion of baseflow to total streamflow to determine the overarching influence on low flow conditions.

Refer to Table 1 for a summary of the estimated groundwater pumping related influence of low flow conditions, or to Appendix A and Appendix B for further information.

It is noted that in some cases, other influences have not been able to be adequately quantified and hence, the reported influences represent multiple factors. This is particularly important for streams that also receive groundwater discharge from the upper aquifer systems as these confound the observed reduction in baseflow.

Land use and other influences

While land uses changes are evident within the catchment since urbanisation and land development practices, there appears to have been little change during the period of interest – i.e., following commencement of Barwon Water's groundwater pumping activities.

Nevertheless, there are forestry / logging activities being undertaken at various locations within the graben. Review of streamflow records during the clearing and re-establishment periods indicate a potential influence from forestry / logging activities. This is likely due to changes in the rainfall-runoff processes during these times. However, these were unable to be quantified as part of this assessment.

Drawing from the work undertaken within Boundary Creek, historic realignment and/or drainage enhancement activities also have the potential to influence low flow conditions, oxidise any naturally occurring acid sulfate soils and/or reduce the resilience of the system to other influences.

Significance of observed hydraulic influences

An assessment of climate related factors that have led to changes in recharge/discharge and rainfall-runoff relationships, show these factors experienced during the groundwater extraction period have led to total streamflow reductions of between 20 and 56 per cent. Via a process of exclusion, based on the observed baseflow/streamflow reductions, groundwater pumping, and other related factors (licenced surface water extraction and land use and other influences) have also been quantified, to the extent practicable. The findings from this work indicate that total streamflow reductions of up to 9 per cent, 6 per cent, 26 per cent and 23 per cent during low flow periods can be attributed to the groundwater pumping related influences identified in the Barwon River, Gellibrand River, Love Creek and Yahoo Creek, respectively. Noting that for Love Creek this includes potential influences associated with licenced surface water extraction and changes in recharge/discharge relationships associated with the upper aquifer systems that cannot be adequately constrained. Similarly for Yahoo Creek, this includes potential influences associated with forestry/logging and changes in recharge/discharge relationships associated with the upper aquifer systems that cannot be adequately constrained. In addition to this, licenced surface water extraction in the Barwon River and Gellibrand River have also been shown to play an important role, with the potential for these to lead to total streamflow reductions of 30 per cent and 21-35 per cent, respectively. Refer to Table 1 for further information.

Based on the information provided in Appendix A and Appendix B and as shown in Table 1, there is no evidence to suggest that environmentally significant adverse impacts – i.e., material harm to human health or the environment, within the broader environment have been caused by Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield.

However, due to the general paucity of data for the potentially susceptible water features located to the east of the Barwon River (Deans Marsh, Matthews and Pennyroyal Creeks), a sufficient assessment of impact cannot be made for this location at this time. The impact assessment outcomes have also been presented on Figure 3.

Table 1 Surface water impact assessment summary under low flow conditions

Surface Feature	Relationship with the LTA	Estimated climate-related influence from observed rainfall deficits	Estimated climate-related influence from changes in rainfall-runoff processes	Estimated groundwater pumping and other influences	Other influences on low flow conditions	Long-term changes in water quality and/or flora or fauna communities	Environmentally significant impacts from pumping identified
Barwon River	Does not receive groundwater discharge from the LTA, but is fed from areas that receive groundwater discharge from the LTA	Nil	20 - 40% of total streamflows (DELWP, 2020)	9% (pumping only)	Potential 30% reduction from surface water harvesting	No	No
GDE's east of the Barwon River	Does not receive groundwater discharge from the LTA, but is fed from areas that receive discharge from the LTA	4.4% of total streamflow		Insufficient data available	N/A	Unclear	Unclear - further work required
Gellibrand River	Receives groundwater discharge from the LTA in or adjacent to LTA outcrops	3.3% of total streamflow		3-6% of total stream flow (pumping only)	21-35% of total stream flow potentially due to surface water extraction based on process of exclusion	No	No

Love Creek	Does not receive groundwater discharge from the LTA directly, but is fed by Ten Mile and Yahoo Creeks that do receive groundwater discharge directly from the LTA	5-12% of total streamflow		19-26% of total streamflow (range of factors)	Potential for influences from surface water harvesting in area, which may account for losses along Love Creek. Love Creek also receives discharge from the upper aquifer system which has not been considered in this assessment as it has not been impacted by pumping	No	No
Ten Mile Creek	Receives groundwater discharge from the LTA in or adjacent to LTA outcrops	7-16% of total streamflow		Nil	Nil	N/A	No
Yahoo Creek	Receives groundwater discharge from the LTA in or adjacent to LTA outcrops	4-9% of total streamflow		18-23% of total streamflow (range of factors)	Potential influences from forestry / logging activities and Climate driven baseflow reduction from upper aquifer system	No	No

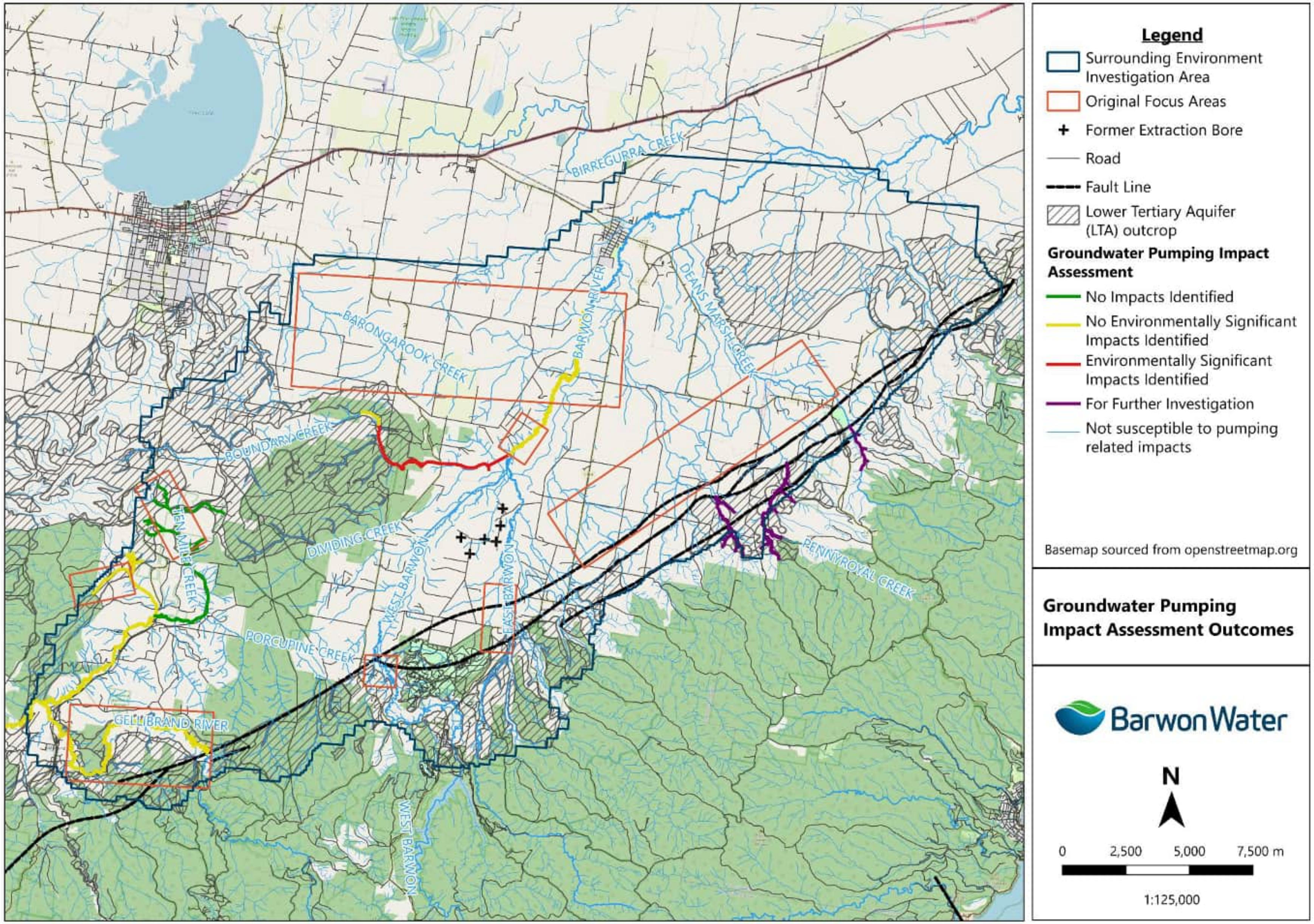

Figure 3 Groundwater Pumping Impact Assessment Outcomes

Outcomes and implications of the Surrounding Environment Investigation

Based on the information presented above and in Appendix A and Appendix B, hydraulic influences from Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield have been identified in Love Creek, Yahoo Creek and to a lesser extent in the Barwon River and Gellibrand River. However, based on the outcomes of the impact assessment, there is no evidence to suggest that the identified influences associated with Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield have led to any environmentally significant impacts (i.e., material harm to human health or the environment) within the broader environment. In line with the approach outlined in the REPP, Phase 2 – works are required to be undertaken in Lower Tertiary Aquifer outcrops in the upper reaches of Deans Marsh, Matthews and Pennyroyal Creeks (refer Figure 3) to better constrain the potential influences and/or resulting impacts in these areas.

While Ten Mile Creek is potentially susceptible to groundwater pumping related influences, the slight decreasing trend in baseflow is within the range of natural variation. As such, groundwater pumping related influences are not considered to have been realised in Ten Mile Creek. The hydrogeological setting of the remaining surface water features within the broader environment means that these are not susceptible to influences from groundwater pumping activities in the Lower Tertiary Aquifer and therefore have not been impacted by Barwon Water's historic management of groundwater pumping activities at the Barwon Downs borefield.

This work has instead identified multiple contributing factors, with groundwater pumping related impacts equal to or in most cases below those that can be attributed to climate related influences on recharge/discharge and rainfall-runoff processes. In some cases, potential impacts from licenced surface water extraction activities, land use changes, and changes in recharge/discharge processes associated with the upper aquifer system have also been shown to have confounded the overarching impacts. As such, with the exception of the further work identified in upper reaches of Deans Marsh, Matthews and Pennyroyal Creeks, in line with the requirements of the section 78 notice and the principles that underpin the REPP, no further work is required within the broader environment.

Similarly, the cessation of groundwater pumping activities and decommissioning of the Barwon Downs borefield extraction bores that have already been committed to as part of the Boundary Creek and Big Swamp Remediation Plan are considered to be the most appropriate course of action to facilitate groundwater level recovery within the Lower Tertiary Aquifer throughout the broader environment. As such, no further remedial actions are proposed at this time. Noting that monitoring of the existing groundwater and surface water assets within the broader environment will continue, at least until successful remediation has been achieved for Boundary Creek and Big Swamp.

As Barwon Water no longer has a groundwater extraction licence, further consideration of these factors is beyond the scope of this investigation and more broadly the section 78 notice. However, the outcomes of this work will provide resource managers and other agencies with a greater understanding of the groundwater and surface water resources in the Barwon Downs graben.

Next steps

Based on the findings from this investigation, Barwon Water propose to undertake the following actions.

Item	Action	Deliverable	Timeframe
1	Continued monitoring of the existing groundwater and surface water assets within the broader environment, at least until successful remediation has been achieved for Boundary Creek and Big Swamp.	Annual Report	Due 30 September annually
2	Completion of targeted investigations in the Lower Tertiary Outcrops in the upper reaches of Deans Marsh, Matthews and Pennyroyal Creek (refer Figure 3) to better understand the potential hydraulic influences and establish if there is any evidence of environmentally significant impacts that could be attributed to Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield.	Phase 2 Investigation Report	Due 30 June 2024

References

Aquade Groundwater Services, 2017, Impacts of Barwon Downs Extraction on Groundwater and Surface Water in the Kawarren Area, January 2017

Barwon Water, 2020, Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP), February 2020

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BlueSphere Environmental Pty Ltd (BlueSphere), 2023a, Hydrogeological Investigation of the Kawarren Sub-basin – Surrounding Environment Investigation, June 2023

BlueSphere Environmental Pty Ltd (BlueSphere), 2023b, Hydrogeological Assessment of the Barwon Downs Sub-Basin – Surrounding Environment Investigation, July 2023

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Jacobs, 2019, Technical Support for Section 78 Scope of Works - Historical Pumping Risk Assessment Method and Results

Lakey, R., & Leonard, J. (1983). Gellibrand Groundwater Investigation - Stage II Report - August 1983. Unpublished.

Appendix A – Hydrogeological Investigation of the Kawarren Sub-basin (BlueSphere, 2023a)

BlueSphere
ENVIRONMENTAL

Hydrogeological Investigation of the Kawarren Sub-basin

Surrounding Environment Investigation

Prepared for:

Barwon Water

55-67 Ryrie Street
Geelong VIC 3220

29 June 2023

Hydrogeological Investigation of the Kawarren Sub-basin

Surrounding Environment Investigation

Distribution

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List of Abbreviations

Abbreviation	Definition
Act	Environment Protection Act 1970
AHD	Australian Height Datum
AMMR	Accumulative Monthly Residual Rainfall
ANZG	Australian and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS	Australian Standard
AASS	Actual Acid Sulfate Soil
ASS	Acid Sulfate Soils
BGL	Below Ground Level
BGS	Below Ground Surface
BOM	Bureau of Meteorology
CCMA	Corangamite Catchment Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Conceptual Site Model
DELWP	Department of Environment, Land, Water and Planning
EECA	Energy, Environment and Climate Action
EPA	Environmental Protection Authority (Victoria)
ERS	Environmental Reference Standard
GDA	Geocentric Datum of Australia
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information System
GMA	Groundwater Management Authority
GW	Groundwater
HA	Hydrogeological Assessment
KIA	Kawarren sub-basin Investigation Area
km	Kilometre
LAWROC	Land and Water Resources Otway Catchment

Abbreviation	Definition
LMTA	Lower-Mid Tertiary Aquifer
LMTD	Lower-Mid Tertiary Aquifer
LTA	Lower Tertiary Aquifer
NA	Not Applicable
NIWA	National Institute of Water & Atmospheric Research
NR	Not Reported
OGA	Otway Group Aquifer
PASS	Potential Acid Sulfate Soil
PCV	Permissible Consumptive Volume
QA	Quaternary Sediments Aquifer
REPP	Remediation and Environmental Protection Plan
RL	Reduced Level
SDLs	Sustainable Diversion Limits
SRW	Southern Rural Water
SWL	Standing water level
TAA	Titratable Actual Acidity
TDS	Total Dissolved Solids
VVG	Visualising Victoria's Groundwater
WDE	Water Dependant Ecosystems
WMIS	Water Measurement Information System

Executive Summary

BlueSphere Environmental Pty Ltd (BlueSphere) was engaged by Barwon Region Water Corporation (Barwon Water) to undertake a Hydrogeological Assessment (HA) of the Loves Creek Catchment area within the greater Barwon Downs Graben. The HA was undertaken in order to assist Barwon Water with meeting the requirements of the Section 78 Notice issued pursuant to the Water Act 1989 as it relates to the investigation of surrounding areas potentially affected by the historical operation of the Barwon Downs Borefield. This HA specifically relates to the previously identified 'high risk' surrounding areas of upper Ten Mile Creek, upper Yahoo Creek and Gellibrand River.

During the course of HA the extent of the investigation area was expanded to encompass the entirety of a feature known as the Kawarren Sub-basin (within which the Loves Creek Catchment is located). The investigation area for this HA has subsequently been referred to as the Kawarren sub-basin Investigation Area (KIA).

Between 1982/1983 and 2016 Barwon Water operated a borefield within a geological feature known as the Barwon Downs Graben, located approximately 70 km south-west of Geelong. The KIA lies within the western portion of the Barwon Downs Graben. The borefield was operated in accordance with a licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water (SRW)) and is referred to by SRW as the 'Gerangamete Groundwater Field'. The aquifer from which groundwater was extracted is referred to as the Lower Tertiary Aquifer (LTA).

Over a period of approximately 30 years, Barwon Water periodically extracted up to 119,000 ML of groundwater to augment surface water supplies during periods of drought. As a result of the pumping, groundwater levels within the LTA were reported to have declined by up to 60 m in the vicinity of the borefield.

In June 2017 Barwon Water acknowledged that the pumping had led to unintended consequences in the Barwon Downs Sub-Area, which is located to the north-east of the KIA, including contributing to the drying out and oxidation of acid sulfate soils in the vicinity of Big Swamp and Boundary Creek. Barwon Water no longer has a licence to extract groundwater from the borefield, and in August 2018 Barwon Water was issued with the Section 78 Notice.

The objectives of the hydrogeological assessment (HA) of the KIA were to:

- Develop a robust conceptual site model (CSM) based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if any impacts that may have resulted from historical groundwater pumping activities at the Barwon Downs borefield have occurred.

The CSM was developed by desktop review of publicly available information in relation to the KIA setting including geology, hydrogeology, climate, topography, hydrology, groundwater dependent ecosystems (GDEs) and acid sulfate soils (ASS). An inspection of the KIA and interview of knowledgeable landholders was also completed. The CSM has been developed with a focus on the LTA in the KIA, and is in large agreement with previous investigations including Lakey & Leonard (1983), Leonard, et al., (1983), Stanley (1991), HydroTechnology (1994) and Aquade (2019).

The CSM developed for the KIA was used to evaluate if impacts have resulted from historical groundwater pumping activities at the Barwon Downs borefield based on the current state of knowledge and the best available data. The evaluation has identified that the historical groundwater pumping activities have led to a decrease of water levels in the LTA of up to 4 m within the KIA. While there is a component of water level decrease that can be attributed to long term rainfall declines, this cannot account for all of the water level decreases observed. The water level reduction observed in the KIA in the LTA are not indicated to reflect the cone of depression associated with pumping, rather alteration of groundwater flow paths by pumping.

Based on the CSM and given that extraction has now ceased it is expected that the water levels in the LTA in the KIA should recover as baseline groundwater flow paths are re-established. Groundwater levels in the KIA have to date stabilised but not yet recovered in the KIA.

Streamflow monitoring records indicate that there have been reductions in the baseflow (i.e. low flow conditions, when waterways are most reliant on groundwater inputs) observed in Yahoo Creek, Loves Creek and the Gellibrand River (summarised in **Table 21**) between 1997 and 2013. Despite this, baseflow continued during the peak pumping period. A minor reduction observed in Ten Mile Creek is consistent with expected natural variation. Both Yahoo and Ten Mile Creeks are fed in part by the LTA, while Loves Creek receives streamflow from both of these creeks, however does not itself receive groundwater directly from the LTA. Within the KIA a number of springs and soaks are fed by the upper aquifer system (LMTA), and anecdotally do not appear to have been affected by pumping.

Of the observed baseflow reductions in Yahoo Creek and Loves Creek, high level, 'back of the envelope' calculations (further described in **Section 5.3**), using best available data, indicate that 15% to 35% is attributed to long-term rainfall decline that occurred during the Millennium Drought. There are insufficient data to directly quantify the potential contribution from groundwater extraction to Yahoo Creek and Loves Creek, however, through a process of exclusion, the remaining 65% to 85% of observed baseflow reduction in Yahoo Creek (corresponding to 18 – 23% reduction relative to total flow) and 55% and 75% in Loves Creek (corresponding to 19 – 25% reduction relative to total flow) is potentially due to a combination of extraction from the Barwon Downs Borefield, possibly exacerbated by the effects of forestry particularly since 2011 and climate driven baseflow reduction from outcrop of LMTA.

In the Gellibrand River at Bunker Hill, which is located within the regional discharge zone for the LTA, groundwater extraction from the LTA can only account for potentially 5-10% of the observed reduction in baseflow based on the current state of knowledge. Approximately 6% is attributed to long-term rainfall reductions, with the balance of the reduction observed in the Gellibrand River (approximately 80%) potentially explained by the effect of licenced surface water extraction during the Millennium Drought given extraction of that scale is possible based on licenced extractions. Importantly, the assessment highlights the cumulative influences of various competing demands on groundwater and surface water resources, particularly during periods of low rainfall.

The framework documented in the Ministerial Guidelines for Groundwater Licensing of High Value GDEs was applied retrospectively to provide a point of comparison to aid in future management and to categorise the potential susceptibility in a consistent and transparent manner. The framework identified portions of Ten Mile Creek, Yahoo Creek, Loves Creek and Gellibrand River as being of 'high' potential susceptibility under the framework.

Whilst the HA has established that there is evidence of varying degrees of hydraulic influence on groundwater and associated surface water features in the KIA due to the historical extraction from the Barwon Downs Borefield, there appears to be limited anecdotal evidence to suggest that the extraction has had a demonstrable impact on the environment within the KIA. One anecdotal observation indicated "severe stress" of vegetation in approximately 2010 along the Gellibrand River. Further, review of the available data has not identified any obvious evidence of environmental significant impacts in the KIA associated with groundwater extraction from the Barwon Downs Borefield. It should be noted however that there is a general paucity of data from which conclusions can be drawn regarding environmentally significant impacts associated with groundwater extraction from the Barwon Downs Borefield.

The findings from this HA can be used to inform long-term management of the groundwater. Importantly, the findings highlight that the combined effects of groundwater extraction, climate, land use and the intimate relationships between groundwater and surface water must be considered.

A number of recommendations have been made, including the recommendation that monitoring continue to be undertaken to verify that the expected groundwater recovery occurs.

1 Introduction

BlueSphere Environmental Pty Ltd (BlueSphere) was engaged by Barwon Region Water Corporation (Barwon Water) to undertake a Hydrogeological Assessment (HA) of the Loves Creek Catchment area within the greater Barwon Downs Graben. It is noted that, during the course of assessment, the extent of the investigation area was expanded to encompass the entirety of a feature known as the Kawarren Sub-basin, which is located within the Barwon Downs Graben. The Kawarren Sub-basin area (within which the Loves Creek Catchment is located) is herein referred to as the Kawarren sub-basin Investigation Area (KIA).

The location of the KIA within the broader Barwon Downs Graben is shown on **Figure F1**.

1.1 Background

Between 1982/1983 and 2016 Barwon Water operated a borefield within a geological feature known as the Barwon Downs Graben, located approximately 70 km south-west of Geelong. The borefield was operated in accordance with a licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water (SRW)) and is herein referred to as the Barwon Downs borefield. It has historically been referred to as the 'Gerangamete Groundwater Field'.

The Barwon Downs borefield extracted groundwater from the aquifer referred to as the Lower Tertiary Aquifer (LTA). The LTA outcrops on the margins of the groundwater catchment and extends to a depth of approximately 600 m below ground surface within the Barwon Downs Graben (see **Sections 4.8.1.1**. and **4.9**).

Over a period of approximately 30 years, Barwon Water periodically extracted a total volume of up to 119,000 ML of groundwater to augment surface water supplies during periods of drought. As a result of the pumping, the pressure head of groundwater within the LTA was reported to have declined by up to 60 m in the vicinity of the borefield. Investigations to date have identified that this, in concert with other factors, is understood to have contributed to unintended consequences on select reaches of Boundary Creek including dewatering, oxidisation of acid sulfate soils and increased fire risk in relation to peat deposits.

In June 2017 Barwon Water acknowledged that the pumping had led to unintended consequences. Barwon Water no longer has a licence to extract groundwater from the borefield.

In September 2018 Barwon Water was issued a Section 78 notice (s78) by SRW, acting on behalf of the Minister (see **Section 2.2.1** for further information), that required Barwon Water to:

a) *Continue no extraction, other than for maintenance and emergency response, and*

b) *Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and*

c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.*

In addition to this, the s78 notice also required the development and implementation of the Boundary Creek, Big Swamp and Surrounding Environmental Protection Plan (REPP), this is currently being delivered under two parallel work packages and which was to (among others) include:

- Identification of appropriate hydrogeological, hydrological and geochemical assessments to support the plan;
- Consult with Corangamite Catchment Management Authority (CCMA);
- Consult with SRW appointed expert reviewer; and
- Engage with the local community and seek ideas and feedback.

The REPP had two objectives (which were working in parallel). These were to:

- Boundary Creek & Big Swamp Remediation Plan – address remediation of confirmed impact in Boundary Creek Catchment; and
- Surrounding Environment Investigation – to investigate if other areas within regional groundwater system have been impacted by extraction.

In 2019 an existing numerical groundwater model was updated and used to consider the whole extent of the LTA as the starting point to identify other potentially impacted areas within the broader aquifer system (Jacobs, 2018a). This work identified eight potentially impacted areas where reductions in groundwater levels/pressures could have led to reductions in groundwater discharge from the LTA. The outcomes of this work completed by (Jacobs, 2018a) were also used to identify what further information and/or monitoring would be required to determine if Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield resulted in any environmentally significant adverse impacts within the broader surrounding environment. This investigation includes three of the eight potentially impacted areas (**Figure F2**).

1.1.1 Stakeholders

In May 2018 Barwon Water engaged with the community and other interested parties to establish a working group for the design of the REPP for Big Swamp and Boundary Creek. A summary of the stakeholders and their interest in the REPP and Surrounding Environment Investigation is provided in **Table 1**, below. The working group engaged independent technical experts to provide independent specialist advice and those independent experts are also provided in **Table 1**, below.

Table 1 Stakeholders

Stakeholder Group	Stakeholder	Interest
Barwon Water's Remediation Reference Group	Corangamite Catchment Management Authority (CCMA)	Regional catchment management authority
	Colac Otway Shire Council	Local council
	Land and Water Resources Otway Catchment (LAWROC)	Local community group representing local landholders who may be impacted by the historic pumping activities
	Environment Victoria	Interested environmental group
	Upper Barwon Landcare Group	Interested community group
	Boundary Creek landowners	Potentially affected landholders
	Traditional Owners	Interested community group
	Other interested community members	Interested community group
Barwon Water's Remediation Reference Group Independent Technical Experts	Professor Richard Bush, Global Innovation Chair, International Centre for Balanced Land Use Office, Monash University	Independent Technical Expert for remaining surrounding environment investigation areas (outside of the KIA)
	Dr Vanessa Wong, Senior Lecturer, School of Earth Atmosphere and Environment, Monash University	Independent Technical Expert
	Dr Darren Baldwin, independent consultant, visiting adjunct professor, School of Environmental Sciences, Charles Sturt University	Independent Technical Expert
Independent Technical Expert	Alan Wade, Principal Hydrogeologist, AQUADE Groundwater Services Pty Ltd	Independent Technical Expert
Regulator	Southern Rural Water	Regulator and Issuer of s78 notice

Stakeholder Group	Stakeholder	Interest
Southern Rural Water's Independent Technical Review Panel (ITRP)		Independent Technical Advice to SRW
Southern Rural Water's Community Leaders Group (CLG)		Community members interested in the REPP and associated works
Department of Energy Environment and Climate Action (DEECA)		Water resource manager for Victoria – will be kept informed of the progress and implementation of the REPP
EPA Victoria		Ensuring appropriate action is being taken to reduce risks and harm to human health and the environment

1.2 Objectives

The objectives of the hydrogeological assessment (HA) of the Loves Creek Catchment are to:

- Develop a robust conceptual site model[1] (CSM) based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield has resulted in any environmentally significant adverse impacts within the broader environment.

The CSM will also form the basis for the subsequent management decisions in the catchment.

1.3 Scope of Work and Methodology

In order to achieve the objectives of the project the following scope was completed:

- Review of existing reports and information (refer to **Section 2**, below);
- Desktop review of publicly available information relating to the KIA setting, geology, hydrogeology, hydrology, rainfall including community gathered and climate, groundwater dependent ecosystems, acid sulfate soils;
- Completion of an inspection of key locations within the KIA and interview with knowledgeable landholders;
- Development of a CSM for the KIA;
- Identification of susceptible water features;
- Apportionment of likely flow impact from historic groundwater pumping activities as opposed to other factors and identification of confirmed areas of impact;
- Overview of changes and/or improvements since cessation of groundwater pumping activities;

[1] 'A conceptual (hydrogeological) model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions (Anderson and Woessner 1992). It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes.' (Barnett B, 2012)

- Consultation with relevant stakeholders including presenting and testing the assumptions in the CSM; and
- Preparation of this report.

The HA was completed in general accordance with Environment Protection Authority (EPA) Victoria Publication 668 Hydrogeological Assessment (Groundwater Quality) Guidelines, September 2006.

2 Key Documents and Information Sources

2.1 Introduction

This section summarises the two key documents that provide context to the current investigation, the various information sources that were accessed and reviewed during the preparation of this report including information provided by some stakeholders invested in the project.

2.2 Key Documents

2.2.1 Section 78 Notice

Barwon Water was issued with a Ministerial Notice, Issued pursuant to Section 78 of the Water Act 1989, Licence Number: BEE032496 on 11 September 2018 requiring Barwon Water to:

a) *Continue no extraction, other than for maintenance and emergency response, and*

b) *Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and*

c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.*

The notice was issued on the basis of findings from several reports which were:

- *A report (Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts, Jacobs June, 2017) found that the operation of the borefield over 30 years was responsible for 2/3 of the reduction of groundwater base flow into Boundary Creek.*
- *An additional report (2016-2017 Technical Works Program Yeodene Swamp Study, Jacobs, November 2017) indicated the licence condition requiring the release of 2 ML/d of supplementary flow into Boundary Creek had not been effective at off setting the impacts of the borefield operation on groundwater base flows in Boundary Creek. This resulted in the creek drying out, generation of acid sulfate soils and release of acid water into downstream.*

Southern Rural Water (SRW) (acting on behalf of the Minister) formed the view that the borefield had caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment.

Section 2.2 of the Notice required: *Barwon Water must prepare and implement the 'Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan'*.

Per Section 2.5 of the Notice:

2.5 By 20 December 2019 Barwon Water must submit to SRW the Plan which includes:

a) *A description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment; this will include:*
   - *Hydrogeological conditions (groundwater levels and quality)*
   - *Hydrology (Surface water quality and flow monitoring)*
   - *Ecological assessment*
   - *LIDAR topographic mapping*
   - *Results of soil sampling program (Soil chemistry, peat profile, incubation tests)*
   - *Additional matters arising from the scope contemplated in Item 2.4.*

b) *An outline and risk assessment of the processes/activities on the Property which may impact on Boundary Creek, Big Swamp and the surrounding environment (including, but not limited to hydrogeology, hydrology and soil chemistry);*

c) *A range of controls and actions that could be practicably carried out to protect and improve the condition of Boundary Creek and Big Swamp and the surrounding environment, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;*

d) *A comprehensive risk assessment of proposed controls and actions documented in c);*

e) The controls and actions to be implemented, including reasonable targets and/or measures of success to be adopted for the purposes of implementation of the plan;

f) A monitoring program to check the controls and actions documented in e);

g) Contingency measures designed to address any issues identified from monitoring results;

h) A schedule of timeframes by which the controls and actions documented in e) will be carried out; and

i) A reporting schedule, whereby Barwon Water will provide a minimum of quarterly updates to SRW which report on the progress of the plan, as well as an Annual Report. The Annual Report must be submitted to SRW and made publicly available by 30 September each year.

The notice remains in effect until Barwon Water can demonstrate to the satisfaction of SRW that the plan has been implemented and measures and outcomes (per Section 2.5 of the Notice) have been achieved. A copy of the Notice is provided in **Appendix A**. In preparing the scope of work for the plan Barwon Water was required to consult with various stakeholders, further described in **Section 1.1.1**, above.

2.2.2 Remediation Environmental Protection Plan

A Remediation and Environmental Protection Plan (REPP) was submitted in December 2019 and last amended in February 2020. The implementation of the REPP is a requirement of a Ministerial Notice issued pursuant to Section 78 of the Water Act 1989 by SRW on 11 September 2018. The REPP includes two key work streams:

- The Boundary Creek and Big Swamp Remediation Plan: Remediation of the confirmed areas of impact in the Boundary Creek catchment; and
- The Surrounding Environment Investigation: Investigation of the surrounding environment to identify if any other areas have been impacted by historical management of groundwater extraction from the borefield.

A numerical groundwater model was initially developed in 1994 by Barwon Water which has since evolved and in 2019 the model was used to assess historical impacts of pumping and identify potential high risk areas. The results of the modelling completed by (Jacobs, 2019) identified eight potentially impacted areas (i.e. areas where groundwater extraction had the potential to have led to a hydraulic influence) requiring further assessment:

- Boundary Creek between McDonalds Dam and Big Swamp;
- Barwon River (East branch);
- Barwon River (downstream of the confluence);
- Gellibrand River and associated Groundwater Dependent Ecosystems (GDEs);
- Ten Mile Creek;
- Yahoo Creek;
- GDEs west of the Barwon River (near Yeodene); and
- GDEs east of the Barwon River (between Barwon Downs and Yeodene).

In June 2017, Barwon Water acknowledged that the historic management of the groundwater pumping activities had led to a reduction in groundwater contribution to the LTA into Boundary Creek, a tributary of Barwon River, This reduction, in conjunction with the changes in land use, Millenium Drought, and the complexities associated with the management and regulation of a private on-stream dam that controls flows into the lower reaches of Boundary Creek, resulted in the increased frequency and duration of 'cease to flow' and 'acid flush' events along Boundary Creek and Big Swamp – a wetland that is primarily fed by inflows from Boundary Creek. This was despite meeting the provisions set out in the groundwater extraction licence(s) that were intended to offset the potential impacts from Barwon Water's groundwater pumping activities on Boundary Creek.

Remedial actions for Boundary Creek and Big Swamp included:

- Cessation of groundwater pumping activities;

- Decommissioning of the Barwon Downs extraction bores;
- Provision of supplementary flows, where required, to minimise the potential for cease to flow events until remediation is successful;
- Prevention of the encroachment of dry vegetation classes; and
- Development of risk-based contingency measures.

A number of data gaps were identified in the Surrounding Environment Investigation, of which this report looks to address. And associated with those data gaps a Surrounding Investigation monitoring asset installation program was completed involving the installation of site specific monitoring assets including 212 groundwater (GW) bores, 5 stream gauges and 6 new vegetation monitoring sites.

The outcomes of the Surrounding Environment Investigation are to be provided to SRW by 31 July 2023.

2.3 List of Reports Considered

During the course of the investigation a number of reports as provided by Barwon Water and independently sourced were reviewed. A list of those reports is provided below and summaries of the reports are provided in **Appendix B**.

- W.J.R. Blake, 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area, Geological Survey of Victoria
- J. Leonard, R. Lakey, R. Blake, 1983, Hydrogeological investigation and assessment - Barwon Down Graben, Otway Basin, Victoria, Geological Survey of Victoria (unpublished)
- R. Lakey, 1983, Gellibrand Groundwater Investigation – Kawarren Pumping Test Report, Geological Survey of Victoria
- R. Lakey, J. Leonard, 1983, Gellibrand Groundwater Investigation – Stage II Report, August 1983
- Geological Survey of Victoria, 1984, Department of Minerals and Energy Submission to Natural Resources and Environment Committee Inquiry into Water Resources Management
- HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area - Kawarren Groundwater Resource Evaluation
- P. Dahlhaus, D. Heislers, P. Dyson, 2002, Groundwater flow systems of the Corangamite Catchment Management Authority Region
- B. Petrides & I. Cartwright, 2006, The hydrogeology and hydrogeochemistry of the Barwon Downs Graben aquifer, southwestern Victoria, Australia
- SKM, 2012, Newlingrook Groundwater Investigation, Gellibrand River Streambed and Baseflow Assessment, 21 December 2012
- F. Glover, 2014, Characterisation of acid sulfate soils in south-west Victoria, Australia
- Aquade Groundwater Services, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area
- Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/2016 - Recharge Rate Assessment
- Aquade Groundwater Services, 2017, Impacts of Barwon Downs extraction on groundwater and surface water in the Kawarren Area
- Jacobs, 2018, Barwon Downs Technical Works Program - Potential impacts and risks from future operation of the Barwon Downs Borefield
- Aquade Groundwater Services, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment
- Jacobs, 2019, Technical support for Section 78 Scope of Works - Historical Pumping Risk Assessment Method and Results

- M. Gardiner, 2013, Otway Water Book 21: An aquifer divide shift and Study of the EVF aquifers in the Gerangamete and Gellibrand Groundwater Management Areas, 2012
- M. Gardiner, 2015, Otway Water Book 28: The Western Front, Ten Mile Creek and Loves Creek Catchment, 2015
- Preliminary Draft Regional Landcare Action Plan for the Corangamite Region, 1993
- Stanley 1991, Preliminary Groundwater Resource Evaluation of the Kawarren Sub-region of the Barwon Downs Graben
- Jacobs 2022, Surrounding Environment Bore Completion Report, Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan (REPP), 25 October 2022
- Austral Research and Consulting 2022, Upper Barwon River Macroinvertebrate Sampling Report 2019-2022
- EAL 2011, Preliminary Inland Acid Sulfate Soil Assessment Report, prepared for LAWROC
- Eco Logical Australia 2022, Barwon Downs Vegetation Monitoring Report, - November 2020, prepared for Barwon Water, 28 June 2022
- Eco Logical Australia 2022, Groundwater Dependent Ecosystem Survey of the Barwon Downs region, prepared for Barwon Water, 19 August 2022
- Jacobs 2015, Barwon Downs Vegetation Monitoring Report
- Jacobs 2017, Barwon Downs Vegetation Monitoring Report
- Muir and Carr 1994, Barwon Downs aquifer flora
- Jacobs 2022, Otway Ranges surrounding areas hydrogeological investigation, October 2022
- Witebsky 1995, Groundwater development options and environmental impacts
- Jacobs 2017, Barwon Downs Technical Works Program, Integration Report, 22 March 2017
- Jacobs 2018, Barwon Downs Hydrogeological Studies 2016-2017, Numerical Model Calibration an Historical Impacts, 22 August 2018
- Aquade 2019, Impacts of Barwon Downs Extraction on Groundwater and Surface water in the Kawarren Area, Part B (Update), 15 November 2019

2.4 Information Sources

During the preparation of this report various sources of information were reviewed including:

- Public Databases:
  - Water Measurement Information System (WMIS);
  - Visualising Victoria’s Groundwater (VVG);
  - GeoVic – Earth Resources;
  - Bureau of Meteorology – Climate and Past Weather;
  - Bureau of Meteorology – Groundwater Dependent Ecosystem Atlas;
  - Australian Stratigraphic Units Database;
- Publicly available information relating to geology, hydrogeology, topography, surface water;
- Previous reports provided by Barwon Water;
- Spatial data provided by Barwon Water;
- Excel databases provided by Barwon Water;

- Community recorded rainfall;
- Site inspection accompanied with knowledgeable community members and landholders;
- Stakeholder informal and formal feedback; and
- Community prepared reports.

3 Kawarren Investigation Area (KIA) Overview

3.1 Introduction

The following sections detail the location of the KIA, a brief history and a brief overview of previous investigations.

3.2 KIA Definition

The KIA sits within the wider region identified as the Barwon Downs Graben, which lies approximately 63 km south west of Geelong. The Barwon Downs Graben covers an area of approximately 480 km^2, extending from the Gellibrand area at its southern most extent and north east towards Birregurra (**Figure F1**). The Barwon Downs Graben is divided into two sub-basins as shown on **Figure F1**, which are referred to as:

- The Barwon Downs Sub-basin; and
- The Kawarren Sub-Basin, i.e., KIA.

The KIA is bound to the north and west by the Barongarook High and Otway Ranges to the south. A topographical high associated with the Barongarook High topographically separates the KIA from the Barwon Downs Sub-basin. The topography is shown on **Figure F4** and further discussed in Section **4.3**.

The KIA sits within the Corangamite Catchment Management Authority (CMA) management area. Loves Creek is the main surface water catchment within the KIA, with Yahoo Creek, Ten Mile Creek and Porcupine Creek sub-catchments all draining into Loves Creek. The Loves Creek catchment drains into the Gellibrand River which borders the south-western boundary of the KIA (**Figure F2**).

3.3 KIA History

Pre-European settlement, the KIA would have been vegetated with clearing of native vegetation for farmland generally occurring during early European settlement circa. 1930s (Gardiner, 2015c; Mary Sheehan & Assoc. , 2003). Rail was developed within the KIA in the 1880s which assisted the forest and livestock industry however, access to the area was largely restricted due to a lack of road transport (Mary Sheehan & Assoc. , 2003).

Between approximately the 1940s and 1970s an increase of land clearing appeared to have occurred, coinciding with soldiers returning from war (Mary Sheehan & Assoc. , 2003) including large tracts of land along Ten Mile Creek (Gardiner, 2015c). Plantations of pine and gum have been in the area since c. 1970s (pers. Comms M. Gardiner) with multiple rotations occurring. These areas are located along the headwaters of both Yahoo Creek and Ten Mile Creek. Large patches of remnant native vegetation remain in the KIA.

Various extractive industries have been documented in the area including clay pits for brick making, ironstone for paint pigments and sand mining at Barongarook; and lime quarries at Kawarren between c. 1903 and 1957 (Mary Sheehan & Assoc. , 2003).

Aerial imagery provided by Barwon Water between 1982 and 2019 (presented in **Appendix C**) indicate several areas within the KIA boundary have been logged including:

- Land to the north of and south of Gravel Pit Road, east of Yahoo Creek Track - 1982;
- Land south of the junction of Campiglis Road and Bull Hill Road - 1983;
- Land south west of the junction of Pipeline Road and Colac-Olangolah Pipeline Track – 1998; and
- Land located at the end of Kents Access – 2000.

These logging areas correspond to areas defined as ‘non native tree areas’ on **Figure F5**.

The Barwon Downs and KIA were first investigated as a potential water supply option to augment Geelong’s drinking water during periods of drought in the 1960s (Blake, 1974). The Barwon Downs borefield was developed in the 1970s and Geelong Waterworks and Sewerage Trust (now Barwon

Water) was granted a licence in 1975, however, extraction did not occur until 1982 (Barwon Water, 2019). Further information regarding the borefield and extraction volumes and periods is provided in **Section 4.9.5,** below.

3.4 Previous Investigations

The KIA and wider Barwon Downs area have been the subject of numerous historical investigations since the approximate 1960s, when the Barwon Downs area was first mentioned as a potential option for a borefield to augment Geelong's water supply during periods of drought. The Barwon Downs area was the first option considered for groundwater supply and planning and investigations occurred c. 1970s before the installation of three production bores in the current borefield area (further detail on the production bores is provided in **Section 4.10.1**, below).

The first phases of investigations were completed on behalf of Geelong Waterworks and Sewerage Trust (now Barwon Water) (Blake, 1974) and identified the main recharge areas of groundwater to the LTA were along the flanks of the Barongarook High, while groundwater flowed from the Barongarook High south west towards Gellibrand River and east north east towards the Barwon Downs sub-basin and the thickest portions of the Barwon Downs graben. Studies completed in the 1980s (Leonard et al., 1983) estimated a recharge of ~14,800 ML/year from Barongarook High to the primary aquifer of interest (Lower Tertiary Aquifer (LTA), noting that these have varied over time and are further discussed in **Section 4.9**).

Leonard et al., (1983) noted that pumping of the borefield was scheduled to commence in February 1983 with a total of three production bores and a combined daily extraction allowance of 35 ML. It was noted that if recharge calculations were correct then the annual extraction allowance of 12,400 ML would exceed recharge from one of the main recharge avenues (Yeodene recharge avenue). A second borefield was proposed and was under consideration pending further pumping test results.

Subsequent pumping tests in the KIA (Lakey, 1984) identified/recommended the following:

- Both the Dilwyn and Mepunga Formations were found to not comprise a homogeneous aquifer. Slow and incomplete recovery was considered to be *due to partial and permanent collapse of aquifer skeleton resulting from depressurising the system from its pristine and possibly slightly over-pressured system*. Similar residual drawdowns were observed in the Barwon Downs borefield – potentially due to the same issue.
- An area of concern in relation to the development of a borefield in the Kawarren area was the impact of reduced water levels on streamflow in Ten Mile Creek and Yahoo Creek, and discharge on the natural springs in the area (presumably it was meant by the authors where these springs are connected to the LTA). Many springs in Kawarren area were understood to be fed by the Clifton Formation.
- Pumping tests indicated that drawdowns would initially stabilise upon recharge from the Gellibrand River and reduction in unconfined storage on the Barongarook High. If pumping exceeds the mean annual recharge of the aquifer then substantial drawdown of the unconfined aquifer and further reduction of the confined aquifer storage was considered likely to occur. Although this could be offset by increased streambed infiltration from Gellibrand River.
- Recommended installation of stream gauges on Yahoo and Ten Mile Creeks, comprehensive survey of springs in the area, completion of additional pumping tests.

An investigation into the recharge area of the Barongarook High by (HydroTechnology, 1994) identified an area of approximately 12 km^2 of outcropping aquifer material which was considered to act as the principal recharge area to the KIA, from a total outcrop area of 28 km^2. A groundwater divide was found to separate groundwater flow from the Barongarook High into the either the Barwon Downs Sub-area or the KIA. Groundwater discharge was considered to occur to streams draining the Barongarook High including Ten Mile Creek and Boundary Creek. HydroTechnology (1994) conclude the sustained pumping (from either or both the Barwon Downs borefield and proposed Kawarren borefield) would reduce water levels on the Barongarook High and thus the groundwater divide would shift resulting in reduction of rejected recharge to the surface water systems, streams and springs. However, the degree and magnitude of the groundwater divide shift would be dependent on the scale of extraction.

The KIA was still being investigated for a potential second borefield up until 2007 (SKM, 2012). This investigation identified the Gellibrand River as being highly connected to the LTA groundwater system and was found to be both currently and historically gaining (receiving groundwater discharge) along various reaches of the river. It was concluded that pumping may *"…induce greater leakage rates from the regional aquitard (Clifton Formation) may impact on springs fed from this formation"* (SKM, 2012). However, this impact was considered by SKM to be dependent on whether the water table in the Clifton Formation was perched or fully saturated, and if fully saturated *"…the magnitude and duration before any potential impacts on springs occur are uncertain."*

A strong connection between springs derived from shallow groundwater were identified as contributing to tributaries of Loves Creek such as Ten Mile, Yahoo, Porcupine and Serpentine Creeks. The report also noted that consideration of other natural factors such as periods of drought and other climatic factors had the potential to impact groundwater baseflow to the Gellibrand River and other streams. SKM (2012) recommended a permissible consumptive volume (PCV) be developed for the Gellibrand Groundwater Management Authority (GMA) that took into account the expected strong connection between groundwater pumping and stream flow.

From approximately 2015, investigations such as (Aquade, 2015), (Aquade, 2017), (Jacobs, 2018a) and (Aquade, 2019) have focussed on the assessment of impacts of borefield pumping on groundwater levels in the LTA in both the Barwon Downs sub-basin and the KIA. The investigations (with a focus on KIA) identified that groundwater extraction had resulted in drawdown of the LTA in the KIA of up to 4 m. Further, a significant reduction of baseflow in Loves Creek was observed post 1997, with the baseflow in Loves Creek (i.e. minimum annual streamflow) reducing by approximately 60% (Aquade, 2019).

Jacobs (2019) predicted a reduction in baseflow of ~6% in the Gellibrand River since the mid-1990s based on numerical modelling. Jacobs also predicted the following impacts:

- Estimated maximum impact associated with historical pumping on Gellibrand River baseflow was ~0.3 ML/day (~2% of baseflow);
- Maximum impact associated with historical pumping on Ten Mile Creek was 0.2 ML/day (~15% baseflow);
- Estimated maximum impact associated with historical pumping on Yahoo Creek was 0.08 ML/day (~8% of baseflow); and
- Estimated maximum impact associated with historical pumping on Loves Creek was 0.02 ML/day (~1% baseflow).

It is noted these investigations focussed on reductions in baseflow as opposed to total streamflow as baseflows are most likely to be driven by groundwater contributions, whereas overall streamflow represents a combination of surface water runoff and groundwater discharge. Further, it is under low flow conditions (e.g. in summer when rainfall and hence runoff are their lowest) when the greatest potential for impacts to occur due to reductions in groundwater discharge to waterways.

A significant body of work has also been conducted by LAWROC and local community members in relation to the KIA and broader Barwon Downs Graben. This has involved extensive documentation of the groundwater and surface water issues in the area, monitoring of rainfall and streamflows, consolidating historical and technical information amongst other things. Much of this work has been published online[2] and has been considered as part of this HA. LAWROC has also commissioned its own technical studies including (Aquade, 2015), (Aquade, 2017), (Aquade, 2019) and (EAL Consulting Service, 2011).

[2] https://www.otwaywater.com.au/

4 Conceptual Site Model

4.1 Introduction

The CSM for the KIA, including consideration of climate, topography and drainage, geology and hydrogeology is presented in the following sections.

4.2 Climate

4.2.1 Regional Conditions

The Otway Ranges record some of the highest rainfall in Victoria with averages over a 30 year period indicating the region has between 1,000 and 1,500 mm/year (see **Figure 1** below). Average annual rainfall between 1960 and 1991 indicated averages of between 900 and 1,200 mm/year (Barwon Water, 2022) indicating an overall increase in average annual rainfall during the most recent 30 year period. Regions inland from the Otway Ranges record average annual rainfall totals of <1,000 mm/year. Regionally the average annual pan evaporation ranges between 1,200 and 1,400 mm/year (see **Figure 1**, below).

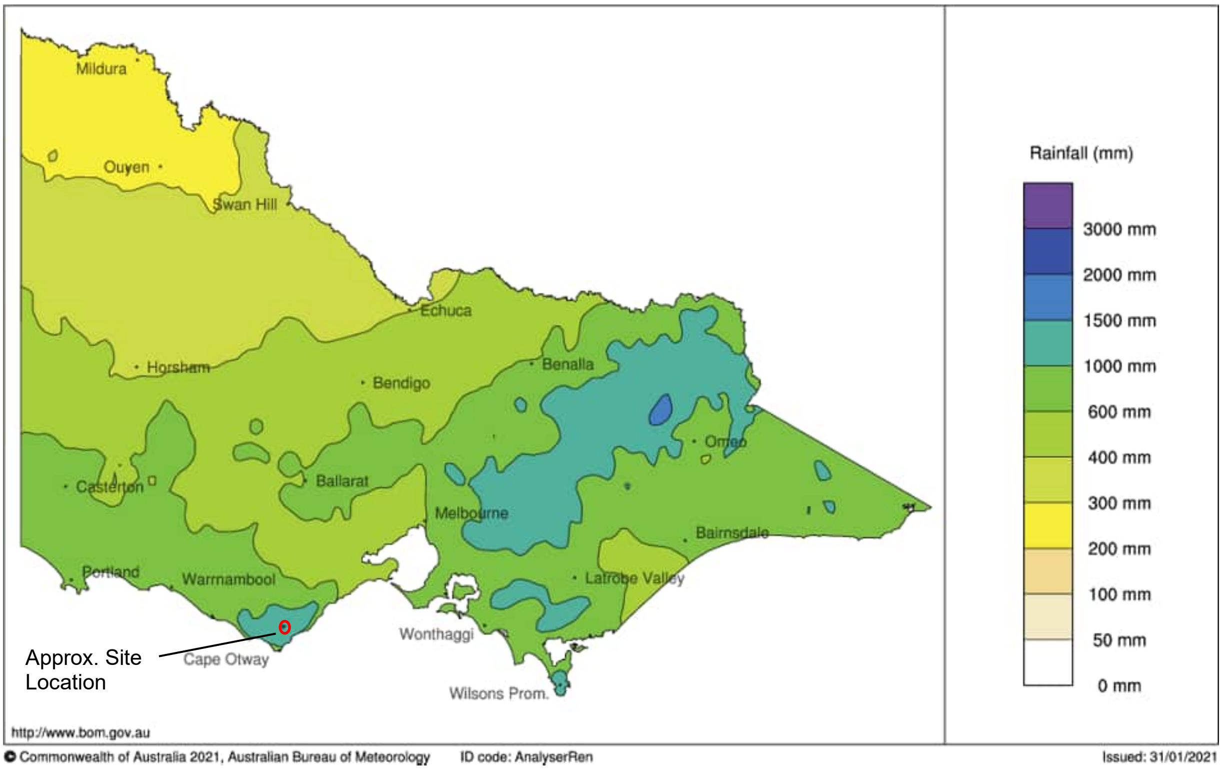

Figure 1 Spatial Trend of Average Annual Rainfall in Victoria (1991 – 2020, 30 year period) (BoM, 2020)

4.2.2 Recognised Drought Periods

A review of Bureau of Meteorology (BoM) data shows approximately seven periods of recognised drought in Australia, since Federation summarised as follows:

- 1895 – 1902 "Federation Drought";
- 1914 – 1915;
- 1937 – 1945 "World War II Drought";
- 1965 – 1968;
- 1982 – 1983 considered one of the most severe in Australia;
- 1997 – 2009 "Millennium Drought"; and

- 2017 – 2019.

The droughts identified during 1982-83 and 1997-2009 indicate rainfall in the KIA was ‘very much below average’ and ‘lowest on record’, respectively as defined by the BoM (see **Figure 2**, below).

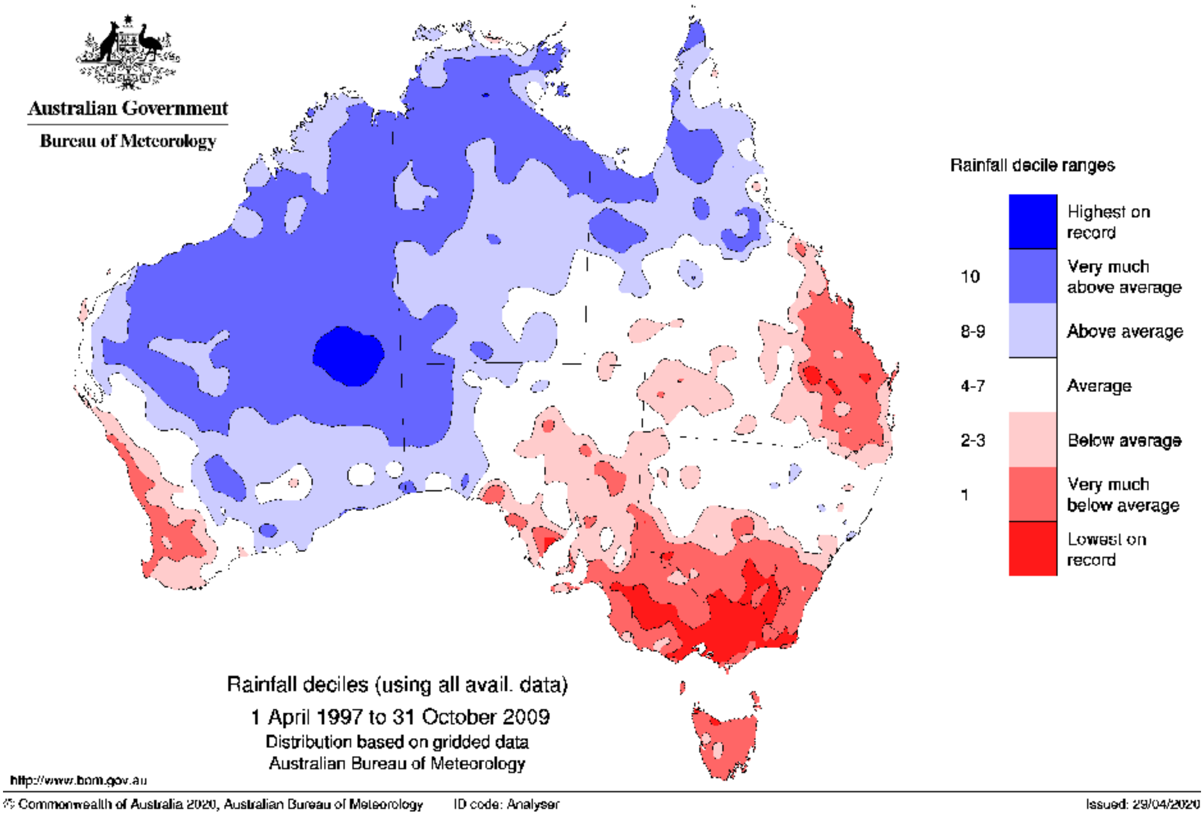

Figure 2 Rainfall deciles for the Millennium drought (1997 to 2009) (Bureau of Meteorology, 2020).

4.2.3 Local Rainfall Conditions

4.2.3.1 Available Data

Rainfall data within the KIA and surrounding areas has been collected by both community members and BoM from nine stations across the Barwon Downs Region. The records start from as far back as 1900 for several of the stations. The locations of the rainfall collection stations are shown on **Figure F3** and their name and station number are provided in **Table 2**, below.

The rainfall records collected and identified as Kawarren Rainfall (M. Calvert) and Wanawong Rainfall (D. Hopkins) have been adopted specifically for this HA based on their long durations which are of specific value to appraising long-term groundwater influence. In addition, the community gathered rainfall records are comparable to official records, including the BoM record from Forrest State Forrest #90040, located approximately 5 km east of the investigation area, which suggests these datasets are sufficiently robust to appraise local rainfall conditions.

Table 2 Rainfall Stations

Station	Type	Source	Within KIA	Period of Collection
Kawarren Rainfall (M.Calvert)	Community Gathered	M.Calvert, Kawarren	Yes Kawarren Area	1900 – 2022
Gellibrand River Forestry #90134	BoM	BoM	Yes Gellibrand River Area	1956 – 2015

Station	Type	Source	Within KIA	Period of Collection
Wanawong Rainfall (D. Hopkins)	Community Gathered	D. Hopkins, Barongarook West	Yes Barongarook Recharge Area	1976 – 2022
Kawarren Rainfall (M. Gardiner)	Community Gathered	M. Gardiner, Kawarren	Yes Kawarren Area	1999 – 2004
Gellibrand Rainfall (B.Dawes)	Community Gathered	B. Dawes, Kawarren East	Yes Gellibrand River Area	2009 – 2022
Forrest State Forrest #90040	BoM	BoM	No	1900 – 2017
Barwon Downs #90004	BoM	BoM	No	1900 – 2022
Barongarook Rainfall (J. Healey)	Community Gathered	J. Healey, Barongarook	No	1978 – 2022
Agroforestry Site #233250	WMIS	WMIS	No	1994 – 2022

4.2.3.2 Average Annual Rainfall

Average annual rainfall is presented for each station in **Table 3**. The peak annual rainfall totals are evident in the southern portion of the KIA (up to 1009 mm/year at Forrest State Forest), with slightly lower totals in the Kawarren area (e.g. 981 mm at Kawarren Rainfall (M.Calvert)). To the east of the KIA, within the Barwon Downs Sub-Area, rainfall totals are much lower, with 611 mm at Agroforestry Site #233250, which is located 7.5 km east of the investigation area and approximately 10 km from Kawarren.

Average annual rainfall, from all rainfall stations over time is shown on **Figure 3**. Periods of below average rainfall (generally coinciding with acknowledged drought periods) are evident throughout the dataset period. The five year moving average smooths the dataset over time. Long term-trends are further described in **Section 4.2.3.3**.

Table 3 Average Annual Rainfall by Station

Station	Average Annual Rainfall (mm/year)	Period of Collection
Kawarren Rainfall (M.Calvert)	981	1900 – 2022
Gellibrand River Forestry #90134	961	1956 – 2015
Wanawong Rainfall (D. Hopkins)	970	1976 – 2022
Kawarren Rainfall (M. Gardiner)	909	1999 – 2004
Gellibrand Rainfall (B.Dawes)	1006	2009 – 2022
Forrest State Forest #90040	1009	1900 – 2017
Barwon Downs #90004	760	1900 – 2022
Barongarook Rainfall (J. Healey)	897	1978 – 2022

Station	Average Annual Rainfall (mm/year)	Period of Collection
Agroforestry Site #233250	611	1994 – 2022

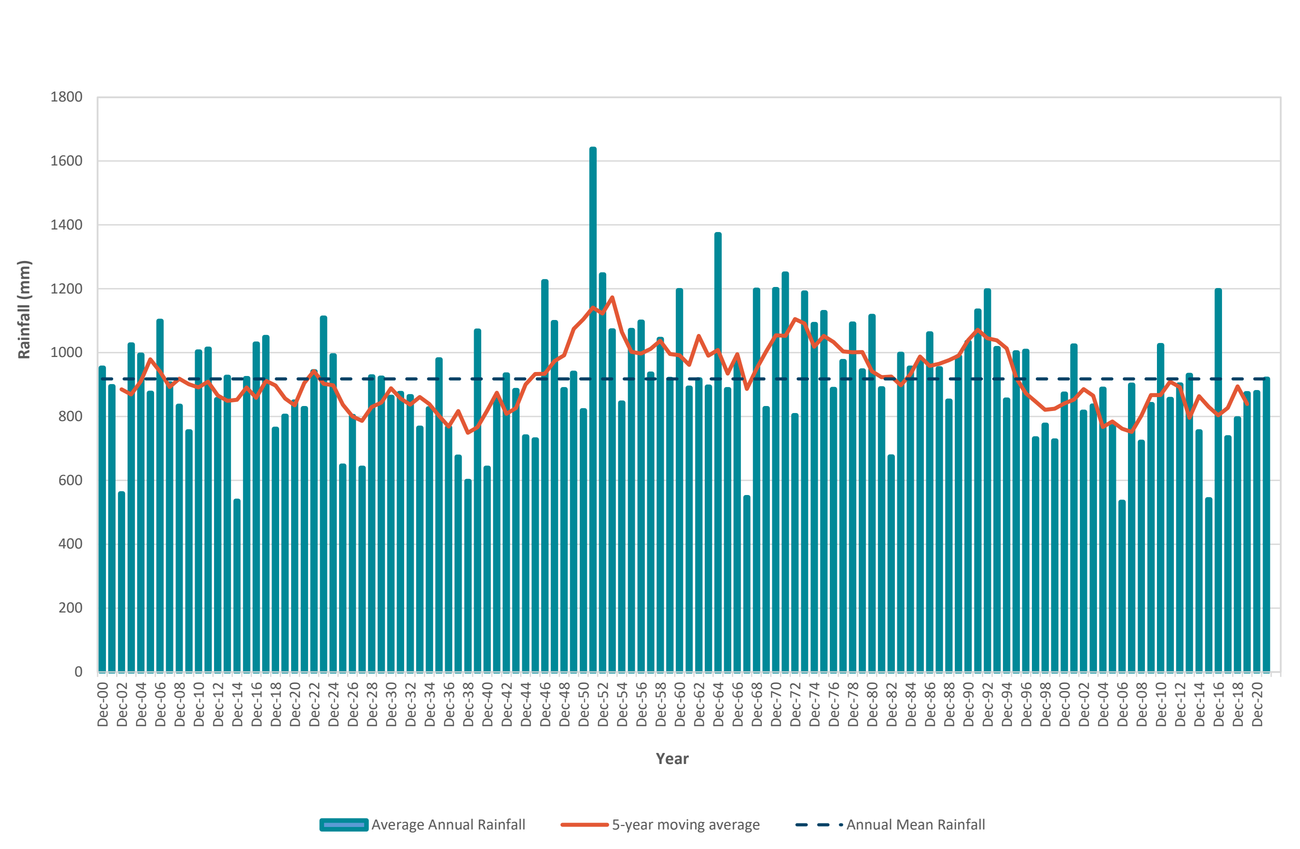

Figure 3 Average Annual Rainfall from nine rainfall station sites

4.2.3.3 Long-Term Rainfall Trends

To provide a further indication of long-term rainfall trends, rainfall data collected has been plotted as accumulative monthly residual rainfall (AMMR) for the nine stations (see **Figure 4**, below). AMRR provides the cumulative deviation of rainfall totals from the average monthly total. A negative deviation indicates a declining rainfall trend (i.e., potential period of drought) and a positive deviation indicates an increasing rainfall trend (i.e. above average rainfall).

The following observations are noted:

- The rainfall data follow a largely consistent pattern with some deviations at several stations, most notable during the late 1990s when data from J.Healey (Barongarook recharge area), Wanawong (D.Hopkins) and Agroforestry #233250 trends up while the remaining data tends to trend down. The trend down corresponds with the Millennium Drought period.
- Rainfall data from J.Healey (Barongarook recharge area) continues to trend down until the last record available (August 2022). This is also the case for data collected from Gellibrand Station #90134, however, the data collected ceases in June 2015, so it is not clear if there is an increase in rainfall.
- From approximately 2017, rainfall appears to stabilise at M. Calvert (Kawarren Area), Agroforestry #233250, Wanawong (D.Hopkins) and D.Dawes (Gellibrand River area) and appear to stabilise close to average monthly totals.

- Conversely from approximately 2017 rainfall continues to decline at J. Healey (Barongarook recharge area), Gellibrand Station #90134, Forrest #90040 and Barwon Downs #90004, remaining well below average monthly totals.

Overall, the long-term patterns are relatively consistent particularly since the 1950s. A period of overall increasing rainfall was evident between the 1950s and approximately 1997, after which a period of decreasing rainfall has prevailed.

The cumulative change in monthly rainfall during the period 1997 to 2009 (i.e. the millennium drought) is provided in **Table 4**. This shows that the cumulative reduction in rainfall from the mean during the Millennium Drought was a deficit of between 426 mm and 1,921 mm over the 13 period. This equates to average annual deficits of between 33 mm/year (in the Barwon Downs Sub-Area) and 148 mm/year at Kawarren (M.Calvert).

It is noted that Kawarren Rainfall (M.Calvert) and Gellibrand River Forestry #90134 show a similar deficit (148 mm/year and 118 mm/year respectively), whereas, Wanawong Rainfall (D. Hopkins) had a deficit of 66 mm/year. Given the average annual rainfall values at each of these stations are comparable, the discrepancy in the deficit appears to represent local variation.

Table 4 Cumulative Change in Rainfall (1997 to 2009) by Station

Station	Average Annual Rainfall (mm/year)	Total Cumulative Change in Rainfall (1997-2009)	Average Cumulative Change in Rainfall (mm/year)	Percentage Change from Mean Annual Rainfall (%/year)
Kawarren Rainfall (M.Calvert)	981	-1921	-148	15%
Gellibrand River Forestry #90134	961	-1528	-118	12%
Wanawong Rainfall (D. Hopkins)	970	-859	-66	7%
Kawarren Rainfall (M. Gardiner)	909	Incomplete record during applicable time period	Incomplete record during applicable time period	-
Gellibrand Rainfall (B.Dawes)	1006	Incomplete record during applicable time period	Incomplete record during applicable time period	-
Forrest State Forest #90040	1009	-1145	-88	9%
Barwon Downs #90004	760	-426	-33	49%
Barongarook Rainfall (J. Healey)	897	-797	-61	7%
Agroforestry Site #233250	611	-599	-46	7%

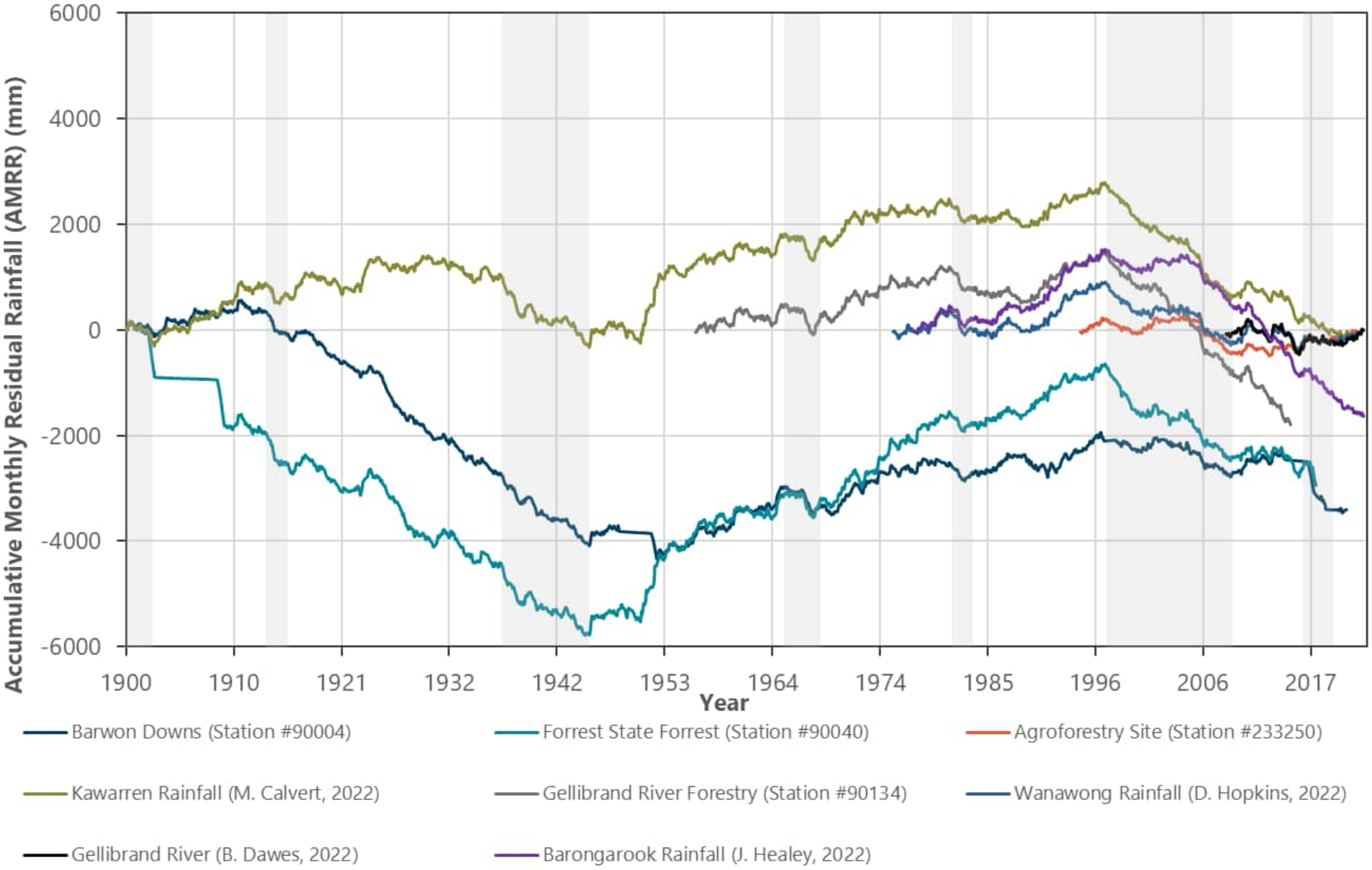

Figure 4 Accumulative Monthly Residual Rainfall (grey shading indicates periods of drought)

4.2.4 Evaporation

The annual pan evaporation for the Barwon Downs region since 1985 has ranged between approximately 1,400 mm/year and almost 1,800 mm/year, which is generally higher than the Victorian average annual pan evaporation (see **Figure 5**, below).

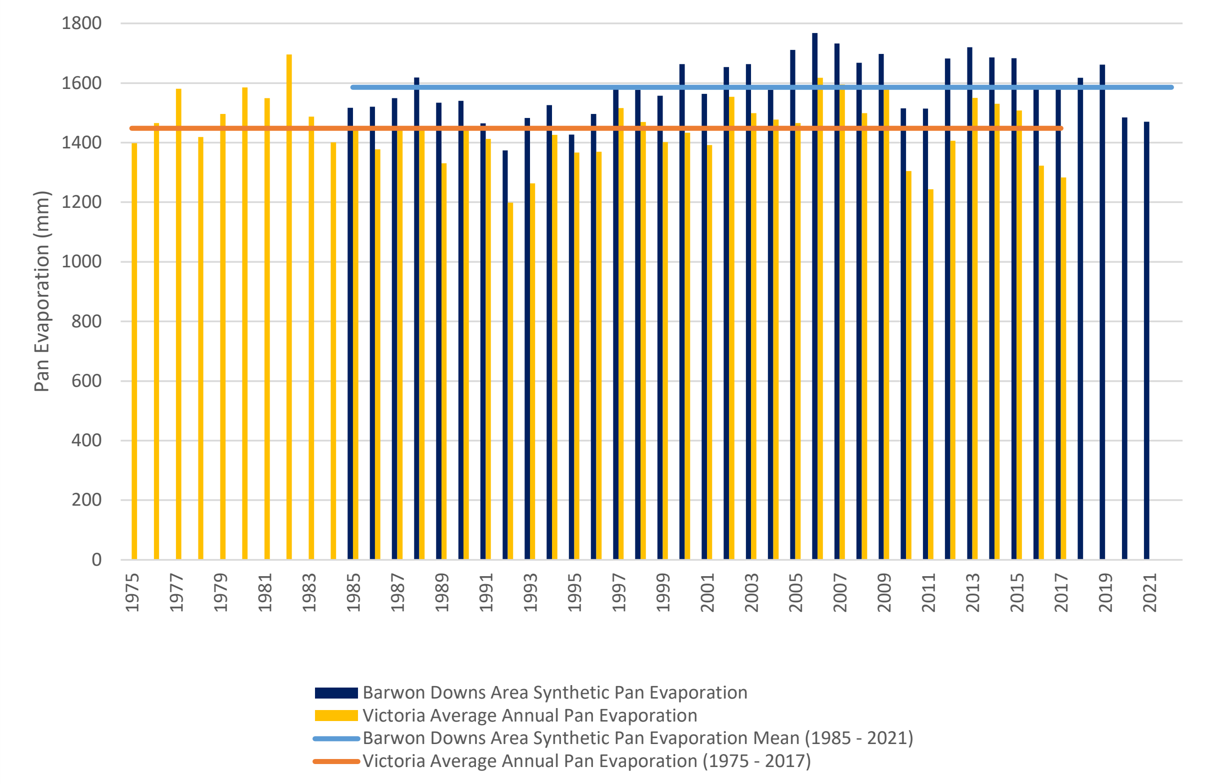

Figure 5 Pan Evaporation Barwon Downs Area

4.2.5 Climate Change

In 2019 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) published a report titled Barwon Climate Projections 2019 (Clarke et al., 2019). This report details the projected change in climate within the Barwon region as a result of global warming from anthropogenic influences. Predicted outcomes are based off of two plausible scenarios of future greenhouse gas emissions: medium emissions and high emissions. Additionally, BoM and CSIRO published a ‘State of the Climate 2022’ report in 2022 (Commonwealth of Australia, 2022).

It is estimated that over the coming decades there will be a decline in total annual rainfall as well as an increase in the natural variability of rainfall. Projected future rainfall values were modelled and compared against the mean annual rainfall from 1986 – 2005. It is projected that under a high emission scenario, there will be a median of 24% decrease in annual rainfall totals with the greatest change (34%) noted in spring. This is largely supported by the Commonwealth of Australia (2022) report which reports that rainfall in south eastern Australia has decreased by around 10% in April to October since the late 1990s, with 19 of the 22 years from 2000-21 being below the 1961-90 average. The April-October period is important as it is generally when peak stream flow occurs in catchments in the south eastern region of Australia. The reduction is due to a *"...combination of natural variability on decadal timescales and changes in large-scale circulation caused by an increase in greenhouse gas emissions."* (Commonwealth of Australia, 2022). The report notes that the Millennium Drought was a major influence in the declining rainfall however, cool season rainfall totals are 7% below the 1900-99 average post 2010 (Commonwealth of Australia, 2022).

A decrease in streamflow is projected to be greater than the predicted decrease in mean annual rainfall with the greatest impacts noted to be present in Victoria’s south-west (DEWLP et al., 2020). It is projected that there may be an average streamflow reduction by up to 50% in some catchments by 2065 (BOM et al. 2020). As a result, catchment runoff generation is expected to decline in the coming decades with the reduction in streamflow. A declining trend in streamflow is seen in more than 60% of

Australia's hydrologic reference stations, with more than 20% showing a statistically significant declining trend (Commonwealth of Australia, 2022).

4.3 Topography

To the south east of the KIA in the Otway Ranges, topographic elevations are approximately 600 m Australian Height Datum (m AHD) and grade relatively steeply towards the south east and north. North of the Otway Ranges the topography grades to elevations of approximately 200 m AHD with local undulations present. Further to the north is the basalt plains of Western Victoria, which form a relatively flat landscape dotted with volcanic eruption points.

The KIA is on the foothills of the Otway Ranges to the south, however, the highest elevations within the KIA occur along the north western boundary at approximately 300 m AHD, along the Barongarook High (**Plate 1** and **Figure F4**). The Barongarook High forms the northern boundary of the KIA at approximately 260 m AHD. While there is an overall relief of high to low towards Loves Creek within the KIA, the area is dominated by ridges and gullies. In some areas of the catchment (e.g., along Gellibrand River) the topography decreases by 100 m AHD over a distance of approximately 400 m, with the river flats lying at ~80 m AHD.

Along the lower reach of Loves Creek, just to the south of Campiglis Road (**Figure F4**) the elevation also decreases to 80 m AHD.

Plate 1 View from Gravel Pit Road, looking east towards Loves Creek Valley, Otway Ranges in distance

4.4 Drainage

The KIA sits within the Otway Coast Basin which extends from east of Torquay to just west of Port Campbell. There are two catchments within the Otway Coast Basin: Gellibrand River catchment and Otway Coast Catchment. The KIA sits within the Gellibrand River Catchment. The Gellibrand River starts in the Otway Ranges south of the KIA before heading north and bordering the KIA along the southern boundary. South west of the KIA, the Gellibrand River flows south west and drains into the ocean.

The Gellibrand River catchment is fed in part by the Loves Creek catchment (see extent of Loves Creek Catchment on **Figure 6** below), within which the KIA sits. Ten Mile Creek, Yahoo Creek and Porcupine Creek are tributaries of Loves Creek. Surface water is discussed further in **Section 4.13**.

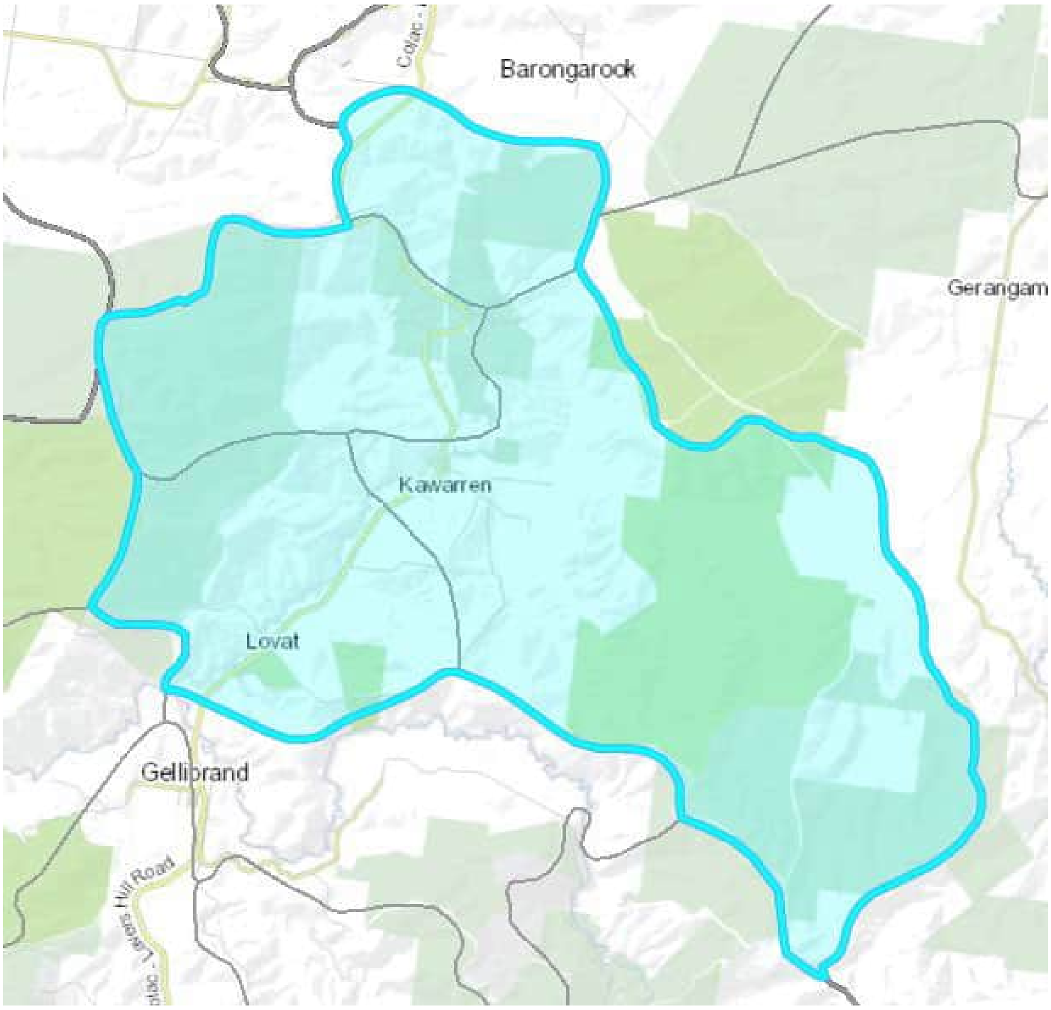

Figure 6 Loves Creek catchment including Ten Mile Creek, Yahoo Creek and Porcupine Creek sub-catchments (MapShare Victoria, Department of Energy, Environment and Climate Action (EECA) formerly Department of Environment, Environment, Land, Water and Planning (DEWLP))

4.5 Vegetation

Regionally the vegetation is predominantly Lowland Forest, Heathy Woodland and Scrubby Foothill Forest as can be seen on **Figure F5**. The Lowland Forest appears to be predominantly located on elevated areas, i.e., Barongarook High, while the Scrubby Foothill Forest appears to be associated with the Otway Ranges.

Locally the dominant vegetation apparent in the KIA is Lowland Forest. Riparian Forest is present along both the upper reaches of Ten Mile Creek and the lengths of Loves Creek and Gellibrand River. The upper reaches of Porcupine Creek is dominated by Heathy Woodland and some Wet Heathland. A Reference Area is noted as being within the National Park area through which Porcupine Creek, or tributaries of Porcupine Creek flow. One anecdotal observation indicated “severe stress” of vegetation in approximately 2010 along the Gellibrand River over areas of Quaternary Sediments and LTA outcrops.

As observed during a site inspection, there are several large pockets of plantations (either blue gum or pines) which are identified as non native tree areas on **Figure F5**. The non native tree areas align with the plantation areas observed during the site inspection (see **Section 4.6**). The largest plantation was observed in the upper reaches of Yahoo Creek and appeared to have recently been cleared. It is understood anecdotally that there have been approximately three rotations of plantations since ~1970s.

4.6 Site Inspection

On the 23 and 24 November 2022 representatives from BlueSphere, Barwon Water, Otway Water and LAWROC completed an inspection of key locations within the KIA and met with and interviewed members of the community. The inspection was completed to:

1) Gain a firsthand appreciation of the local conditions; and
2) Interview community members who have springs or soaks on their properties.

A summary of the interviews and follow up interviews with other members of the community is provided in **Appendix D**. Information obtained during the site inspection and interviews is documented throughout the report.

Overall it was evident from the inspection that springs and soaks are utilised extensively for stock and domestic purposes, forming a highly valued local resource. Many of these springs occur in areas that are underlain by the LMTA (mostly Gellibrand Marl). Visual observation indicates that these springs occur at the break of slope, suggestive of shallow water tables in this area.

The anecdotal information did not reveal any consistent evidence to suggest that the extraction has had a demonstrable impact on the environment within the KIA. However, specific concerns regarding potential acid sulfate soils, loss of stream flow and decline of native fish and platypus populations were noted. There were concerns expressed that the pumping from the Barwon Downs borefield had affected their springs, or that future extraction could have material impact on their water supply.

4.7 Land Use Review

Regionally land use generally corresponds with the changes in topography with the elevated areas generally corresponding with forested (and in some instances national parks) areas and the lower areas generally corresponding with farming.

Within the KIA, the land use appears to be a mix of forested areas, plantations and farming. As is the case regionally, farming is generally constrained to the lower elevations of the KIA while the forested areas are predominantly in the higher elevations.

As discussed in **Section 3.3**, above, plantations of pine and gum have been in the area since c. 1970s (pers. Comms M. Gardiner) with multiple rotations occurring. These areas are located along the headwaters of both Yahoo Creek and Ten Mile Creek. Large patches of remnant native vegetation remain in the KIA.

Aerial imagery provided by Barwon Water between 1982 and 2019 (presented in **Appendix C**) indicate several areas within the KIA boundary have been logged including:

- Land to the north of and south of Gravel Pit Road, east of Yahoo Creek Track - 1982;
- Land south of the junction of Campiglis Road and Bull Hill Road - 1983;
- Land south west of the junction of Pipeline Road and Colac-Olangolah Pipeline Track – 1998; and
- Land located at the end of Kents Access – 2000.

These logging areas correspond to areas defined as ‘non native tree areas’ on **Figure F5**.

A review of recent Google Earth imagery indicates that in 2011, the land observed in the 1982 aerial image (i.e., that to the north and south of Gravel Pit Road and east of Yahoo Creek Track had been cleared and by 2014 it appeared to have been replanted. During 2022 the area had again been cleared. Based on the aerial images available there does not appear to be any obvious evidence of vegetation dieback along either Ten Mile or Yahoo Creeks during pumping.

One anecdotal observation indicated “severe stress” of vegetation in approximately 2010 along the Gellibrand River over areas of Quaternary Sediments and LTA outcrops.

Gardiner (2015c) further details land use change in the KIA and notes very little land use change for approximately the previous 50 years. Prior to that readily accessible land that was suitable for agriculture was cleared.

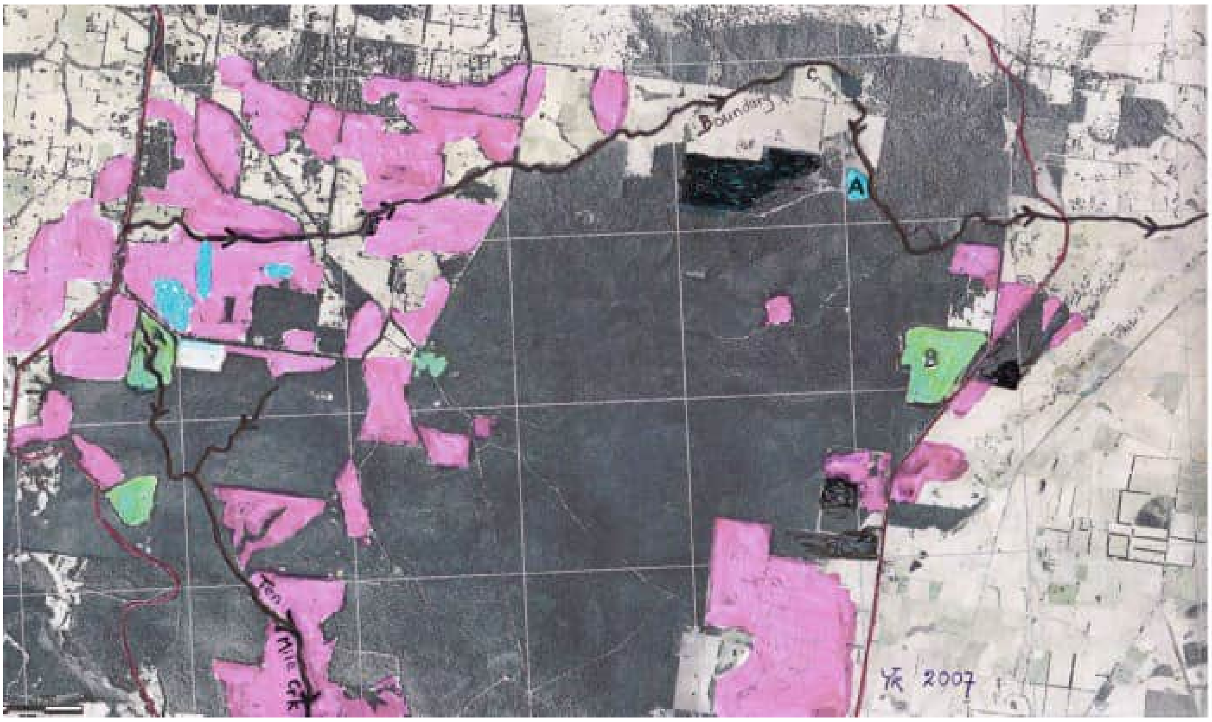

Figure 7 Map 55 from (Gardiner, 2015c) showing areas cleared of trees between 1947 and 1977 (pink shading), between 1977 and 2007 (blue shading). Green shading indicates areas planted out with pine or eucalyptus

4.8 Geology

4.8.1 Structural Setting

The KIA sits within the Otway Basin which is an east-west aligned trough containing a thick sequence of Tertiary aged sediments and volcanics. The Otway Basin is divided into a number of *intra-basinal structural embayments, troughs and highs* (Holdgate & Gallagher, 2003) of which the Port Campbell Embayment is one.

The KIA is located in north-eastern corner of the Port Campbell Embayment (see **Figure 8**). The region within which the KIA sits is dominated by faulting along northeast /south west alignments with the Loves Creek-Barwon Fault and the Bambra Fault bounding the KIA and the wider Barwon Downs Graben area to the north west and south east (see **Figure 8** below). It should be noted that the Loves Creek-Barwon Fault was reclassified to a monocline by (Tickell et al., 1991).

During the Late Cretaceous period, the Otway Group was block faulted with the Otway Ranges and the Barongarook High undergoing an initial uplift (Lakey & Leonard, (1983); Tickell et al., (1991). During the mid-Tertiary period the north eastern portion of the Port Campbell Embayment underwent another major tectonic event during which the area was block faulted by a series of northeast-southwest trending faults (Tickell et al., 1991) (see **Figure 9**, below). Tertiary sediments were deposited within the down-thrown blocks in geological features referred to as grabens. The Tertiary sediments are considered to be largely undisrupted by the faulting and were 'draped' over the Otway Group in either anticlinal or synclinal folds (Stanley, 1991).

4.8.1.1 Grabens

The Barwon Downs Graben and Carlisle River Graben are the two main structural low features in the north-eastern portion of the Port Campbell Embayment and separate the structural highs of the Otway Ranges to the south east and the Barongarook High to the north west (see **Figure 9**, below). The Barongarook High is dominated by several north easterly trending anticlines and north westerly trending monoclines, which have further divided the Barongarook High into several minor structural elements over which the Otway Group are generally encountered at shallow depths, or even outcrop in valley sides (Lakey & Leonard, 1983).

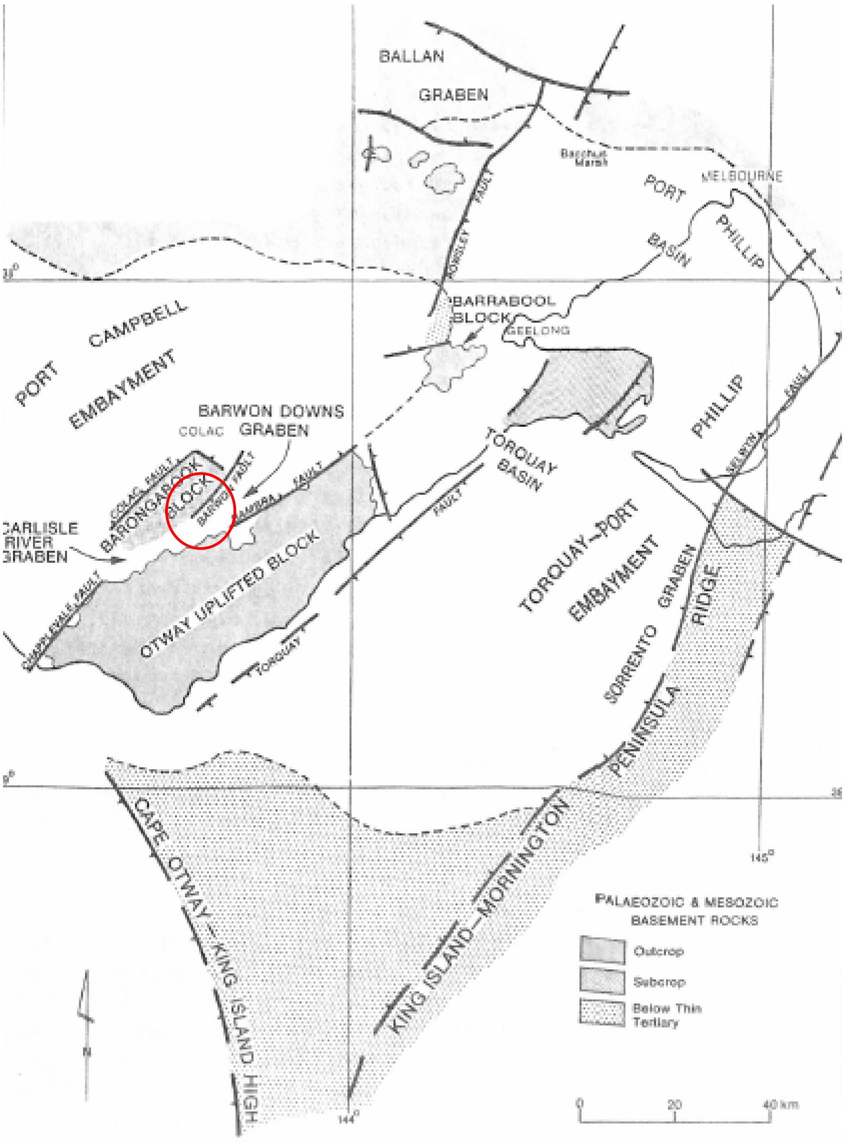

Figure 8 Regional Tectonic Setting, Eastern Otway Basin (after Department of Minerals and Energy (1984)) (approximate KIA Location shown in red)

The Barwon Downs Graben is bordered by the Loves Creek Monocline in the north, separating the graben from the Barangarook High (**Figure 9**). To the south the Bambra Fault separates the graben from the Otway Ranges.

The Barwon Downs Graben is separated into two distinct sub-basins, the Kawarren sub-basin (i.e. the KIA, also previously referred to as the Gellibrand Depression) and the Barwon Downs sub-basin. The centre of the KIA is underlain by the Barwon Downs syncline, which is orientated in a south-west to north-east orientation.

The Barwon Downs Graben is at its widest in the north eastern portions of the graben and narrows to the south west near Gellibrand where the Loves Creek Monocline and Bambra Fault converge (**Figure F1**). The narrowing of the graben is coincidental with a shallow basement structural high referred to as the Gellibrand Saddle (see **Figure 9**, below).

The KIA sits within the Kawarren sub-basin which is the south westerly extension of the Barwon Downs Graben. The Kawarren sub-basin is a half graben associated with the Loves Creek Fault and the Kawarren Fault (Lakey & Leonard, 1983).

4.8.1.2 Yeo Dome Basement High

The Kawarren sub-basin is partially separated from the Barwon Downs sub-area by a basement high that is bordered by the Boundary Creek and Barwon Monoclines to the north and south respectively (**Figure F1**). This area is referred to as the 'Yeo Dome'. This term was first used by Leonard in 1983 to describe a marl covered basement high. It is understood that this interpretation was based upon a geological investigation borehole drilled on 1 June 1979 (bore 307437/Gerangamete 8004). The borelog describes 19.5 m of Narrawaturk Marl overlying Eumerella Formation (Otway Group).

However, Stanley (1991) subsequently stated that *'drilling in the area previously regarded as the marl covered bedrock high, the Yeo Dome, has shown that this structure does not exist, but resulted from the misinterpretation of lithology by previous workers (Tickell et al., 1991)'*. BlueSphere's review indicates that the structure (a basement high) does exist, however, it is not marl covered. Reinterpretation of the lithology by Tickel et al., (1991) and further drilling by HydroTechnology (1994) established that a basement high was present, however, it was covered in Dilwyn Formation, not marl. BlueSphere uses the term Yeo Dome herein to describe the basement high and not specifically the sediments that overlie it.

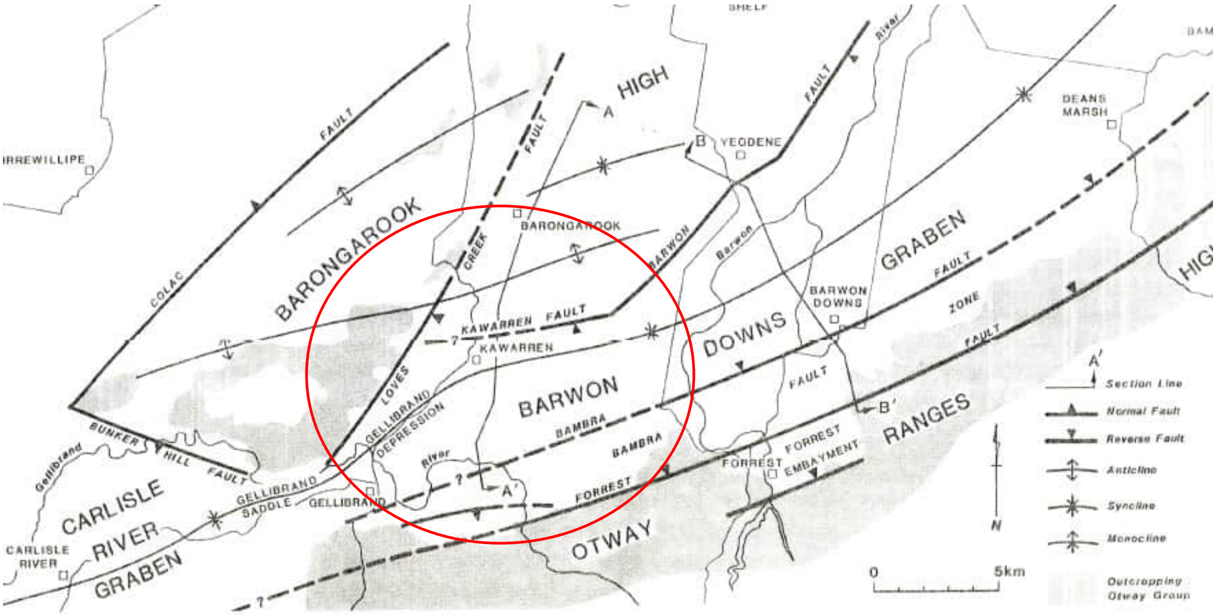

Figure 9 Regional Structural Setting (Leonard, Lakey, & Blake, 1983)

4.8.1.3 Basement Topography

The basement topography is presented in detail in **Figure F8**, which presents contours of the top of the basement (Otway Group) in m AHD. The top of basement contours indicates the Barwon Downs graben tilts eastwards with the basement deepening to depths of -300 m AHD at the eastern boundary of the KIA. The deepening of the basement to the east follows the approximate alignment of the Barwon Downs Syncline (**Figure F8**).

The basement is at depths of up to -300 m AHD in the eastern portion of the KIA, before gradually shallowing to approximately -100 m AHD in the south west, in the vicinity of the Gellibrand Saddle. The Yeo Dome is evident to the north of the Barwon Monocline, where the basement attains elevations in the order of 200 m AHD.

4.8.2 Regional Surface Geology

The regional surface geology from the Colac 1:250,000 geological map sheet is presented on **Figure 10** below and representative cross sections from the 1:50,000 geological map sheet are shown on **Figure 11**.

To the south of the Bambra Fault are Cretaceous Aged sediments of the Otway Group (shown in bright green) (**Figure 10**). These dominate the elevated areas to the south of the KIA and also the Barongarook High to the west and north. The Tertiary age sediments including those grouped in the

Wangerrip Group (refer **Section 4.8.3**) also outcrop on the Barongarook High and to the south on the flats associated with the Gellibrand River. Between the elevated Otway Group is a sequence of Tertiary age sediments which were deposited during major regressive and transgressive cycles (Lakey & Leonard, 1983). These dominate the KIA.

Beyond the Barongarook High to the north and west of the KIA is another area where there is a deep sequence of Tertiary sediments, referred to as the Port Campbell Embayment. To the north the Tertiary sediments are overlain by basalts of the Newer Volcanics; these form a flat plain with volcanic eruption points forming localised elevated areas. To the west of the KIA more recent Tertiary sediments outcrop forming a series of paleo ridge lines representing the former coastal extent. In the KIA the paleo ridge lines (Hanson Plain Sand) and basalt of the Newer Volcanics are not present.

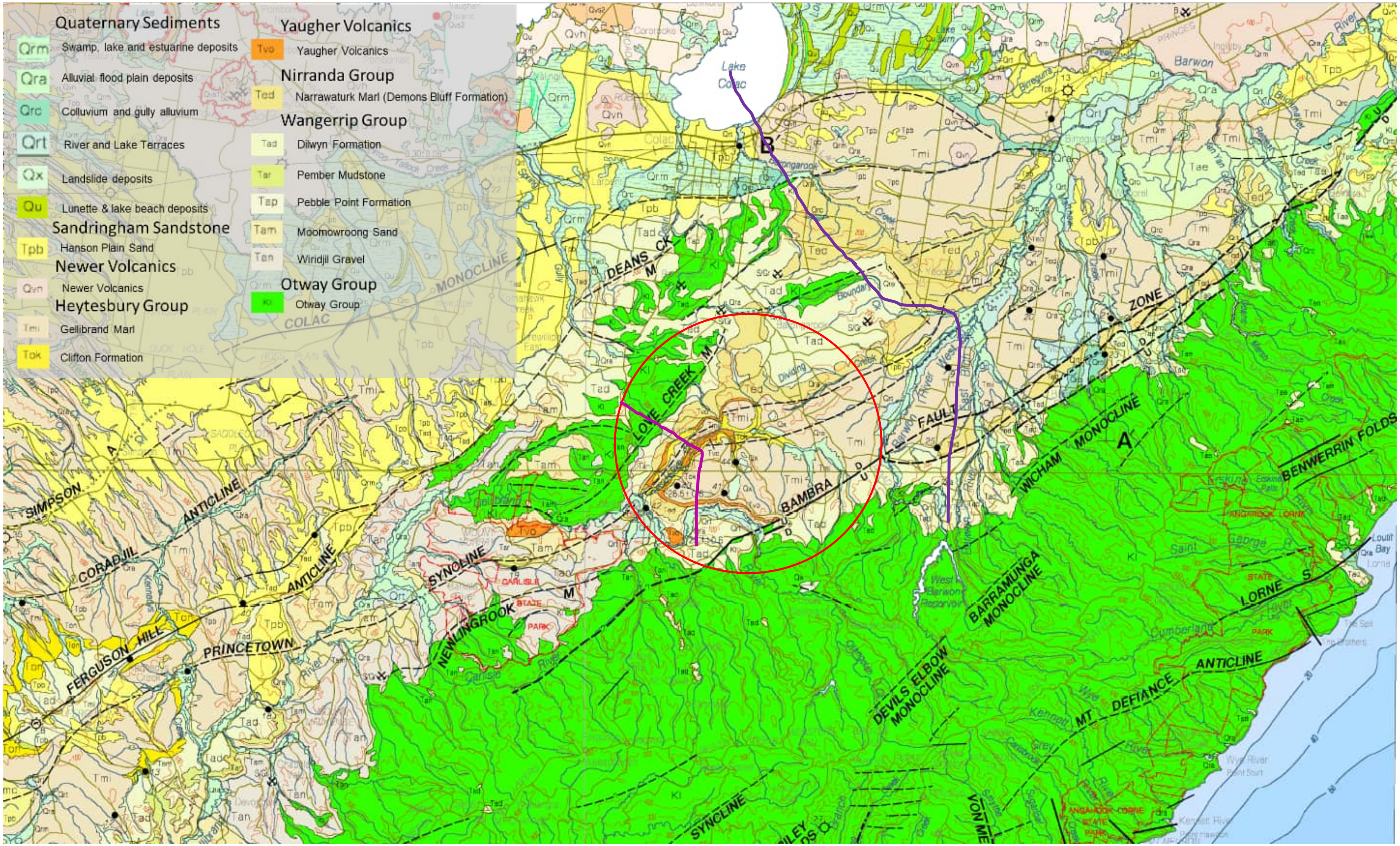

Figure 10 Regional Surficial Geology (Colac 1:250,000 Geological Map Series) (approx. KIA area shown in red, A-A' alignment purple, B-B' alignment pink)

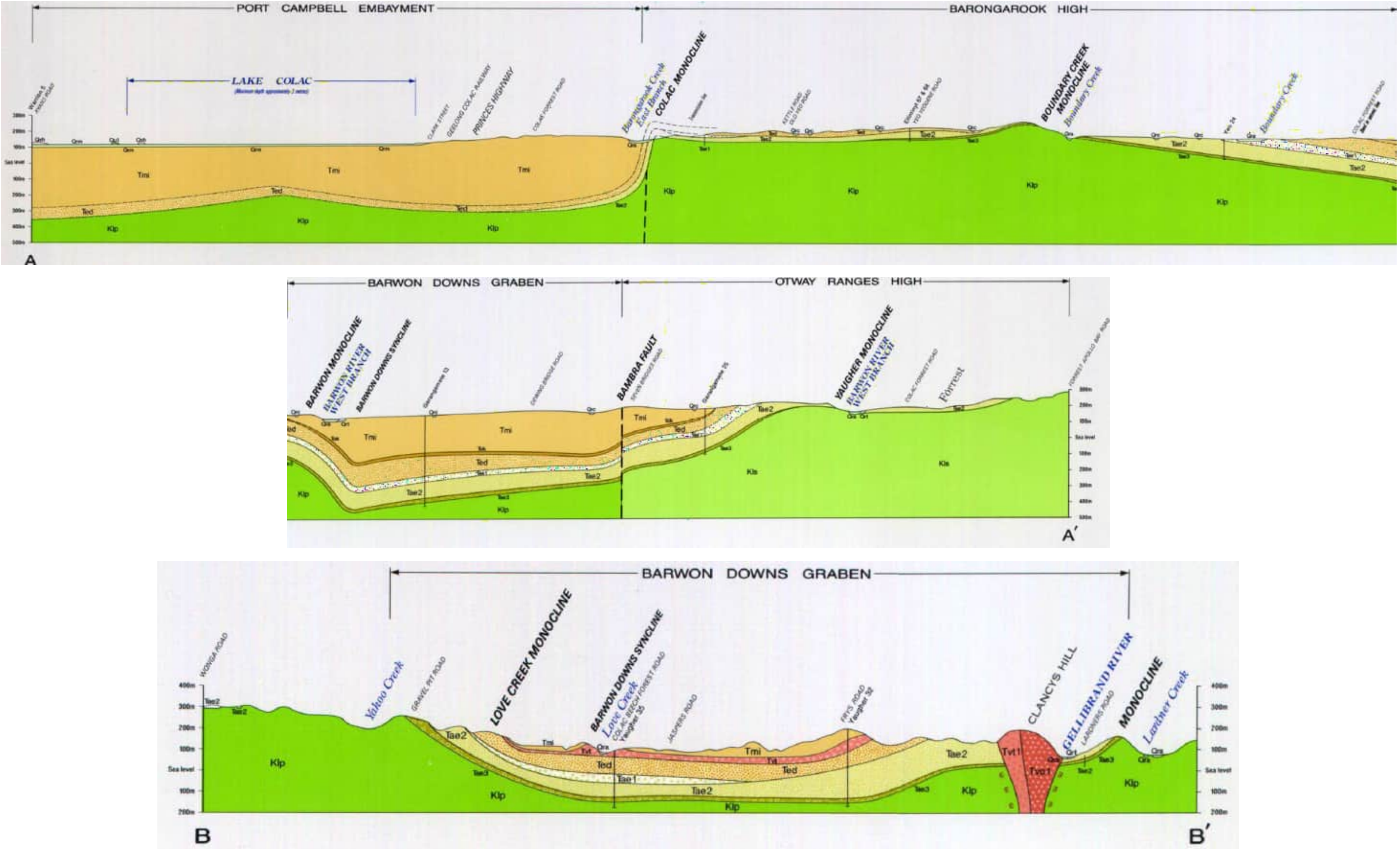

Figure 11 Regional Geological Cross Sections (Colac 1: 50,000 Geological Map Series)

4.8.3 Geology of the KIA

A map showing the surficial geology in the KIA is presented on **Figure F9**. Four geological cross sections have been prepared (**Figure F12** - **Figure F15**), presenting the sub-surface geology along the following alignments:

- A-A': north east to south west extending across the whole of the KIA;
- B-B': north west to south east extending across the whole of the KIA;
- C-C': north west to south east extending across the south western corner of the KIA to present the narrowing of the KIA and the structural high of the Gellibrand Saddle; and
- D-D': north to south extending down the eastern boundary of the KIA to present the thinning of the Tertiary sediments along the boundary of the KIA and the Barwon Downs sub-basin.

A summary of each of the geological formations, depositional environment, lithological description, approximate thickness and distribution and outcropping areas within the KIA is provided below in **Table 5**. In summary (in order of youngest to oldest):

- Quaternary Sediments.
- Between the Loves Creek monocline to the north and Bambra Fault to the south the basement is overlain by a thick sequence of Tertiary sediments comprising:
  - The Heytesbury Group including the Clifton Formation and Gellibrand Marl.
  - The Nirranda Group is comprised of the Mepunga Sands Formation, and the Narrawaturk Marl (Demons Bluff Formation) both of which underlie the KIA.
  - Wangerrip Group: Pebble Point Formation and the Dilwyn Formation, of which the Pember Mudstone forms the base. For the purposes of this report, and for consistency with previous investigations the Mepunga Sands Formation is also included within the Wangerrip Group.
- The Otway Group is the oldest rock that outcrops in the KIA and forms basement.

Table 5 Detailed Stratigraphy (Top to Bottom of Sequence)

Unit	Depositional Environment	Age	Lithology Description	Distribution	Thickness	Outcrop
Quaternary Sediments						
Quaternary Sediments	River, swamp, alluvial deposits	Quaternary	Mixed sediment composition – mostly moderately to poorly sorted and poorly to unconsolidated	Largely limited to creek and river alignments	Up to 6 m along the Gellibrand River. While outcropping of these units is indicated along creek alignments, this appears to be localised based on recent drilling along both Yahoo and Ten Mile Creek. The drilling did not identify Quaternary Sediments.	Largely limited to creek and river alignments
Heytesbury Group						
Gellibrand Marl	Deep to shallow marine	Late Oligocene – Middle Miocene	Predominantly calcareous clayey silt, less commonly calcareous fine sand, calcareous silty clay and marl. Commonly glauconitic. Shelly in parts. Bluish grey in colour Outcropping of the Gellibrand Marl causes oxidation and it is difficult to distinguish from the Narrawaturk Marl (Tickell et al.,1991)	Present across the Site	The marl is up to 200 m thick in the far eastern portion of the KIA and thins to ~10 m in the central portion, along Loves Creek.	The Gellibrand Marl outcrops across the majority of the KIA
Clifton Formation	Shallow marine / littoral, minor beach deposits	Late Oligocene – Early Miocene	Cream-white bryozoal limestone, limonitic calcareous quartz sand or sandstone. Occasionally glauconitic. The base of the unit can be conglomerate with basalt boulders. In the upper sections it can be interfingered with Gellibrand Marl. Blake (1974) reported the unit becoming siltier in the centre of the KIA.	Predominantly in the centre of the KIA area and extends northwards	Up to 50 m thick in the central portion of the KIA, around the confluence of Yahoo Creek and Loves Creek (**Figure F11**).	A small outcrop of Clifton Formation can be seen to the immediate north of the confluence of Loves Creek and Yahoo Creek. Very small outcrops of the formation are noted along Gellibrand River to the south west of the KIA.
Older Volcanics						
Yaugher Volcanics	The initial eruption occurred in sub-marine conditions with small flows of pillow basalt, this was followed by explosive eruptions	Late Oligocene	Generally interbedded with the Narrawaturk Marl.	The volcanics within the KIA area originate from a volcanic plug, Clancy's Hill, located to the north of Gellibrand River in the south western corner of the KIA	Up to 60 m thick in the southern portion of the KIA and thin to approximately 10 m in the northern portion. Likely absent from the Barongarook High area. The volcanics occurred over several flows and are thickest in the central portion of the KIA, along the Loves Creek alignment where they also outcrop.	The outcrops of Yaugher Volcanics along Loves Creek are representative of pillow basalt while the outcrop along Gellibrand River is considered to represent a different flow from that of the Loves Creek outcrop (Tickell et al., 1991)
Nirranda Group						
Narrawaturk Marl[3]	Deep marine	Late Eocene – Late Oligocene	Olive grey to brownish grey marl, silty marl, calcareous mudstone and muddy limestone. Thin beds of calcareous sandstone are also present. Commonly glauconitic and limonitic (Douglas & Ferguson, 1988). Interbedded with Yaugher Volcanics near the top of the sequence Tickell et al., (1991) describe the Demons Bluff Formation as 'calcareous silt which is locally sandy and clayey and contains abundant shelly fragments. High amounts of very fine carbonaceous material gives the marl a dark brown colour.	Underlies the KIA. Appears to be absent at the south western boundary	~90 m in the central region of the KIA, with ~40 m thickness of Yaugher Volcanics interbedded near the top of the Narrawaturk Marl. The Narrawaturk Marl thins along the Gellibrand River to only 4 m (Jacobs, 2022). Thins in the upper reaches of Ten Mile Creek to ~20 m (**Figure F12**)	The Narrawaturk Marl outcrops in the upper reaches of Ten Mile Creek, however, the creek itself incises through the Narrawaturk Marl exposing the underlying Wangerrip Group sediments. The Narrawaturk Marl extends in a thick band along the western margin of the KIA. Small outcrops are present along Loves Creek (see above – Narrawaturk Marl is orange colouring) and along the northern edge of Gellibrand River.

[3] The Narrawaturk Marl is often referred to as the Demons Bluff Formation. The most recent geological mapping (Tickell et al., 1991) has differentiated these units given that the differing depositional setting of these two units. As they were deposited contemporaneously with each other they do transition into one another which makes differentiation challenging. To maintain consistency with previous descriptions in the KIA BlueSphere has adopted the term, Narrawaturk Marl in this HA when referring to either of these units or their transitional equivalents.

Unit	Depositional Environment	Age	Lithology Description	Distribution	Thickness	Outcrop
			Basalt is interbedded in the upper formation in the Kawarren area.'			
Wangerrip Group						
Mepunga Formation[4]	Tickell et al., 1991 describe it as originating from a fluviatile environment, with some minor marine influence	Late Eocene	Well sorted reddish-brown limonitic quartz sand, calcareous limonitic sand and limonitic sandy limestone Lakey (1983). The sand is considered to be very mature with grains characteristically very well rounded (Lakey R. , 1984).	Across the KIA	Thinnest in the central east portion of the KIA at ~10 m and thickest (~50 m) in the central portion of the KIA. The formation outcrops in thin bands along the western margins of the Site and along portions of Ten Mile Creek.	The surficial geology in the KIA (**Figure F9**) has not differentiated between the three formations. However, the 1:50,000 Colac Geological Map sheet has differentiated the three unit and the observations are provided below: The Mepunga Formation outcrops in thin bands along the western margins of the Site and along portions of Ten Mile Creek The Dilwyn Formation outcrops of the formation are present along the north western, northern and southern boundaries of the KIA.. As detailed in **Section 4.8.1.2** above an area historically termed the Yeo Dome has been reinterpreted as the Dilwyn Formation. The Pember Mudstone is not known to outcrop The Pebble Point Formation outcrops in thin bands along the north western boundary of the KIA and along the southern most margin of the KIA, south of the Gellibrand River.
Dilwyn Formation[5]		Late Eocene – Early Palaeocene	Fine to medium grained sand bedded into units 2 – 10 m thick, which are separated by layers of clay and silt that are generally <2 m thick (Tickell et al., 1991). Clean quartz sand interspersed with thinner beds of yellow to light brown clayey sands, with gamma ray logs indicating it is characterised by sandstone layers alternating with thinner mudstone units Lakey (1983).	Across the Barwon Downs Graben.	Thickest in the south western portion of the KIA along alignment of Barwon Downs Syncline (up to 120 m thick). Generally between 20 and 70 m thick within the remainder of the KIA.	
Pember Mudstone	Holdgate & Gallagher (2003 describe it as originating from a transgressive – regressive repetitions of sandstone-siltstone-claystone	Late Eocene – Early Palaeocene	Tan to grey siltstone, mudstone and shale, usually pyritic, carbonaceous and micaceous, and locally glauconitic (Holdgate & Gallagher, 2003). Fine grained clastic consisting of grey to dark brown and black mud, clay and silt, which was commonly micaceous and carbonaceous, and also contains glauconitic and limonitic clays and pyrite (Lakey, 1983).	Across the Barwon Downs Graben	Generally 10 – 15 m thick across the KIA.	
Pebble Point Formation[6]	Primarily in a transgressive shallow marine environment	Late Eocene – Early Palaeocene	Predominantly quartzose sand and gravel (poorly to well sorted) usually with significant quantities of grey lithic pebbles (mainly of Palaeozoic aged fragments of siltstone, sandstone, chert and hornfels). In places it is represented by compacted silty and gravelly sand with a ferruginous cement (Lakey, 1984). Holdgate & Gallagher (2003) describe the formation as ferruginous (mainly quartz) sandstone, grit and conglomerate, with less common fossiliferous beds	Across the Barwon Downs Graben	The Pebble Point Formation is ~6 m thick along southern margins of KIA in vicinity of Gellibrand River and up to 31 m thick along southern slope of Barongarook High.	
Otway Group						
Eumeralla Formation	Interbedded volcanogenic sandstone and mudstone of a fluvio-lacustrine deposition	Early Cretaceous	Sandstone is the dominant rock type of the Otway Group and is generally fine to medium grained, moderately to well sorted and may be cross bedded. Both the sandstone and mudstone are characterised by high proportions of lithic and feldspathic grains and these give the sandstone a characteristic 'pepper and salt' appearance. The colour of the mudstone can vary in colour from light grey to dark grey and greenish grey in fresh rock (Tickell et al., 1991). The volcanogenic rock fragments are generally fine grained, highly altered volcanics with lesser amounts of quartzite, mica-schist and micro-granite	Widespread across the Port Campbell Embayment.	In central part of Barwon Downs Graben the Otway Group is up to 800 m thick	The Otway Group outcrops along the margins of the KIA (**Figure F9**). Depths to the top of the Otway Group decrease substantially to the south west of the KIA, in the area identified as the Gellibrand Saddle (shallow basement structural high). Along the north western margins of the KIA the Otway Group is increasingly shallower before outcropping along the edge of the Barongarook High (see **Figure F9**, **Figure F13**). The Otway Group also outcrops in the northern portion of the Barongarook High, north of the KIA. Along the south eastern margins of the KIA, the Otway Group outcrops on the south eastern side of the Bambra Fault.

[4] Also referred to as the Upper Eastern View. The Mepunga Formation is included in the Nirranda Group (Holdgate & Gallagher, 2003) but for the purposes of this HA is considered as part of the Wangerrip Group
[5] Also referred to as the Middle Eastern View. Note the Pember Mudstone has been regarded as the lower member of the Dilwyn Formation but has separated out for the purpose of this HA.
[6] Also referred to as the Lower Eastern View. The Pebble Point Formation is equivalent to the Moomowroong Sand and Wiridjil Gravel units encountered elsewhere.

4.9 Hydrogeology

4.9.1 Hydrostratigraphy

There are a number of hydrostratigraphic units within the KIA. These are described in **Table 6** below and either relate to an individual geological formation, or a combination of geological units that share comparable hydrogeological properties. Each hydrostratigraphic unit has been classified as either an aquifer or aquitard. These are defined as:

- Aquifer: Geological formation which contains and yields water; and
- Aquitard: Geological formation which cannot transmit significant quantities of water but can transmit small quantities (not totally impermeable).

It is important to note that these are adopted as relative terms and have also been adopted based on best available information. Where there is uncertainty or variability with regard to the hydrogeological properties of a geological formation this has been highlighted.

The predominant aquifers and aquitards identified within the KIA are (from oldest to youngest):

- Otway Group Aquifer (OGA) – Comprising the Eumerella Formation of the Otway Group;
- Lower Tertiary Aquifer (LTA) – Comprising the Pebble Point, Dilwyn and Mepunga Sands Formations;
- Lower-Mid Tertiary Aquitard (LMTD) – Comprising the Narrawaturk Marl;
- Lower-Mid Tertiary Aquifer (LMTA) – Yaugher Volcanics, Clifton Formation and Gellibrand Marl; and
- Quaternary Aquifer (QA) – Quaternary Sediments.

A summary of the aquifers and aquitards including description, occurrence and nature are described further in **Table 6** below. Further detail is provided in **Sections 4.9.2** to **4.9.6** below.

Table 6 Summary of Regional Aquifers / Aquitards (Top to Bottom of sequence)

Geological Group	Geological Formation	Hydrostratigraphic Unit	Lithological description	Characteristic	Occurrence	Type and Form	Comment
Quaternary Sediments	River, swamp, alluvial deposits	Quaternary Aquifer (QA)	Alluvial deposits, clays, sands	Poorly characterised	Localised aquifers associated with drainage lines. Most strongly developed in the vicinity of the Gellibrand River.	Unconfined	Local groundwater flow systems exist which are likely to be in hydraulic connection with surrounding hydrostratigraphic units.
Heytesbury Group	Gellibrand Marl Clifton Formation Yaugher Volcanics	Lower Mid Tertiary Aquifer (LMTA)	Basalts fractured rock; limestone, sand gravel	Gellibrand Marl: Low permeability, local flow systems producing water Clifton Formation: Highly permeable Yaugher Volcanis: poorly characterised	Gellibrand Marl occurs at the surface within the central KIA area, east of Gellibrand River. Small outcrops of volcanics occur along the Loves Creek alignment and Gellibrand River terraces. The Clifton Formation predominantly exists in the eastern portion of the KIA and is more strongly developed in the Barwon Down Sub-Area (**Figure F11**). Small outcrops of Clifton Formation occur at the confluence of Yahoo and Loves Creeks.	Unconfined	Due to a paucity of information these have been grouped together. The Clifton Formation is likely to form its own aquifer, and is typically confined beneath the Gellibrand Marl. Minor aquifers likely to exist within the Gellibrand Marl (particularly in the more sandy upper zones) and Yaugher Volcanics where fractured.
Nirranda Group	Narrawaturk Marl	Lower Mid Tertiary Aquitard (LMTD)	Silty marl	Very low permeability and very thick	Occurs consistently to the east of the Gellibrand River. Minor occurrences identified just to the west of Gellibrand River (Jacobs, 2022)	Confining layer	Considered to act as a confining unit to the underlying LTA based on hydraulic properties and thickness.

Geological Group	Geological Formation	Hydrostratigraphic Unit	Lithological description	Characteristic	Occurrence	Type and Form	Comment
					Outcrops within Loves Creek and in elevated areas proximal to Yahoo Creek and Ten Mile Creek		
Wangerrip Group	Mepunga Formation Dilwyn Formation Pember Mudstone Pebble Point Formation	Lower Tertiary Aquifer (LTA)	Quartz sands, gravels, clay and silts	Mepunga Formation: Highly permeable Dilwyn Formation: Highly permeable Pember Mudstone: minor aquitard Pebble Point Formation: Highly permeable	Occurs throughout the Barwon Downs graben predominantly between the Bambra Fault and Loves Creek Monocline. Large portion of the aquifer is sub-surface and is thickest in the Barwon Downs Graben – up to 300 m thick (**Figure F10**)	Confined in central KIA. Unconfined at areas of outcrop including Barongarook High, Otway Ranges and in the vicinity of the Gellibrand Saddle.	Forms the principal aquifer in the KIA. Was the source of the Barwon Downs Borefield. The outcrop along Barongarook High is the primary recharge point for the LTA. Aquifer is disconnected across the Bambra Fault, at least in the section along Gellibrand River and bordering the south eastern boundary of the KIA, i.e. recharge south of Bambra. Although some lithological variability is evident, the individual units appear to be in strong hydraulic connection and are considered to form a single aquifer system.
Otway Group	Eumerella Formation	Otway Group Aquifer (OGA)	Sandstone / Siltstone fractured rock	Poorly characterised	Present beneath the entire KIA at depths of up to 500 – 600 m below ground level. Outcrops along the Otway Ranges and along Barongarook High.	Confined Unconfined in areas of outcrop	Not considered to form a significant aquifer in comparison to the overlying LTA.

4.9.2 Quaternary Aquifer (QA)

There is little information available regarding the properties of the QA. Tickell et al., (1991) considered that the thin deposits of Quaternary sediments within the KIA are considered to have a low potential of forming an aquifer in their own right. Rather, these deposits are likely to form local groundwater flow systems which are likely to be in hydraulic connection with surrounding hydrostratigraphic units.

The QA is most well defined in the Gellibrand River, where up to 6 m of sediments has been reported overlying Narrawaturk Marl at locations GRBH01/GRBH02 (Jacobs, 2022). Thinner sequences of QA have been reported directly overlying LTA, e.g. at bores 108898, 108899 (SKM, 2012).

SKM (2012) report that the QA and LTA are in direct hydraulic connection in the Gellibrand River area, with upward hydraulic gradients with the QA existing under 'normal conditions' and periodic downward gradients from the QA to LTA during periods of higher river flow. Specifically, there the potentiometric surface in the LTA exceeds the base of the QA, the QA is expected to receive discharge from the LTA. Conversely where the potentiometric surface in the LTA is below the base of the QA, the LTA is expected to receive infiltration from the QA.

4.9.3 Lower-Mid Tertiary Aquifer (LMTA)

The LMTA comprises three individual geological units (Gellibrand Marl, Clifton Formation and Yaugher Volcanics), all of which have the potential to form aquifers in their own right to varying degrees. Given the paucity of information in the KIA these have been grouped together. A summary of information as presented in (Tickell et al., 1991) is provided in the following sections.

The Clifton Formation of the LMTA is considered to be highly permeable material, while the Gellibrand Marl is generally considered to have low permeability, confining the underlying Clifton Formation. (Tickell et al., 1991) notes that the more sandy facies of the Gellibrand Marl (generally towards the top of this unit) is a minor aquifer. There is no documented information on the Yaugher Volcanics forming an aquifer, however, it is expected to be water bearing where fractures are developed and within interflow zones. BlueSphere has broadly classified all these units as aquifers noting the individual variation within each sub-unit and acknowledging the paucity of information. It is noted that SKM (2012) broadly refers to all units above the LTA as an aquitard however, our review indicates that this is not accurate.

As documented in (Tickell et al., 1991) bore yields up to 10 L/s have been reported for the Clifton Formation. The Gellibrand Marl is a locally utilised source of groundwater for stock and domestic purposes with bore yields of between 0.1 to 0.5 L/s (Tickell et al., 1991).

Recharge to the Gellibrand Marl is likely to be via direct infiltration of rainfall, with groundwater discharge primarily occurring via springs and/or soaks at break in slopes. Groundwater flow systems in the Gellibrand Marl are subsequently considered to follow the local topography with flow paths classified as local in extent.

It is apparent that a significant number of springs within the KIA originate from groundwater discharge from the Gellibrand Marl and these form a locally important stock and domestic water supply for landholders. This is discussed further in **Section 4.13.3**.

The Clifton Formation predominantly exists in the eastern portion of the KIA; it outcrops in a small area adjacent to the confluence of Yahoo and Loves Creeks in the KIA and becomes more laterally extensive and thicker to the east. It is possible that the area in the vicinity of this outcrop represents an intake area for the Clifton Formation as there are no other surficial expressions in the KIA. However, there are no groundwater wells screening the Clifton Formation in the KIA to verify this, nor to confirm groundwater flow direction. There is no evidence to suggest that the area of Clifton Formation outcrop at the confluence of the Loves and Yahoo Creek is acting as a discharge zone based on streamflow records.

Leakage from the Gellibrand Marl and upward leakage through the LMTD are also potentially contributing to recharge of the Clifton Formation, however the amount of leakage from the Gellibrand Marl is not known and based on the permeability contract between these two units, is likely to only represent a small amount; the relative influence of various recharge sources is not known.

4.9.4 Lower Mid Tertiary Aquitard (LMTD)

The Narrawaturk Marl[7] forms the Lower Mid Tertiary Aquitard (LMTD) within the KIA. The LMTD, where present, confines the LTA to the east of the Gellibrand River, thus separating the LTA from the LMTA. The LMTD is approximately 90 m thick in the central region of the KIA, however, thins along the Gellibrand River and in the upper reaches of Ten Mile Creek, where the LTA is between ~4 and ~20 m thick, respectively. The LMTD was previously considered to overlie the Yeo Dome, however, more recent investigations indicate the LTA directly overlies the OGA in this area.

There has been no direct measurement of the hydraulic properties of the LMTD within the KIA. Therefore, inferences can only be made based on observations elsewhere in the Barwon Downs Graben and the nature of the geology encountered in outcrop and boreholes, where the geology and setting are similar to the KIA, so the hydraulic properties are considered likely to be similar.

Hydraulic conductivities for the LMTD as reported in (Jacobs, 2018) appeared to show a correlation with screen depth whereby bores screened at <25 m below ground level reported a hydraulic conductivity range of between 0.026 to 0.3 m/day, while bores screened >35 m reported hydraulic conductivities between 1.8×10^{-5} to 5.8×10^{-4} m/day. These are well below the range of K values reported in the LTA (4 m/day to 22.1 m/day, **Table 7**).

Based on the thickness of the LMTD (~90m), K of 1.8×10^{-5} to 5.8×10^{-4} m/day, i of 0.07 (**Section 4.9.5.4**) and n_e of 5%, it would take in the order of 300 to 10,000 years for water to transmit vertically through the LMTD. The timeframe for groundwater to transmit vertically through the LMTD where it thins to ~4 m would be between 13 to 435 years, while where it is ~20 m it would take in the order of 67 to 2000 years. This highlights that whilst the groundwater movement is possible between the LTA and LMTA through the LMTD, it is very slow to occur (particularly where the LMTD is up to 90 m thick), and consequently the flux would be a minor contributor to the water balances in surrounding units separated from the LTA by the LMTD.

This is supported by measured water levels of bore 64242 screened in the LMTD, which showed little if any response when compared to water levels in 64230 screened in the LTA, which showed a decrease in water levels during peak pumping periods (Jacobs, 2018). This is also seen to a lesser degree in nested bores in Big Swamp (TB1b (LMTD) and TB1c (LTA)), albeit post pumping.

Three bores located in the Barwon Downs sub-basin area (G19, G18 and M22) are screened within the Clifton Formation which is separated from the LTA by the Narrawaturk Marl by approximately 95 m, 145 m and 200 m, respectively. As can be seen by the hydrograph of these three bores (see **Figure 13**, below) there has been a minor response in water level reductions at G18 and G19 (~1 m decrease). At bore M22 there has been up to 7 m decrease. It is noted that bore M22 underwent refurbishment in 2014/15 and since then water levels have stabilised substantially. This suggests that the 7 m decline observed is potentially an artefact of bore construction and not the permeability of the Narrawaturk Marl, however, this cannot be confirmed with the available data; this represents a data gap. In any case, on balance the CSM indicates that there is flux (albeit relatively minor flux) between the LTA and the Narrawaturk Marl with an approximately 1 m decrease in water level over a 12 year period at G19 where the Narrawaturk Marl is approximately 95 m thick. This is largely consistent with the calculations presented above.

[7] The Narrawaturk Marl is often referred to as the Demons Bluff Formation. The most recent geological mapping (Tickell et al., 1991) has differentiated these units given that the differing depositional setting of these two units. As they were deposited contemporaneously with each other they do transition into one another which makes differentiation challenging. To maintain consistency with previous descriptions in the KIA BlueSphere has adopted the term, Narrawaturk Marl in this HA when referring to either of these units or their transitional equivalents.

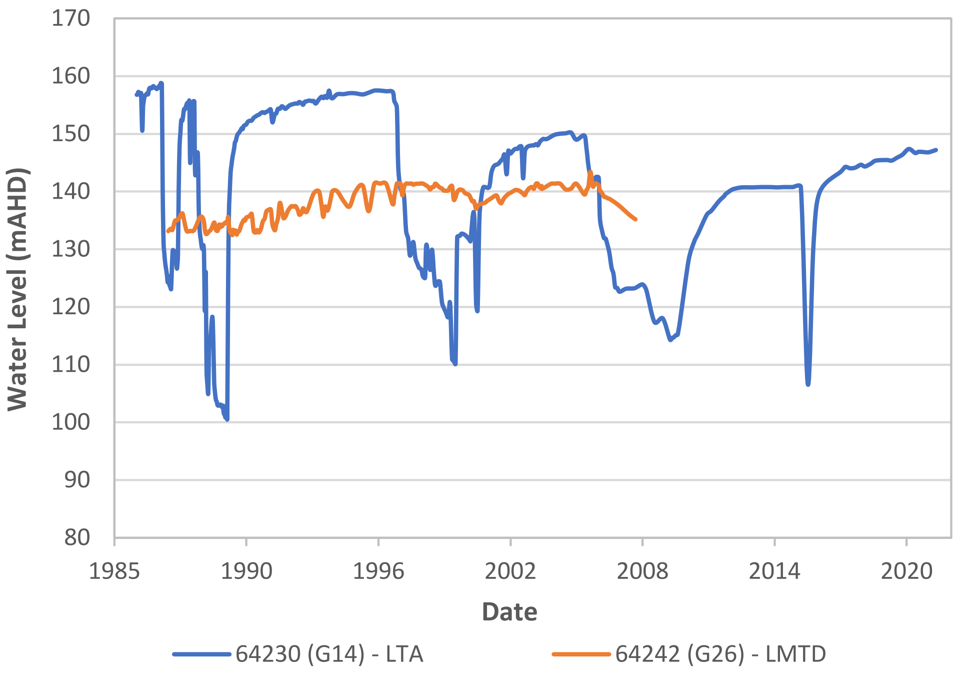

Figure 12 Bore hydrographs in LTA and LMTD

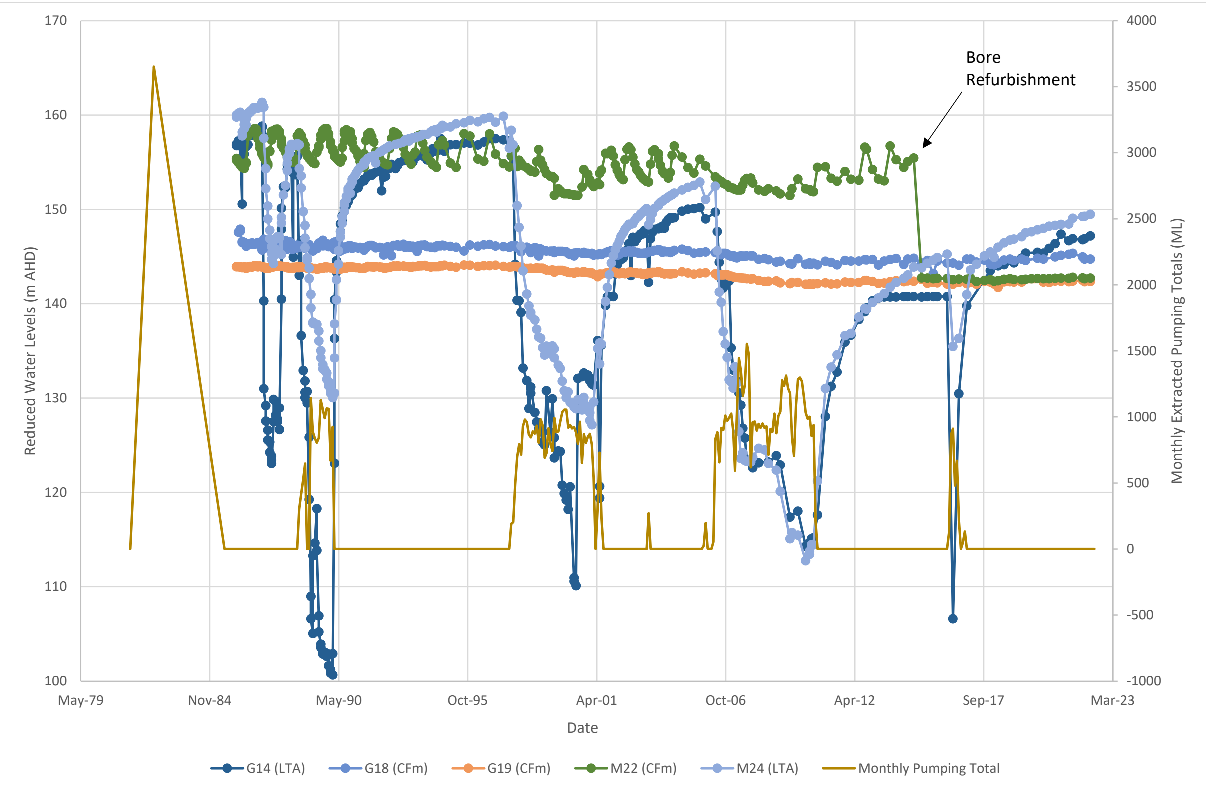

Figure 13 Bore Hydrographs in LTA and Clifton Formation (uncertainty regarding M22 water levels pre refurbishment)

4.9.5 Lower Tertiary Aquifer (LTA)

4.9.5.1 Aquifer Distribution

The LTA extends across a large area, as far north as Birregurra, and south into the Carlisle River Graben (Department of Minerals and Energy, 1984). The LTA is thickest between the Bambra Fault (along the south eastern margin) and the Loves Creek Monocline (along the north western margin) in the Barwon Downs sub-basin with thicknesses of up to 300 m. The LTA thins to approximately 50 m between the Barwon Downs and Kawarren sub-basins before thickening to 200 m along the Barwon Downs Syncline (**Figure F10**). The aquifer attains a thickness of up to 150 m in the Carlisle River Graben (Department of Minerals and Energy, 1984).

The LTA outcrops on margins of the KIA, principally to the north (Barongarook High) and along the northern flank of the KIA adjacent to the Loves Creek Monocline where LTA sediments are exposed (**Figure F10**). Here the aquifer is unconfined. The outcrops of LTA are relatively thin (between ~25 m and 50 m) (see **Figure F12**, **Figure F13**, **Figure F14**).

The LTA outcrops to the south of the Bambra Fault are indicated to be disconnected from the LTA by faulting (**Figure F15**), although in the southern portion of the KIA along Gellibrand River and the south eastern boundary of the KIA the off-set appears to be reduced such that some connectivity might be possible, albeit considered to be largely insignificant (**Figure F14**).

As discussed in **Section 4.8.1.2** there is a direct hydraulic connection across the Yeo Dome between the KIA and Barwon Downs Sub-Area.

The majority of the LTA in the KIA is confined, with between 100 and 200 m of sediments overlying the LTA between Kawarren and the confluence of Loves Creek and Gellibrand River. Two zones of deeper LTA sediments have been identified within the KIA. One extends in an alignment beneath Ten Mile Creek and the other within a thin valley between the Yeo Dome and the Bambra Fault, which connects the Barwon Downs Sub-Area with the KIA. This has been referred to as the Pipeline Restriction by (Aquade, 2017).

Investigations by (Witebsky et al., 1995) and subsequently (Petrides & Cartwright, 2006) described the existence of a groundwater barrier separating the Barwon Downs sub-basin from the KIA based on responses in observation bores to the borefield production. Whilst no structural feature was identified in this area (Witebsky et al., 1995) was of the opinion the LTA thinned with the aquifer thinning from over 150 m in the borefield area to 20 m at the inferred barrier. Aquade (2019) considered that the barrier was not a barrier, rather a restriction through which the aquifer could still flow albeit reduced.

BlueSphere's review indicates that the LTA is continuous across the Pipeline Restriction, consistent with HydroTechnology (1994) and Aquade (2019). This is based upon a review of the geological information, and the hydraulic response and flow trends in the KIA.

4.9.5.2 Groundwater Flow Systems

Potentiometric surface plans of the LTA have been reproduced (after Leonard et al., 1983) and prepared for 2010 and 2022, and are presented on **Figure F16**, **Figure F17** and **Figure F18**, respectively. The 1983 potentiometric surface contours are considered to represent the baseline, pre-pumping conditions.

The 1983 potentiometric surface plan indicates that recharge to the LTA in the KIA occurs via rainfall infiltration where the LTA outcrops at the surface on the Barongarook High. Recharge to the LTA then flows through the aquifer via two main recharge avenues termed the Yeodene Recharge Avenue and the Kawarren Recharge Avenue (see **Figure 14**, below).

Recharge in the Barongarook High flows in a southerly direction parallel to Ten Mile Creek within an area of locally deeper LTA sediments referred to as the 'Kawarren Recharge Avenue' (see **Figure 14**, below), which is considered to be the primary flow path in the KIA. A cross section showing this flow path, perpendicular to flow, is provided in **Figure 15**. Groundwater thereon flows to the south-west where a component discharges into the Gellibrand River (to the west of Clancys Hill) which is a regional groundwater discharge zone. Some through flow is indicated to continue further west of the KIA in the LTA.

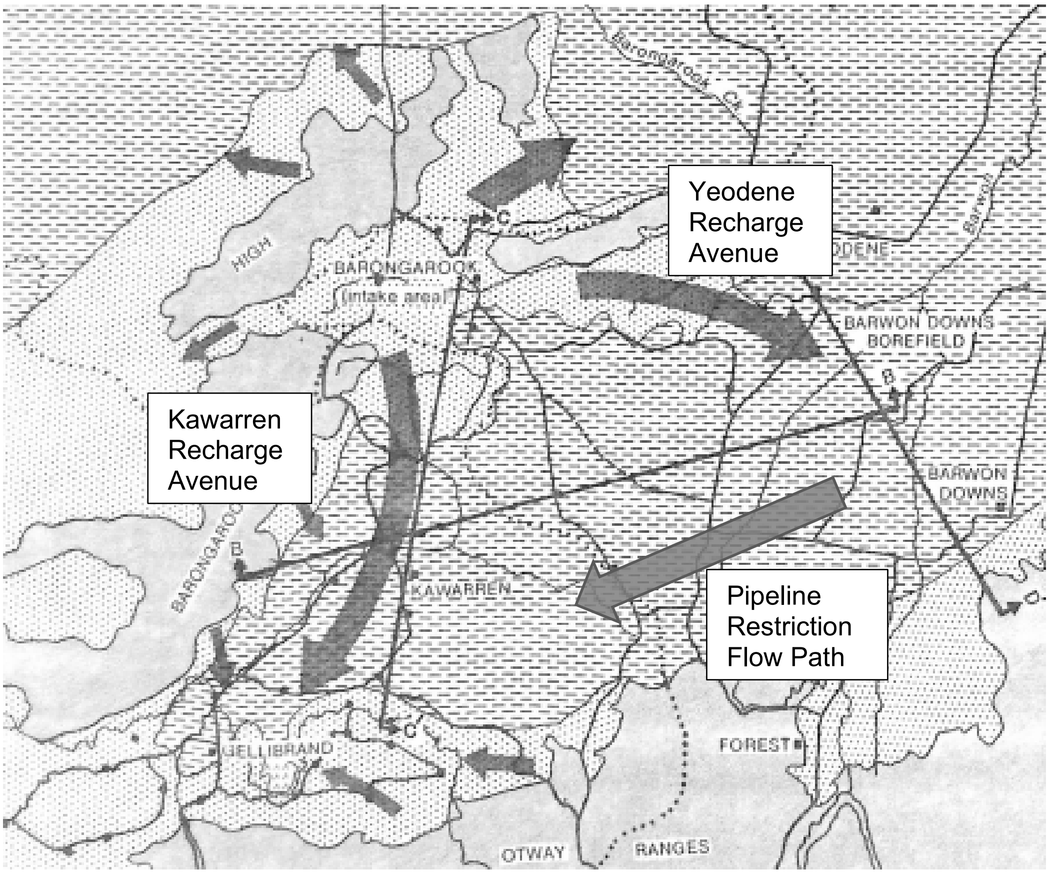

Figure 14 Recharge Avenues (Modified from (Department of Minerals and Energy, 1984))

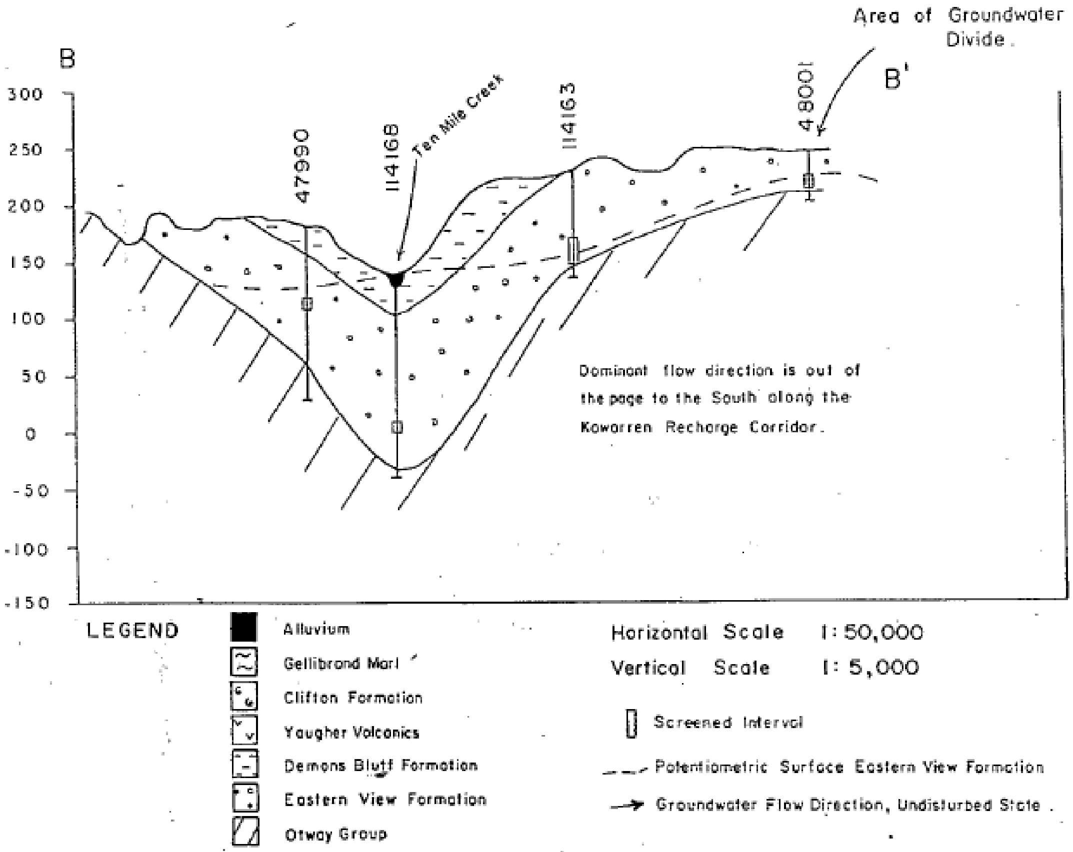

Figure 15 Cross Section of Kawarren Recharge Avenue after (HydroTechnology, 1994)

A second dominant groundwater flow path originates from the north-eastern side of the Barongarook High flowing in a south-easterly direction via the ‘Yeodene Recharge Avenue’, which lies within the Barwon Downs sub-basin. This flow path splits into two, with one component of flow heading east to south-east to the Barwon Downs sub-basin where the gradient of the LTA is largely flat. The second component from the ‘Yeodene Recharge Avenue’ wraps around the previously identified Yeo Dome bedrock high and flows along a narrow valley between the Barwon Downs Sub-Area and the KIA referred to as the Pipeline Restriction (Aquade, 2017). Groundwater in this flow path discharges in the Gellibrand River in the reach east of Clancys Hill.

It is noted that the potentiometric contours of (Leonard et al., 1983) do not extend across the Yeo Dome on the understanding at the time that it was a marl covered basement high. However, as documented in (Stanley, 1991) following reinterpretations, and subsequent reinterpretations by Hydrotechnology (1994) and BlueSphere (this report) it was established that the Yeo Dome was not marl covered but rather covered in LTA. As such the more recent groundwater flow interpretations (i.e., those shown on **Figure F17** and **Figure F18**) show connection of the LTA over the basement high.

As shown in (Lakey & Leonard, 1983) and on **Figure F14**, the LTA is partially isolated from the Gellibrand River by the intrusive volcanic plug of Clancy’s Hill. This constriction combined with the basement high at the Gellibrand Saddle promotes the groundwater discharge to the Gellibrand River.

The potentiometric surface of the LTA at the end of the Millennium Drought period and post the more intensive groundwater extraction period in 2010 are described further in **Section 5.1**.

4.9.5.3 LTA Hydraulic Parameters

A number of previous investigations have reported on and collated pumping test information on the LTA. This has been summarised in (Department of Minerals and Energy, 1984) and is presented in **Table 7** below.

Lakey & Leonard (1983) have also documented transmissivity values of the LTA specifically within the KIA, which range between 40 and 450 m^2/day, corresponding to hydraulic conductivities of between 0.01 and 100 m/day, respectively. The Lakey & Leonard (1983) transmissivity and hydraulic conductivity values are based on pumping tests completed on groundwater bores in the KIA, while the information presented in **Table 7** is based on pumping tests predominantly completed in the Barwon Downs area. As such the Lakey & Leonard (1983) data are considered more representative of the KIA LTA.

A pumping test report by (Lakey, 1984) completed in the KIA documented transmissivity values of between 728 and 4,408 m^2/day. It is not clear from BlueSphere’s review how the differences in transmissivity have come about compared to Lakey & Leonard (1983), and as such the transmissivity values reported by Lakey & Leonard (1983) are considered more representative of the KIA.

Stanley (1991) reports that slug tests were undertaken from 33 groundwater bores along the Gellibrand River down-stream of Forest Lodge where LTA outcrops. The average hydraulic conductivities ranged between 7.5 m/day and 15 m/day depending on the analytical method adopted. BlueSphere has not cited the primary data.

Table 7 LTA Hydraulic Properties Summary

Test Site	Pumping Bore	No of Observation Bores	Aquifer(s) tested	Total length screened interval (m)	Pumping Rate (m3/day)	Test Duration (days)	Drawdown in Production Bore at Test End (m)	Transmissivity of Aquifer Interval test (m2/day)	Hydraulic Conductivity of aquifer tested (m/day)	Storage Coefficient
Barwon Downs	GW1	4	Mepunga; Dilwyn	40	7179.12	1.6	50.6	366	9.2	3.0×10^{-4}
Gerangamete (Barwon Downs Borefield)	GW2	6	Dilwyn; Pebble Point	75	5564.16	5.0	25.75	512	6.8	3.2×10^{-4}
	GW2A	-	Mepunga; Dilwyn; Pebble Point	78	7732.8	0.08	21.45	650	8.3	2.8×10^{-4}
	GW4	-	Mepunga; Dilwyn; Pebble Point	82	7776.0	0.02	37.25	-	-	-
	GW5	-	Mepunga; Dilwyn; Pebble Point	79	7776.0	0.04	21.55	-	-	-
Wire Lane	Muroon 23	1	Pebble Point	13	984.96	0.83	9.50	64	4.9	1.8×10^{-5}
Deans Marsh	Whoorel 6	1	Dilwyn	14	1330.56	0.54	-	-	-	-
Forrest Lodge	Yaugher 8014	4	Dilwyn; Pebble Point	42	1114.56	3.06	24.60	320	7.6	2.4×10^{-3}

Test Site	Pumping Bore	No of Observation Bores	Aquifer(s) tested	Total length screened interval (m)	Pumping Rate (m3/day)	Test Duration (days)	Drawdown in Production Bore at Test End (m)	Transmissivity of Aquifer Interval test (m2/day)	Hydraulic Conductivity of aquifer tested (m/day)	Storage Coefficient
Gellibrand	Yaugher 27	3	Dilwyn	15	2743.80	10.0	24.88	220	14.7	5×10^{-4}
Mcdonalds Lane	Yaugher 31	1	Dilwyn	10	497.68	2.08	43.40	40	4.0	1.5×10^{-2}
Carlisle River	Newlingrook	1	Dilwyn	50	1870.68	2.00	1.76	1100	22.1	2.2×10^{-3}
Kawarren	Yaugher 37	4+	Dilwyn; Mepunga	72	5413	6.5	-	970	13.5	3.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 50		-	-	-	-	968	-	3.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 35 (108910)		-	-	-	-	1056	-	1.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 34 (108909)	-	-	-	-	-	728	-	1.1×10^{-3}
Kawarren	Yaugher 51	Barongarook 54 (47986)	-	-	-	-	-	4408	-	4.8×10^{-3}

4.9.5.4 Hydraulic Gradients

The horizontal gradients of the LTA in the KIA have been estimated based on a number of previous investigations and as presented in **Table 20** in **Section 5.4.4.** The horizontal hydraulic gradients have ranged between 0.018 and 0.026 in the Kawarren Recharge Avenue area, while they are on average 0.006 at the Pipeline Restriction.

Upward vertical hydraulic gradients have been reported at nearby bores within the LTA in the Barwon Downs Sub-Area, with values of 0.0076 and 0.025 (Witebsky et al., 1995). Vertical hydraulic gradients in the vicinity of Boundary Creek were between 0.049 and 0.1.

Previous investigations including (Jacobs, 2018) have identified vertical leakage of groundwater from the LTA to the LMTD as a potential discharge process for the LTA. In the Gellibrand River area (SKM, 2012) calculated vertical gradients of between 0.05 to 0.17. SKM (2012) report that the QA and LTA are in direct hydraulic connection, with upward hydraulic gradients with the QA existing under 'normal conditions' and periodic downward gradients from the QA to LTA during periods of higher river flow.

It is noted that Figure 15 and 16 of (SKM, 2012) show groundwater flow paths within the LTA extending upward into what SKM refer to as the 'aquitard' (comprising Narrawaturk Marl, Yaugher Volcanics, Clifton Formation and Gellibrand Marl) and discharging at the surface. Whilst there is upward hydraulic gradients from the LTA, that is not to say that groundwater is likely to actually be migrating upward through these sequences and dominating spring discharge to any significant degree. That is, the Narrawaturk Marl appears to be acting as a competent confining layer where it overlies the LTA (refer to **Section 4.9.4**).

4.9.5.5 Flow Rates and Residence Times

The average linear velocity of groundwater within the LTA via the two key flows paths (Kawarren Recharge Avenue and the Pipeline Restriction) have been calculated using:

$$V = Ki \div ne$$

The average linear velocities represent the actual rate that groundwater is moving within the aquifer. These are summarised in **Table 8**. Based on the length of each key flow path, expected residence times have also been calculated.

Table 8 Average Linear Velocity Kawarren Recharge Avenue and Pipeline Restriction

Parameter	Kawarren Recharge Avenue	Pipeline Restriction	Comment
K (m/day)	1	1	Lower end of the range of values reported in **Section 4.9.5.3**. This has been adopted as bores are typically screened in high productivity zones, which biases the K values to higher numbers.
i	0.006	0.003	Consistent with values in Section **5.4.4**
n_e	0.1	0.1	Consistent with porosity value adopted by Atkinson et.al (2014)
V (m/day)	0.06	0.03	Calculated
Average flow path length (km)	10	2.5	Flow paths as per (Leonard et al., 1983) (i.e. pre-pumping)

Parameter	Kawarren Recharge Avenue	Pipeline Restriction	Comment
Years to travel flow path	~450	~225	Calculated

Atkinson et al., (2014) reported radiocarbon ages for groundwater in the LTA between 380 and 9,260 years. At the lower end of the scale this accords with the estimate for the Kawarren Recharge Avenue and for groundwater flow via the pipeline restriction.

Atkinson et al., (2014) did note that groundwater from groundwater bores around the Gellibrand Discharge area indicated a large component of groundwater was recharged during or post the 1950s, which they considered was indicative of two flow systems in the LTA in this area comprising a shallow local flow system that has limited connectivity with the deeper flow system (Atkinson et al., 2014).

Atkinson et al., (2014) calculated residence times based on a porosity of 0.1 and hydraulic conductivities of 0.2 – 2 m/day of between 1,000 years and 10,000 years, which were consistent with the radiocarbon ages of groundwater in the LTA.

4.9.5.6 Aquifer Recharge and Discharge Estimates

The main recharge mechanism for the LTA is via rainfall infiltration direct to the aquifer where it outcrops on the margins of the KIA. The principal recharge to the LTA within the KIA is the Barongarook High. HydroTechnology (1994) defined a 12 km^2 recharge zone on the Barongarook High that influences the LTA within the KIA. Some recharge is also likely to occur along the western flank of the KIA adjacent to the Loves Creek Monocline where LTA sediments are exposed. The LTA exposures to the south of the Bambra Fault are indicated to be disconnected from the LTA within the KIA (refer to **Figure F15**) and therefore these are not considered to constitute recharge areas to the LTA.

A range of recharge estimates to the LTA have been made. These are summarised in **Table 9** below. Discharge estimates to Gellibrand River are also included.

Table 9 Previous LTA Recharge and Discharge Estimates (as quoted)

Recharge (ML/year)	Discharge (ML/year)	Recharge/ Discharge Zone	Assumptions/comments	Source
6,570 (estimated from gallons/day)	-	Kawarren (via pipeline)	• Intake area is ~119 km2 (converted from square miles) • Approximately 388 km2 confined aquifer area • Between G13 and G11 average thickness of sands is 61 m (converted from feet), the width of the basin is 13 km (converted from miles) and the average field hydraulic conductivity is 341 L/day (converted from gallons).	Blake, 1974
8,500	-	Barongarook to Kawarren Avenue	• Intake area ~54 km^2 • Effective infiltration of 27.4 cm/year or 30% annual precipitation using 900 mm for mean annual precipitation. • The authors noted that recent modelling had inidcated tha the recharge estimate was too high, and that there was a structural	Leonard et al., 1983

Recharge (ML/year)	Discharge (ML/year)	Recharge/ Discharge Zone	Assumptions/comments	Source
			or stratigraphic barrier between the KIA and the Barwon Downs sub-basin.	
8,430	-	Barongarook to Kawarren Avenue	• Intake area for Barwon downs Graben is ~31 km^2 • Effective infiltration of 27.4 cm/year or 30% annual precipitation (using 900 mm as mean annual precipitation)	Lakey & Leonard, 1983
3,100	-	Kawarren (via pipeline)	• Through-flow via the Pipeline Restriction caclulated via portioning recharge on the eastern side of the Barongarook High using flow net analysis (i.e. calculation is reliant on recharge estimates).	Lakey & Leonard, 1983
-	12,000	Gellibrand River	• Hydrograph separation using data from 1979-1980 at gauges 235227 and 235308. Equates to a baseflow of ~33 ML/day.	Lakey & Leonard, 1983
3,000	-	Barongarook to Kawarren Avenue	• Intake area for Barwon downs Graben is ~31 km^2 • Effective infiltration of 27.4 cm/year or 30% annual precipitation (using 900 mm as mean annual precipitation)	Lakey & Leonard, 1984[8]
500	-	Kawarren (via pipeline)	• Reported to be via flow-net analysis (Aquade Groundwater Services, 2019)	Lakey & Leonard, 1984[7]
1,500 – 2,000	-	Barongarook to Kawarren Avenue	• Based on 10 km^2 of outcropping LTA • Effective infiltration rate of 17% (using mean annual precipitation of 1,000 mm)	Stanley, 1991
0	-	Kawarren (via pipeline)	• Considered at the time to no longer exist based on pump test responses noting further investigaton was recommended.	Stanley, 1991
1,600	-	Barongarook to Kawarren Avenue	• Based on 12 km^2 of outcropping LTA. • Effective infiltration rate of 16% (using mean annual precipitation of 1,000 mm)	HydroTechnology, 1994
300	-	Kawarren (via pipeline)	• K – 1 m/day (broad range of values, however, average is 1	HydroTechnology, 1994

[8] Note BlueSphere has not cited this reference

Recharge (ML/year)	Discharge (ML/year)	Recharge/ Discharge Zone	Assumptions/comments	Source
			m/day and so considered more representative) • Hydraulic gradient of 0.03	
-	No more than 2,900 ML/year	Gellibrand River	• Based on minimum flow increase between gauges 235202 and 235227 as presented in (SKM, 2012)	Aquade, 2019
Could be >500 ML/year	-	Kawarren (via pipeline)	• Considered based on the drawdown response within the Kawarren basin that the flux could be >500 ML/year	Aquade, 2019

Notes: K – hydraulic conductivity.

The initial recharge estimates for the KIA (Blake, 1975) and (Lakey & Leonard, 1983) (8,430 ML/year via Kawarren Avenue plus 3,100 ML/year via the Pipeline Restriction) were revised down by Stanley (1991) to a total of 1,500 to 2,000 ML/day based on a reduction in recharge area (31 km^2 to 12 km^2) and recharge rate (30% to 17%). It is understood from Stanley (1991) that the initial recharge estimates of Lakey & Leonard (1983) were revised in 1984 to 3,000 ML/year via the Kawarren Avenue and 500 ML/year via the Pipeline Restriction, however, BlueSphere has not been able to obtain the source material for these estimates.

Flow across the Pipeline Restriction was omitted by Stanley (1991) due to uncertainty regarding the connectivity between the Barwon Downs Sub-Area and the KIA in this area. Historical investigations also inferred no connectivity of the LTA between the KIA and the Barwon Downs sub-basin area with the LTA inferred to pinch out (e.g. Witebsky et al., 1995 and Petrides & Cartwight, 2006).

On the basis of further drilling by HydroTechnology (1994) the recharge estimates were further refined to 1,600 ML/day via the Kawarren Avenue and 300 ML/year via the Pipeline Restriction. This was based on refinement of effective recharge area (12 km^2), recharge rate (16%) and further evaluation of the geometry of the Pipeline Restriction. Lakey & Leonard (1983) did acknowledge at the time that the initial recharge rate was too high and further investigations were proposed.

Stanley (1991) estimated based on stream flow analysis conducted by Hebblethwaite & James (1990) that of the recharge to the LTA via the Kawarren Avenue, approximately 440 ML/year and 290 ML/year discharges from the LTA into Ten Mile Creek and Yahoo Creek respectively. These constitute ~27% and ~18% of the total recharge to the LTA via the Kawarren Avenue using the refined recharge estimates of HydroTechnology (1994). The remainder of the estimated recharge (~55% or 880 ML/year) is therefore considered to transmit into the deeper LTA.

More recently, on the basis of groundwater modelling, Jacobs (2018) estimated the recharge to be 5% of annual rainfall. This recharge rate has not been adopted for this investigation as it is considered inconsistent with the nature of the LTA outcrop present (i.e., higher recharge rates would be expected). It is understood the 5% value has been derived based on calibration of the groundwater model; the 5% value likely represents the long-term average, which would encompass periods of lower rainfall in the geological past, such as the last glaciation approximation 5,000 years ago, noting that groundwater ages in the order of 20 thousand years old have been reported within the LTA (Petrides & Cartwright, 2006).

Based on BlueSphere's review of the recharge estimates, it is considered that the HydroTechnology (1994) estimate represents the most appropriate estimate of recharge via the Kawarren Avenue, with the clarification that not all of this ultimately recharges the deeper portions of the LTA; 45% discharges as baseflow into Ten Mile and Yahoo Creeks, with the balance (880 ML/year) recharging the deeper portions of the LTA.

With regard to the Pipeline Restriction, BlueSphere's review indicates that the LTA is continuous across the Pipeline Restriction, consistent with HydroTechnology (1994) and Aquade (2019). This is supported by the hydraulic response to pumping observed in the KIA (refer to **Section 5.1**), which was also identified by Aquade (2019). Whilst the LTA does thin substantially from approximately 200 m in the Barwon Downs sub-basin to approximately 10 m (64237/G21) at the area termed the 'Pipeline Restriction' (Aquade, 2019), as shown in LTA thickness map (**Figure F10**) and cross section (**Figure F15**) and basement contours (**Figure F8**), it would appear that there is potentially a zone of thicker LTA sediments in the western portion of the Pipeline Restriction (100 m at 64227/G11). However, it is noted that there is uncertainty regarding the extent and thickness of the LTA in this area, and this underpins the through flow estimation. In view of this uncertainty the through flow estimates of HydroTechnology (1994) are considered most reasonable, noting that the through flow may be higher than the existing estimate as per (Aquade, 2019).

Lakey & Leonard (1983) estimated that 12,000 ML/day was discharging from the LTA into the Gellibrand River based on streamflow analysis of data from the Gellibrand River. Aquade (2019) derived an estimate of no more than 2,900 ML/year using the same approach as Lakey & Leonard (1983) but with data from 2007 to 2009. Both of these calculations do not take into account any throughflow that does not express to the Gellibrand River.

4.9.6 Otway Group Aquifer

There is little information available regarding the properties of the OGA. Tickell et al., (1991) consider the OGA to be a poor aquifer producing little water and generally having a low permeability, with several records indicating bore yields in the range of 0.1 – 1.26 L/s. Where a fracture and/or joint is encountered then the aquifer may be considered a minor aquifer.

The OGA outcrops along the Otway Ranges and Barongarook High. In this area the OGA is unconfined with recharge occurring via direct infiltration of rainfall. Discharge is expected to occur via either evapotranspiration or via direct discharge into local streams (Tickell et al., 1991) where the OGA outcrop (Tickell et al., 1991) also note that discharge of groundwater from the OGA provides the base flow of the streams during dry periods. Where the OGA is overlain by the LTA, groundwater is expected to either discharge from the OGA into the LTA, or vice versa depending on the hydraulic potentials (which are not known in the KIA).

Groundwater flow within the OGA is expected to broadly follow topography and flow in a south/south westerly direction.

4.10 Groundwater Resource Utilisation

4.10.1 Registered Extractive Use Bores

A search of the Water Measure Information Systems (WMIS) database identified a number of registered extractive use groundwater bores within the KIA (**Figure F7**). Within the KIA three groundwater bores were registered for domestic/stock use while the remaining were either observation or non groundwater.

4.10.2 Barwon Downs Borefield

The history of the borefield has been documented in Jacobs (2018a) and is briefly summarised below:

- The drought of 1967-68 resulted in reduced water supply levels for Geelong, prompting investigations of a groundwater resource to augment supplies for the Geelong region by the Geelong Waterworks and Sewerage Trust (now Barwon Water).
- The Barwon Downs Graben was identified as a significant groundwater resource following investigations and a trial production bore was constructed in 1969, followed by an additional bore in 1977 at Gerangamete.
- Stage I of the borefield involved the construction of three production bores (see **Table 10**, below), while Stage II was to construct an additional three bores (Lakey & Leonard, 1983).
- An additional two production bores were installed in 2001.

Table 10 Production Bore Summary (after Barwon Water)

Production Bore ID	Date Installed	Bore Depth (m)	Screen Interval (m)	LTA[1] Units
GW2A	20 May 1982 Relined in 1998 and refurbishment works in 2016	543	383 – 542	Mepunga, Dilwyn, Pebble Point
GW3	1983 Relined in 1997 and refurbishment works in 2016	538.8	361 – 538.8	Mepunga, Dilwyn, Pebble Point
GW4	15 February 1982 Relined in 1997 and refurbishment works in 2016	645	452.5 – 645	Mepunga, Dilwyn, Pebble Point
GW5	29 November 1981 Re-sleeved in 1987 and refurbishment works in 2016	506	350 – 506	Mepunga, Dilwyn, Pebble Point
GW6	12 January 2001 Refurbishment works in 2016	552	328.5 – 488.2	Mepunga, Dilwyn, Pebble Point
GW8	31 January 2001 Refurbishment works in 2016	561	339 – 547	Mepunga, Dilwyn, Pebble Point

Notes: 1. LTA – Lower Tertiary Aquifer – refer to **Sections 4.8** and **4.9** for further detail.

4.10.2.1 Licence

Barwon Water was issued with a licence by the State Rivers and Water Supply Commission (now Southern Rural Water) in 1975. It is, however, noted that the borefield did not commence operation until the 1982-83 drought. The licence allowed the operation of four production bores. The licence was renewed several times between the period of 1975 and 2019 and allowances are summarised below in **Table 11**. In 2019 Barwon Water let the licence expire.

Table 11 Licence Conditions

Licence Period	Maximum Daily Extraction	Maximum Annual Extraction	Maximum 10 year Extraction
1975 – 1990 Renewed two times for 5 year periods up to 2000	42.5 ML	12,600 ML	80,000 ML
2000 - 2004 From 2000 temporarily extended 3 times for a total of four years	42.5 ML	12,600 ML	80,000 ML
2004 – 2019	55 ML	20,000 ML	80,000 ML

Licence Period	Maximum Daily Extraction	Maximum Annual Extraction	Maximum 10 year Extraction
Extra conditions included long term (100 year period average extraction rate of 4,000 ML/year)			

4.10.2.2 Operational History

The operational history of the borefield has been documented in Jacobs (2018a) and is summarised in the table below and is also presented graphically in **Figure 16**. However, based on correspondence from Barwon Water the documented extraction volumes have potentially been reported differently over the years, e.g. if the reporting has been completed over a calendar year or a financial year. There has also been some uncertainty regarding extraction in the 1980s and if the volumes related to Barwon Water needing the water to supplement water supply or it was during a pump test.

Between the granting of the licence in 1975 and the end of the licence 2019 (44 year period) extraction occurred five times.

Based on correspondence from Barwon Water it is understood that bores GW6 and GW8 were used the most during the extraction periods, followed by GW5, GW4 (due to being deeper and less affected by draw down), GW2A. Production bore GW3 was typically used last as it had approached trigger levels earlier than the other bores.

Table 12 Pumping Summary

Pumping Period	Extracted Volume	Comment
1983	3,652 ML	Corresponded to the 1982-83 drought
1988 – 1990	19,074 ML	Corresponded with a pumping test, no recorded drought
1997 – 2001	36,820 ML	Corresponded with the first half of the Millennium drought – 1997 – 2001
2003	271	Correspond with drought period
2005 – 2010	52,683 ML	Corresponded with the second half of the Millennium drought – 2005 – 2010
2015 – 2016	3,449.1 ML	Corresponded with a ‘record dry summer’ (Jacobs, 2018a)
Total Volume Extracted	115,949.1 ML	Up to 119,000 ML

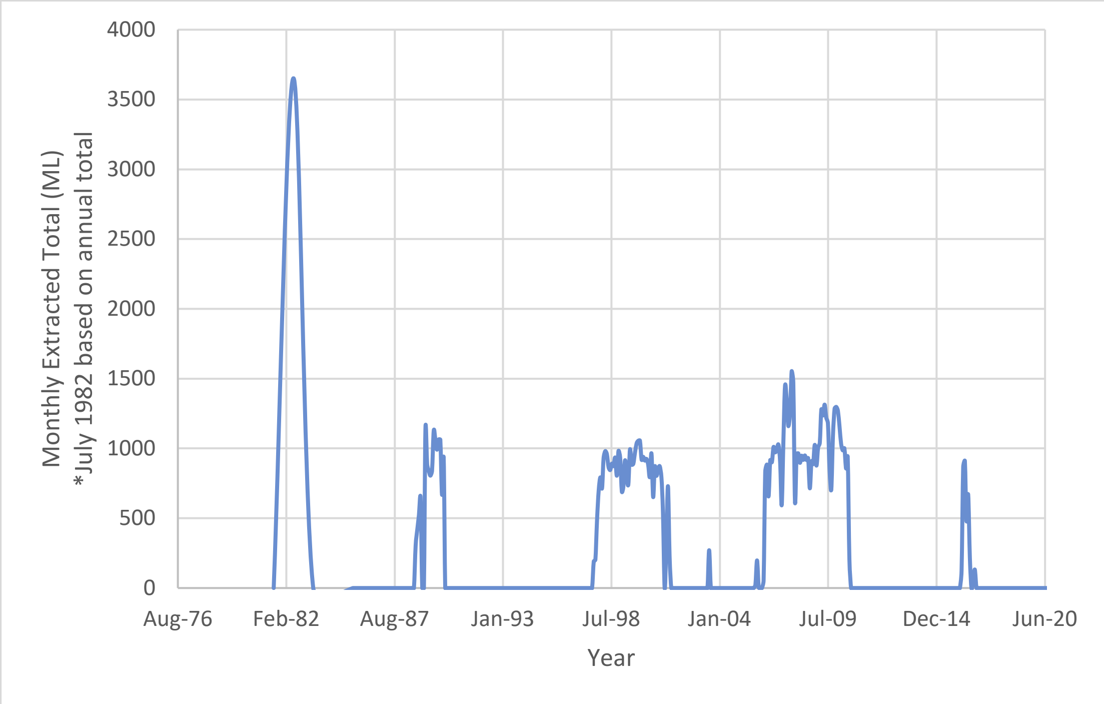

Figure 16 Monthly Extracted Total

4.11 PCV Amendment Rationale

On 26 June 2019 an order was made under Section 22A of the Water Act 1989 in relation to the permissible consumptive volume (PCV) for the Gellibrand and Gerangamete Groundwater Management Areas (GMAs). The PCV for the Gerangamete GMA was previously set as 20,000 ML/year with no more than 80,000 ML in consecutive period of ten years[9]. This was equivalent to the Barwon Water licence current at the time.

The PCV was reduced to 239 ML/year with no more than 30 ML/year under a licence for the purpose of pump tests. A PCV for the Gellibrand GMA of 0 ML was established. The PCV was amended due to concerns regarding impacts, to support remedial actions and focus on allowing the groundwater system to recover - not stabilise (as would be the case if the sustainable yield was matched), and to honour existing licences.

The 2019 PCV of 239 ML/year essentially reflected the cessation of extraction from the Barwon Downs Borefield and honours the balance of existing licences in the Gerangamete GMA, of which there are three individual licences[10]. Further, the PCV was also reduced to support and facilitate recovery of the LTA. The Gerangamete Local Management Plan was last updated in April 2023 and is to be reviewed on an as needs basis [11].

It is understood that the sustainable yield was not re-evaluated in amending the PCV. That is, the PCV amendment was based solely on honouring existing water rights.

4.12 Groundwater Quality

The quality of groundwater in the LTA, LMTA and QA has been documented to various degrees and a range of available groundwater salinities (Total Dissolved Solids (TDS)) for each aquifer grouping is provided in **Table 13** below sourced from (Tickell et al., 1991).

[9] Victorian Government Gazette, Permissible Consumptive Volume Groundwater Order 2011, No. G28, Thursday 14 July 2011
[10] Hopkins-Corangamite Groundwater Catchment Statement, Southern Rural Water, 18 September 2019
[11] Gerangamete Groundwater Management Area Local Management Plan, Version 1, April 2023

Table 13 Salinity Range of Aquifer/Aquitard Groupings

Aquifer/Aquitard Grouping	TDS Range (mg/L)
Otway Group Aquifer	1,000 – 3,000
LTA	200 – 500
LMTD	695 – 2,529*
LMTA Clifton Formation Gellibrand Marl	 500 500 – 1,500
QA	130 – 299*

Notes: - indicates no data available.

- Data from Jacobs (2018)

The quality of groundwater in the KIA has been documented in several historical investigations including Lakey & Leonard (1983). The groundwater quality has been reported as good and a summary table of minimum and maximum concentrations of major ions, TDS and nitrate is provided in **Table 14**, below, (after Lakey & Leonard, 1983).

Table 14 Statistical Analysis of Groundwater Quality Data - Gellibrand Area

Parameter	Minimum Concentration	Maximum Concentration	ADWG
	mg/L	mg/L	mg/L
TDS	52	1,050	
Chloride	16	565	
Carbonate	0	10	
Bicarbonate	4	137	
Sulfate	0	73	
Nitrate	0	60	50
Calcium	0	42	
Magnesium	1	43	
Sodium	10	298	
Potassium	1	7	
Iron (total)	0.2	20	
Iron (soluble)	0.1	2	
Silicate	1	39	
Total hardness	7	220	

Parameter	Minimum Concentration	Maximum Concentration	ADWG
	mg/L	mg/L	mg/L
pH*	2.5	9.5	

Notes: * - no units for pH

The following is noted regarding the quality of groundwater in the LTA:

- The TDS concentrations indicate the groundwater would be classified as Segment A2 (by adopting the lowest TDS concentration) in accordance with the Environmental Reference Standard (ERS) (2017).
- In some cases nitrate concentrations were reported above Australian Drinking Water Guidelines. (Lakey & Leonard, 1983) attributed this to septic and/or agricultural inputs within the area.
- Iron concentrations were lower than those reported in the Barwon Downs area, where treatment was required to remove iron, indicating that were a second borefield to go ahead in the 1980s water would likely not require treatment for iron.

4.13 Surface Water

4.13.1 Regional Setting

As described above in **Section 4.3**, the KIA sits within the Otway Coast Basin which extends from just east of Breamlea to just west of Port Campbell. There are two catchments within the Otway Coast Basin: Gellibrand River catchment and Otway Coast Catchment. The KIA sits within the Gellibrand River Catchment. The Gellibrand River starts in the Otway Ranges south of the KIA before heading north and bordering the KIA along the southern boundary. South west of the KIA, the Gellibrand River flows south west and drains into the ocean.

The Gellibrand River catchment is fed in part by the Loves Creek catchment, within which the KIA sits.

4.13.2 Local Surface Water Systems

There are five key surface water bodies within the KIA that are focussed on in this report; they are:

- Ten Mile Creek;
- Yahoo Creek;
- Porcupine Creek;
- Loves Creek; and
- Gellibrand River.

A summary of the surface water bodies (based on information sourced from MapShare Vic, Energy, Environment and Climate Action (EECA) website) and associated gauges is provided below in **Table 15**.

Table 15 Summary of Surface Water Catchments in KIA

Surface Water Body	Description	LTA Outcrop	Catchment Area	Stream Gauge	Mean Annual Flow	Minimum Flow Threshold (for farm bypasses)	Maximum Daily Extraction Volume
Ten Mile Creek	Originates from the southern margins of the Barongarook High and flows south/south east before joining Porcupine Creek at McDonalds Road, Kawarren East and forming Loves Creek. It is understood that Ten Mile Creek runs throughout the year and it is expected that a proportion of the flow of Ten Mile Creek is fed by groundwater.	The upper reaches of Ten Mile Creek flow along outcrops of the units described as the LTA	9.3 km^2	235239 located at the junction of Cashins and Robinson Road (locally referred to as Robinson Track)	6.9 ML/day	2.7 ML/day	3.8 ML/day
Yahoo Creek	Originates from the western flank of the Site area in the south western extension of the Barongarook High. The creek flows north east along the minor gully before heading south east and joining Loves Creek at Kawarren. It is understood anecdotally that Yahoo Creek runs throughout the year and similar to Ten Mile Creek it is expected that a proportion of the flow is fed by groundwater.	The upper reaches of Yahoo Creek also flow along outcrops of the LTA	17 km^2	235240 located on the lower reaches of Yahoo Creek	6.4 ML/day	4.3 ML/day	3.2 ML/day
Loves Creek	Loves Creek is fed by Ten Mile Creek, Yahoo Creek and Porcupine Creek. Porcupine Creek does not have a sub-catchment area as defined by EECA, rather forms part of the upper Loves Creek catchment area which incorporates the confluence of Ten Mile Creek and Porcupine Creek and the confluence of Loves Creek and Yahoo Creek. Porcupine Creek originates in the south eastern corner of the KIA and flows north west before joining Ten Mile Creek and forming Loves Creek. It is understood (anecdotally) that both Porcupine Creek and Loves Creek flow throughout the year.	The upper reaches of Loves Creek flow along outcrops of Quaternary Sediments and unconfined Clifton Formation, while the lower reaches flow along a combination of Quaternary Sediments, Yaugher Volcanics and Narrawaturk Marl	Upper loves Creek catchment is 76.9 km^2, which is consistent with what (Hebblethwaite & James, 1990) determined (74 km^2). While the lower Loves	There is one stream gauge along the lower reaches of Loves Creek (235234) located downstream of 235240 There is one former stream gauge along Porcupine Creek (235241) located	6.9 ML/day	2.7 ML/day	3.8 ML/day

Surface Water Body	Description	LTA Outcrop	Catchment Area	Stream Gauge	Mean Annual Flow	Minimum Flow Threshold (for farm bypasses)	Maximum Daily Extraction Volume
		Porcupine Creek flows along outcrops of Quaternary Sediments and likely small portions of Gellibrand Marl	Creek catchment area is 18.3 km^2	immediately upstream of the confluence with Ten Mile Creek			
Gellibrand River	Gellibrand River originates in the Otway Ranges south east of the KIA and flows north west and bordering the KIA along the southern boundary. South west of the KIA the Gellibrand River flows south west and drains into the ocean. Loves Creek joins Gellibrand River just north of the Gellibrand township. Other contributors to Gellibrand River within or bordering the KIA include Lardners Creek and Charleys Creek.	Portions of the Gellibrand River in the KIA flow over outcrops of the LTA, while south west of the KIA the river flows predominantly along outcrops of the LTA	The portion of the Gellibrand River catchment that falls within the KIA area is 21.6 km^2, while the portion that Loves Creek flows into is 59.1 km^2.	There are several gauges along Gellibrand River. The gauges that have been used are Gellibrand River @ Gellibrand 235228 located just to the east of the Gellibrand township and Gellibrand River @ Bunkers Hill 235227 located downstream of the Loves Creek and Gellibrand River confluence	21.6 ML/day	3.9 ML/day	4.5 ML/day

4.13.3 Springs / Soaks

There are a large number of springs and soaks located along the waterways mentioned above as well as on various local landholders' properties.

For the purposes of this report the following definitions of a spring and soak have been adopted:

- Spring: A discrete place where groundwater flows naturally from a rock or soil onto the land surface or body of surface water, generally with a current. That is a spring has flow.
- Soak: An area where water percolates slowly to the land surface, generally without a perceptible current. That is a soak does not have flow.

The springs have been investigated historically by (among others) (Gardiner, 2020b) (Hebblethwaite & James, 1990) (Stanley, 1991) and (SKM, 2012). The springs identified in the previous investigations along with those compiled by local landholder Malcolm Gardiner and those discussed with other knowledgeable landholders are presented on **Figure F19** – **Figure F22**.

Whilst there are several springs located along the upper reaches of both Ten Mile and Yahoo Creeks, along the outcrops of LTA, the majority of springs are located in the lower reaches and along Porcupine Creek, where either the Narrawaturk Marl or Gellibrand Marl outcrops. The majority of the springs tended to occur at a break in slope which is consistent with LMTA derived discharge.

During interviews with knowledgeable landholders in the Kawarren area, the majority of which were located in the Loves Creek valley, they indicated that the springs or soaks on their respective properties had largely not dried up and continued to flow or seep throughout the year. A reduction in flow or seep was observed during summer months, while an increase in flow or seep was observed during winter months.

4.13.4 Hydrological Characteristics

Catchment characteristics of four of the key surface water bodies in the KIA have been summarised from (Hebblethwaite & James, 1990) in **Table 16**, below.

Table 16 Surface Water Catchment Hydrological Characteristics (adapted from Hebblethwaite and James 1990)[1]

Aspect		Units	Ten Mile Creek (235239)	Yahoo Creek (235240)	Porcupine Creek (235241)	Loves Creek (235234)
Catchment Area		km^2	10.7	15.0	33.3	73.8
Typical Summer Flow (i.e. baseflow)		ML/day	1.2	0.8	0.2	2.2*
Baseflow Index[2]	(Lower Limit)	%	36	22	24	30
	(Best Estimate)	%	46	27	28	34
	(Upper Limit)	%	61	34	32	40
Baseflow	10th Percentile	ML/day	4.46	4.35	13.38	27.23
	50th percentile	ML/day	2.02	1.07	1.91	6.12
	90th percentile	ML/day	1.42	0.84	0.30	2.66
	98th percentile	ML/day	1.27	0.81	0.17	2.29

Aspect		Units	Ten Mile Creek (235239)	Yahoo Creek (235240)	Porcupine Creek (235241)	Loves Creek (235234)
Total Flow	10th Percentile	ML/day	7.54	12.87	37.49	60.32
	50th percentile	ML/day	2.64	1.27	4.06	9.85
	90th percentile	ML/day	1.49	0.87	0.36	2.90
	98th percentile	ML/day	1.27	0.81	0.17	2.29
Baseflow Contribution per Unit Catchment Area[3]		ML/day/km^2	0.112	0.053	0.006	0.0298

Notes: 1. Based on data from prior to June 1990 (i.e. prior to LTA extraction by Barwon Water) and therefore are considered to represent pre-extraction baseline conditions.
2. Baseflow index is the ratio of baseflow to total flow in each stream.
3. Typical summer flow divided by catchment area
* The typical summer flow presented by Hebblethwaite and James 1990 appears to be based on the sum of typical summer flows in Ten Mile Creek Yahoo Creek and Porcupine Creek and not the flow data. It is noted this does not match the flow records for Loves Creek, which show a typical summer flow in the order of 1 ML/day.

The data presented in **Table 16** indicates that Ten Mile Creek has the greatest amount of baseflow per unit areas, followed by Yahoo Creek and Loves Creek, however, it is noted that Loves Creek does not flow over LTA outcrops. Rather Loves Creek receives inflows from both Ten Mile Creek and Yahoo Creek that do flow over LTA outcrops. The greater amount of baseflow per unit area presumably reflects the proportion of LTA that outcrops in each of these catchments (i.e. Ten Mile Creek has the highest amount of outcrop from which groundwater can discharge). Porcupine Creek has no LTA outcrop within its catchment that is connected to the regional LTA aquifer, and subsequently has only 5% of the baseflow that Ten Mile Creek has on a per area basis (i.e. 0.006 ML/daykm^2 versus 0.112 ML/day/km^2). Hebblethwaite and James 1990 note that Ten Mile Creek and Yahoo Creek constitute approximately 90% of the baseflow in Loves Creek. BlueSphere notes that based on a typical summer flow of 2.2 ML/year in Loves Creek as an approximation of base flow, Ten Mile Creek accounts for approximately 55% of base flow and Yahoo Creek approximately 35%.

4.13.5 Surface Water Quality

Previous investigations including (SKM, 2012), (Stanley, 1991), (Witebsky, Jayatilaka, & Shugg, 1995) have undertaken varying analysis of surface water quality of one or more of the five main surface water bodies in the KIA. A brief summary of surface water quality is provided below.

The following is noted regarding the quality of surface water in the region:

- Spring salinity (EC) results collected from 11 spring locations, ranged between 270 – 2,300 (Witebsky, Jayatilaka, & Shugg, 1995);
- River EC sampling suggests that on average, the Gellibrand River is recharged by a groundwater source with a higher salinity than the river originating upstream of Stevensons Falls (SKM, 2012);

4.13.6 Surface Water Utilisation

A summary of existing surface water users, as sourced from the Victorian Water Register website (waterregister.vic.gov.au) is provided in **Table 17**, which accounts for licenced users only and does not account for any existing water rights. There are a number of licenced surface water users who are able to utilise this water for stock and domestic, irrigation and dairy purposes. Annual licences limits are issued for this purpose. It is noted that the specific location of these licenced users has not been evaluated.

Table 17 Summary of Licenced Surface Water Extraction

Water source			Gellibrand River Tributary	Gellibrand River	Loves Creek	Yahoo Creek	Porcupine Creek	Ten Mile Creek	Lardner creek
Total Number of licences			11	33	20	NA	1	1	1
Tradable extraction licence			4	30	13	NA			1
Not tradable extraction licences			7	3	7	NA	1	1	
Use for extracted water	Irrigation		8	11	9	NA	1	1	
	Domestic/stock			13	8	NA			
	Industrial/commercial			1					
	Dairy		3	8	3	NA			1
Annual extraction volume (ML)			129.9	936	543.5	NA	18	31.6	6
Annual extraction volume per use (ML)	Irrigation	Tradable	44.1	788.2	203.4	NA			
		Not Tradable	77.4	77.6	302.7	NA	18	31.6	
	Domestic/stock	Tradable		30.8	17.6	NA			
		Not Tradable				NA			
	Industrial/ commercial	Tradable		3.5					
		Not Tradable							
	Dairy	Tradable	7.4	30.8	19.8	NA			6
		Not Tradable	1	5.1		NA			

4.14 GDEs

There is limited data with regards to groundwater dependent ecosystems (GDEs) in the KIA. A review of the BoM Groundwater Dependent Ecosystems Atlas (2023) and incorporation of data provided by Barwon Water identified small areas of potential GDEs (**Figure F24**).

The BoM GDE Atlas indicates a high potential for a GDE along the Gellibrand River alignment, and a small portion of the eastern section of Porcupine Creek. Barwon Water has identified two areas along both Ten Mile and Yahoo Creeks for GDEs.

Previous investigations completed by (Eco Logical Australia, 2022a) found that identification of GDEs based solely on risk based modelling was difficult and that further works to target areas where the LTA outcrops was recommended. The further works (Eco Logical Australia, 2022b) found that the water tables at the investigation areas along Ten Mile Creek and Yahoo Creek varied between 5 and 20 m, while the water table levels at the Gellibrand River investigation area averaged 5 m depth. The potential for GDEs in the relevant investigation areas were found to be high for Ten Mile Creek, Yahoo Creek and Gellibrand River. While Ten Mile and Yahoo Creeks and Gellibrand River receive groundwater discharge, they are not entirely reliant on groundwater and as such it is difficult to definitively classify these water bodies as purely GDEs.

Based on observations made by local landholders (see **Section 4.13.3**) there is potential for GDEs to exist in the KIA in an around Loves creek and its tributaries. However, it is noted that the springs/soaks identified in this area are not fed by the LTA, rather the overlying LMTD.

4.15 Acid Sulfate Soils

Acid sulfate soils (ASS) are generally soils derived from sediments that are rich in sulfide minerals such as pyrite. ASS can exist in either a coastal or inland setting with inland ASS being present within the Barwon Downs region. Sulfide rich sediments are often deposited during a time of raised sea levels which provide the ideal environment for their formation due to the abundance of sulfate in seawater.

Acid sulfate soils can be classified as either a potential acid sulfate soil (PASS) or actual acid sulfate soil (AASS) depending on whether the soil has undergone oxidation. PASSs are sediments which contain sulfide minerals and have the potential to produce acid with oxidation while AASS are soils which have undergone oxidation and released acidity. The oxidation of these sediments can occur when the water table or stream that is responsible for maintaining anoxic, reducing conditions, is altered or lowered by either natural or anthropogenic processes (for example, drought, climate, through land use change, drainage enhancement, groundwater extraction, physical disturbance etc).

Investigations undertaken by (EAL Consulting Service, 2011), (Jacobs, 2015) and Jacobs 2022 have attempted to determine if there are areas of ASS within the Barwon Downs region. Samples were collected along creeks, river ways and swamp areas within the Barwon Downs catchment area. The sampling events involved the collection of soil samples and the analysis for Chromium Reducible Sulfur analysis and pH sampling. Results from 28 sample locations were reviewed and compared against the EPA Publication 655.1 criteria values for sandy soils (18 mol H^+ / tonne). Sample locations and ASS classification is provided on **Figure F23**.

Of the 28 sample locations, four are located within the investigation area and include;

- SH1 – Spiny Horn Creek
- YH1 – Yahoo Creek
- PC4 – Porcupine Creek
- GRBH01/GRBH02 – Gellibrand River

A summary of ASS classification and reported analytical results is provided in (**Appendix E**) and summarised in **Table 18** below.

Table 18 Summary of Acid Sulfate Soil Classification

ASS Type*	Locations	Highest Net Acidity Result (mol H^{+}/tonne)
Inside the investigation Area		
Actual ASS	PC4	89^
Potential ASS	PC4 and SH1	N/A
Possible ASS	-	-
Not Identified	YH1 and GRBH01/GRBH02	14 (GRBH01/GRBH02)
Greater Barwon Downs Catchment		
Actual ASS	BSBH13LTA, SB1 – SB17	11,942 (SB14)
Potential ASS	SB1, SB2, SB4 – SB7, SB10-SB12, SB14 – SB17, BSBH13LTA and WBBH01/WBBH02	11,942 (SB14)
Possible ASS	DMBH01V/DMBH02V and McD1	N/A
Not Identified	NYBH01/NYBH02 and PCBH01V/PCBH02V	11 (PCBH01V/PCBH02V)

Notes: * Determined by comparing against a criteria value of 18 mol H^{+}/ tonne
^ Value from maximum reported Titratable Actual Acidity value.

Of the locations analysed a total of 19 were identified to have AASS present with one located within the KIA. In addition, 17 locations were identified to have potential ASS present with two located within our investigation area.

Sample location PC4 located along Porcupine Creek, was identified to have actual and potential ASS with a TAA (titratable actual acidity) of 89 mol H^{+}/tonne. While this value is above the EPA criteria value for sandy soils (18 mol H^{+}/tonne) it is comparably lower than those values reported in Big Swamp with a maximum net acidity value of 11,942 mol H^{+}/tonne (SB14). BlueSphere's findings made from reviewing the above reports are consistent with that made by (Gardiner, 2020b).

The available information suggests that ASS are not likely to be widespread in the KIA based on the limited extent of Quaternary swamp deposits which are liable to ASS formation (most likely limited to Porcupine and Serpentine Creeks which drain the LMTA). In addition, the role of the marl and other natural acid neutralising materials is not well understood. One location (SH1) was identified by EAL Consulting Service (2011) to have a high natural acid neutralisation capacity however the source, type and efficiency was not determined. Anecdotally there does not appear to be widespread evidence of oxidation of ASS within the KIA, however, as PASS is present it is a relevant consideration for future surface water and groundwater management.

5 Impact Assessment

On the basis of the hydrogeological CSM developed for the KIA, a high level evaluation of potential hydrogeological and hydrological impacts of groundwater extraction from the Barwon Downs Borefield on the KIA has been undertaken. This is then used to establish whether potentially environmentally significant impacts have occurred. An environmentally significant impact is taken to mean a deleterious environmental affect principally on the near surface environment, manifested as effects such as vegetation loss, water quality deterioration, oxidation of acid sulfate soil, reduction in macroinvertebrate/fish populations, loss of spring/water flow etc.

5.1 Groundwater Potentiometric Surface Trends

Hydrographs have been prepared for groundwater bores with available long term water level records in the KIA and are presented in **Appendix F**. Additionally, water level change between 1997 and 2013 has been presented on **Figure F25**. The groundwater bores have been grouped into three main groups:

- Upper Ten Mile Creek reaches and recharge area;
- Kawarren/Loves Creek area; and
- Gellibrand River.

The hydrographs of bores in the Upper Ten Mile Creek area and the water level change (**Figure F25**) show varying trends of water level declines or increases with the following observed:

- Bores 113705 and 48001 show a water level decline of between 2.7 and 4.3 m, respectively, while bores 113707 and 47990 show a water level decline of ~1.4 m between 1997 and 2013.
- Bores 114168 and 114169 show a steady increase in water levels up until ~2005 before flattening.

The hydrographs of bores in the Kawarren/Loves Creek area and the water level change (**Figure F25**) show varying trends of water level declines or increases with the following observed:

- All bores within this area show a water level decline of >3.2 m between 1997 and 2013, i.e., during the peak groundwater pumping/extraction period.
- Bore 108910 shows the highest water level decline of 4.1 m.

The hydrographs of bores in the Gellibrand River area and the water level change (**Figure F25**) show varying trends of water level declines or increases with the following observed:

- There has been <1m decline in water levels at bores in the Gellibrand River area between 1997 and 2013.
- The water levels show fluctuations however, have largely remained stable.

The potentiometric surface of the LTA in 2010 (further detailed in **Section 4.9.5**, above) (**Figure F17**) shows a largely similar groundwater flow system to that presented in 1983, however, groundwater flow to the south west, through the Pipeline Restriction area is now reversed and flow is to the north east towards the borefield. This would have had the effect of intersecting the through-flow that would have otherwise entered the KIA via the Pipeline Restriction.

The differences in water level change between 1997 and 2013 (as shown on **Figure F25**) in bores in the lower reaches of Ten Mile Creek(no change), compared to those bores in upper reaches of Ten Mile Creek (up to 2.7 m) are considered to be due to the connectivity of the LTA in the upper Ten Mile Creek area across the Barongarook High. Given the spatial relationship, it is inferred that the decline in groundwater levels in Upper Ten Mile Creek is not related to the intersection of the Pipeline Restriction groundwater flow path by groundwater pumping (as is the case for the majority of the KIA) but rather due to watertable decline propagating along the Yeodene recharge avenue, leading to a shift in the groundwater divide in this area.

There has been a reduction in groundwater levels in the LTA in the KIA of up to 4 m between 1997 and 2013, which corresponds to the peak groundwater pumping/extraction period and the Millennium Drought. While there is a coincidental correlation with long-term rainfall patterns, high level calculations indicate that the long-term rainfall deficit cannot account for all the groundwater level reductions that have occurred and rather the decreases are likely to be predominantly due to the groundwater extraction from the LTA (refer to **Section 5.4**).

5.2 Identification of Susceptible Water Features

Potentially susceptible water features, based on a regional groundwater numerical model, were identified (Jacobs, 2018a). These potentially susceptible water features have been refined based on the CSM of the KIA (as presented in **Section 4**).

The primary susceptible water features are:

- Ten Mile Creek and Yahoo Creek where the potentiometric surface of the LTA bores is greater than the surface elevation and therefore groundwater has the hydraulic potential to discharge into these creeks. A review of the water level at TMCBH02 (screened in the water table aquifer which is inferred to be LTA based on the interpretation of the logs) and the water level at Ten Mile Creek would indicate (at this particular location at least) that this section of Ten Mile Creek is susceptible as the potentiometric surface is greater than the creek water elevation; and
- Gellibrand River groundwater discharge area where the potentiometric surface of the LTA bores is greater than the surface elevation. A review of the water level at 108917 (screened in the LTA) and the water level at Gellibrand River would indicate (at this particular location at least) that this section of the Gellibrand River is susceptible as the potentiometric surface is greater than the river water elevation. Other bores installed recently by Barwon Water (GRBH01 and GRBH02, adjacent to Clancys Hill) show potentiometric surfaces below the river water elevation, which would indicate at this particular location that there is the likelihood of periodic changes between discharge and recharge; this is consistent with the intersection of the LTA with the volcanics at this location.

While secondary susceptible water features have been identified as:

- Loves Creek given Ten Mile Creek and Yahoo Creek both feed Loves Creek; and
- Downstream Gellibrand River given the upstream susceptible water features as described above.

These are highlighted on **Figure F25**.

A recharge/discharge area plan for the LTA has been prepared based on the 1983 potentiometric surface contours (i.e., unaffected by pumping) and the topographic elevation contours (see **Figure F26**). There is a degree of uncertainty in the expected discharge areas as they are based on comparison contours with differing intervals, however, it is noted that at least the lower area of expected discharge along Ten Mile Creek is consistent with Figure 13 of SKM (2012). Based on the potentiometric surface contours and the topographic contours at least half of the Ten Mile Creek reach is expected to be a discharge area for the LTA. A much smaller area is shown along Yahoo Creek. There is low certainty regarding the areal extent of discharge along Yahoo Creek, however, it is expected that groundwater discharge does occur along Yahoo Creek.

5.3 Observed Surface Water Flow Trends

Publicly available stream monitoring records available on WMIS have been evaluated to identify potential surface water flow trends. Available stream flow data from the following surface water bodies has been considered:

- Ten Mile Creek;
- Yahoo Creek;
- Porcupine Creek;
- Love Creek;
- Lardner Creek; and
- Gellibrand River (upstream and including of Bunker Hill).

The stream flow records include a data quality code attached to each data point. A high level review of the data quality indicates that there are a number of instances where the data quality has been flagged. For example, since 2000 the minimum daily flow in any given year at gauge 235234 (Loves Creek @ Gellibrand) has been accompanied with a with description ‘rating extrapolated 1.5 times the maximum flow gauged’. The implication of this on overall data quality is not certain. BlueSphere has interpreted the data as is and has not undertaken any data modification or corrections.

Streamflow analysis has been undertaken through consideration of minimum daily flow on both a monthly and annual basis. Minimum daily flow has been utilised as it provides the closest approximation of inflows other than those associated with surface water runoff from rainfall (e.g. groundwater, bank storage etc). This is referred to as baseflow.

Consideration of the minimum daily flow in any given month basis provides an appreciation of the seasonal variability in baseflow. Comparison of the lowest minimum daily flow in any given year provides information regarding long-term baseflow trends that are most likely associated with groundwater inflows.

Streamflow trends for Loves Creek and its tributaries (Ten Mile Creek, Yahoo Creek and Porcupine Creek) are shown on **Figure 17** to **Figure 20**, and streamflow trends for Gellibrand River and Lardner Creek, are shown on **Figure 22** and **Figure 23**. Long-term rainfall trends and extraction totals from the Barwon Downs Borefield are also shown on the figures for comparative purposes. Note the y-axis on these graphs has been truncated (i.e., not all data are shown) as the emphasis is on the absolute minimum values.

The 10th percentile minimum daily flow in any given year has been calculated for three distinct time periods to provide a degree of quantification of long-term streamflow trends (where present). The time frames considered are:

- Pre 1997, being all available data from prior to the Millennium Drought;
- Data from 1997 to 2009 (i.e. the Millennium Drought), which is the time period in which ~80% of all extraction from the Barwon Downs borefield occurred.
- Data from post 2009, representing the period following peak groundwater extraction from the Barwon Downs borefield.

A summary of the calculated baseflow within each stream is provided in **Table 19**. The baseflow in each stream has also been expressed as a percentage of the baseflow in the Gellibrand River at Bunker Hill (station 235227), which lies within the discharge of the LTA groundwater flow system (refer to **Section 4.9.5.2**). A summary of the key observation is provided following.

It is noted that the calculation method adopted above (absolute minimum daily flow in any given year) differs from that adopted in (Earth Tech Engineering Pty Ltd, 2006), which calculated statistics based on low-flow (Dec to May) and high-flow (June to November) regimes. This reflects the differencing focusses of each investigation. The Earth Tech approach would have the result of leading to higher baseflow estimates than that adopted by BlueSphere.

Table 19 Gellibrand River Baseflow Estimates and Streamflow Contribution

Station ID^	Location	Baseflow Estimate (ML/day)[1]			Observed Net Reduction in Baseflow (ML/day)	% Contribution to Gellibrand River @ Bunker Hill			Comment
		<1997	>1997-2009	>2009		<1997	>1997-2009	>2009	
Love Creek									
235239	Ten Mile Creek @ Kawarren	0.84	ID	0.77	0.07	NC	NC	NC	Very slight potential decreasing trend ~0.07 ML/day, within expected natural range of variation.
235240	Yahoo Creek @ Kawarren	0.76	ID	0.02	0.74	NC	NC	NC	Decreasing trend evident between <1997 and >2019 of 0.74 ML/day
235241	Porcupine Creek	0.09	ID	ID	-	NC	NC	NC	No visual trend evident between <1997 and 2009
235234	Love Creek @ Gellibrand	1.02	0.47	0.2	0.82	4.5%	3.1%	0.3%	Decreasing trend evident between <1997 and 2020 of 0.82 ML/day, increase since 2020 up to 1.57 ML/day
Upper Gellibrand River									
235202	Gellibrand River @ Upper Gellibrand	0.54	1.09	1.72	-1.18	2.4%	-	-	An increasing trend in baseflow of 1.18 ML/day is evident.

Station ID^	Location	Baseflow Estimate (ML/day)[1]			Observed Net Reduction in Baseflow (ML/day)	% Contribution to Gellibrand River @ Bunker Hill			Comment
		<1997	>1997-2009	>2009		<1997	>1997-2009	>2009	
235236	Gellibrand River @ D/S of Dam Site	1.63	ID	ID	-	7.2%	-	-	Insufficient data for trend appraisal
235228	Gellibrand River @ Gellibrand	3.88	ID	ID	-	17.3%	ID	ID	Insufficient data for trend appraisal
235231	Gellibrand River @ Raffertys Lane Gellibrand	ID	ID	ID	-	-	-	-	Insufficient data for trend appraisal
Lardner Creek									
235210	Lardner Creek @ Gellibrand River	1.33	2.59	1.53	-0.20	5.9%	17.4%	8.6%	A slight increasing trend in baseflow of 0.2 ML/day is evident, within expected range of variation.
Middle Gellibrand River									
235227	Gellibrand River @ Bunker Hill	22.44	14.86	17.78	4.66	-	-		A decrease of 7.58 ML/day evident between <1997 and 1997-2009. Levels have then shown an increase, net reduction of 4.66 ML/day

Notes:

2. 10th percentile of minimum annual streamflow. Zero readings associated with equipment malfunction have been removed.

ID – Insufficient data.

NC – Not calculated as these creeks are upstream of Loves Creek and therefore their contribution to Gellibrand Creek is captured by the Loves Creek data.

5.3.1 Loves Creek and Tributaries

With respect to Loves Creek and its tributaries Ten Mile Creek, Yahoo Creek and Porcupine Creek, a decrease in baseflow was evident in Yahoo Creek between the pre 1997 baseflow and post 2019 baseflow of approximately 0.74 ML/day (**Figure 17**). Yahoo Creek emanates from LTA outcrop, however it is noted that the gauge along Yahoo Creek is not underlain by LTA, rather LMTD, and a proportion of groundwater discharge (albeit expected to be minor relative to LTA contributions) from the LMTD may occur and contribute to baseflow. A similar trend was not observed in Ten Mile Creek (**Figure 18**), which also emanates from LTA outcrop, with only a slight potential decreasing trend ~0.07 ML/day within expected natural range of variation observed. Porcupine Creek also did not show any obvious trend (**Figure 19**), noting this waterway is predominantly located on LMTA outcrop.

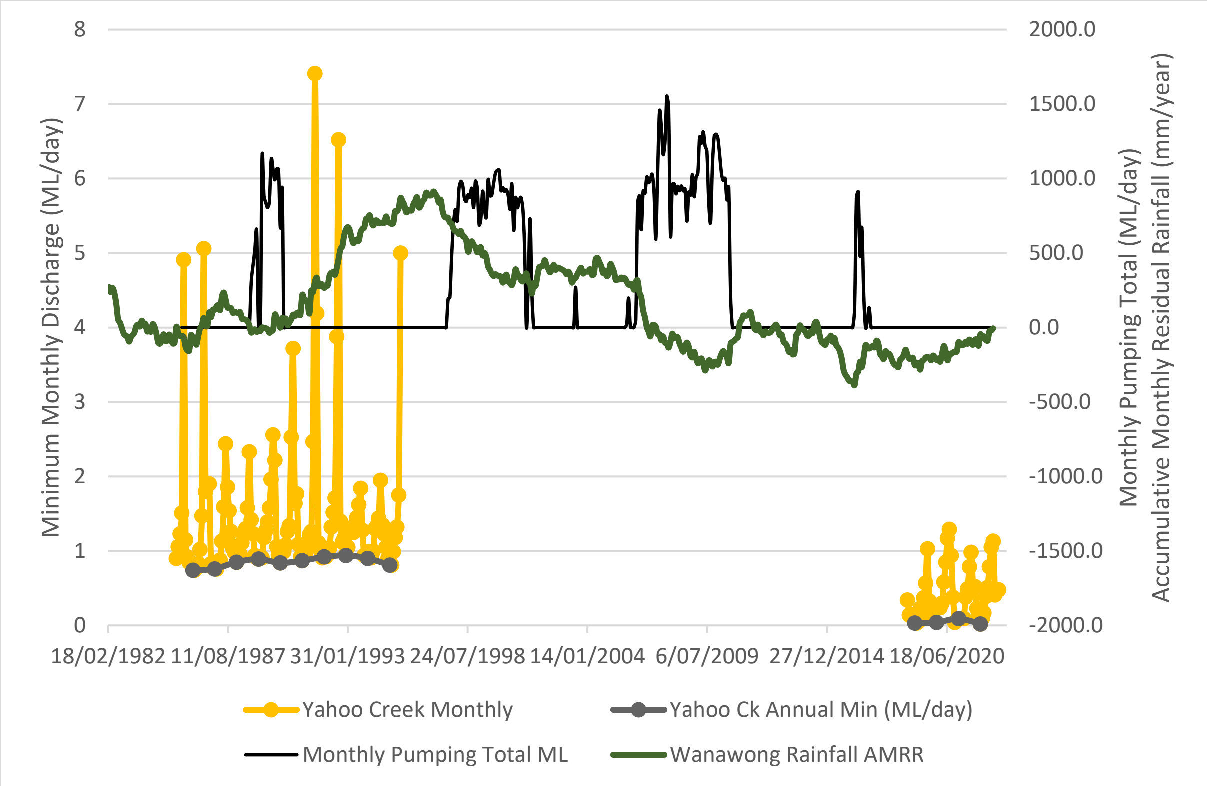

Figure 17 Minimum Monthly and Annual Streamflow Observations – Yahoo Creek

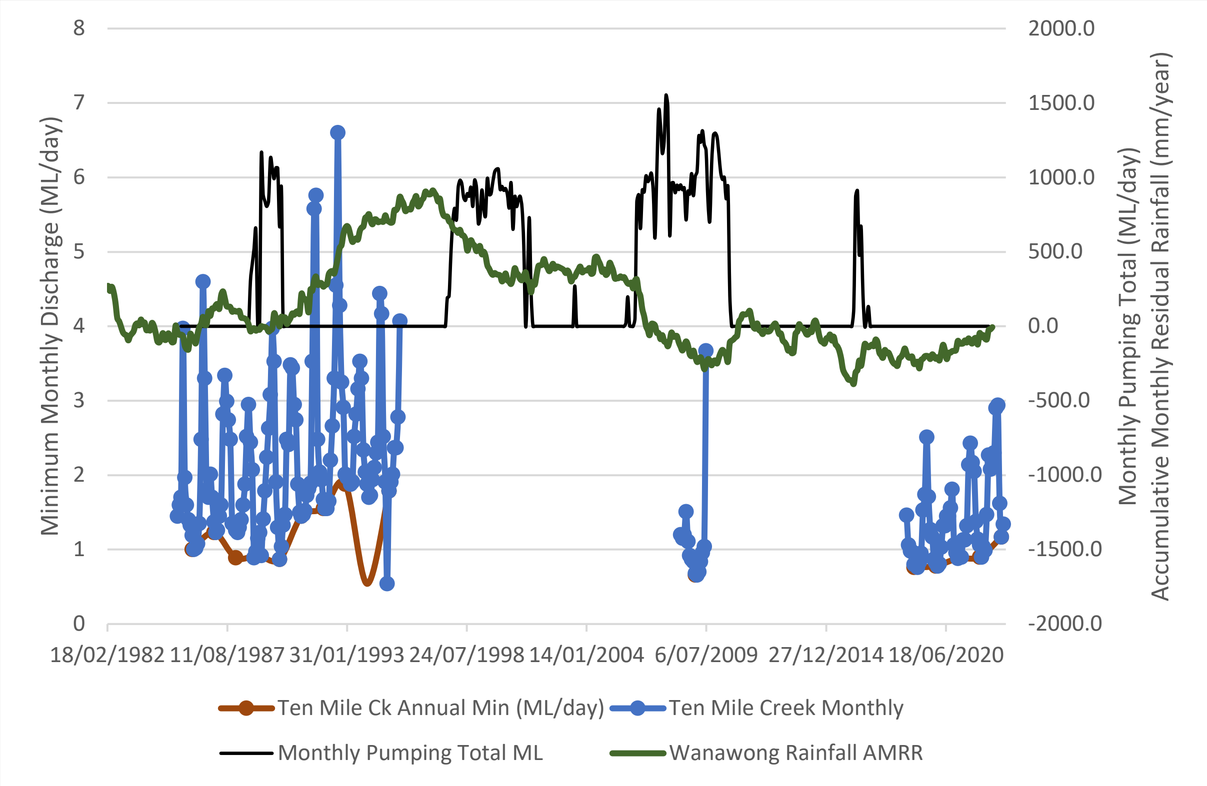

Figure 18 Minimum Monthly and Annual Streamflow Observations – Ten Mile Creek

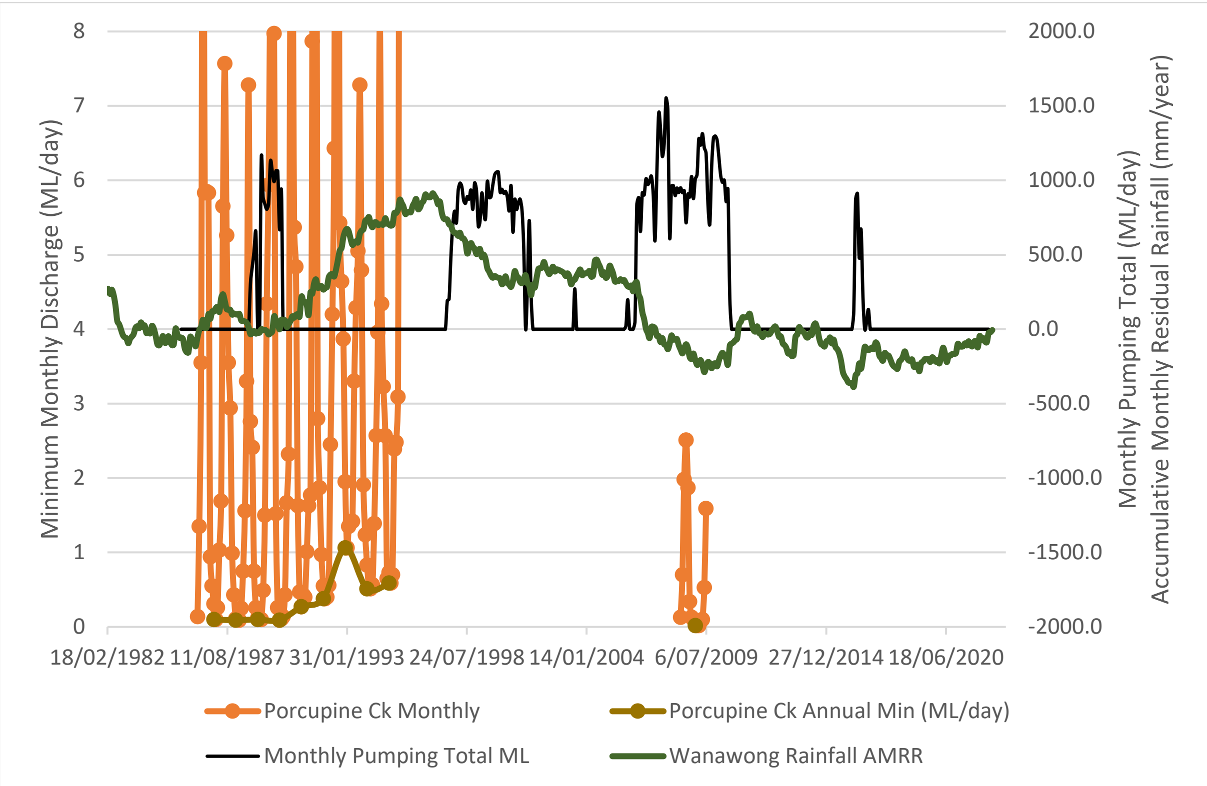

Figure 19 Minimum Monthly and Annual Streamflow Observations – Porcupine Creek

Loves Creek itself, down-stream of the confluences with Ten Mile Creek, Yahoo Creek and Porcupine Creek showed a decreasing trend between <1997 and 2020 of 0.82 ML/day (**Figure 20** and logarithmic scale presented on **Figure 21**). Baseflow levels have shown an increase since 2020 up to 1.57 ML/day. Aquade (2019) noted that a 60% decline in baseflow levels between 1997 and 2019 had occurred, which is consistent with these findings. The potential contributors to this are explored further in **Section 5.4**. It is noted that the gauge along Loves Creek is not underlain by LTA, rather LMTD, and a proportion of groundwater discharge (albeit expected to be minor relative to LTA contributions) from the LMTD may occur and contribute to baseflow.

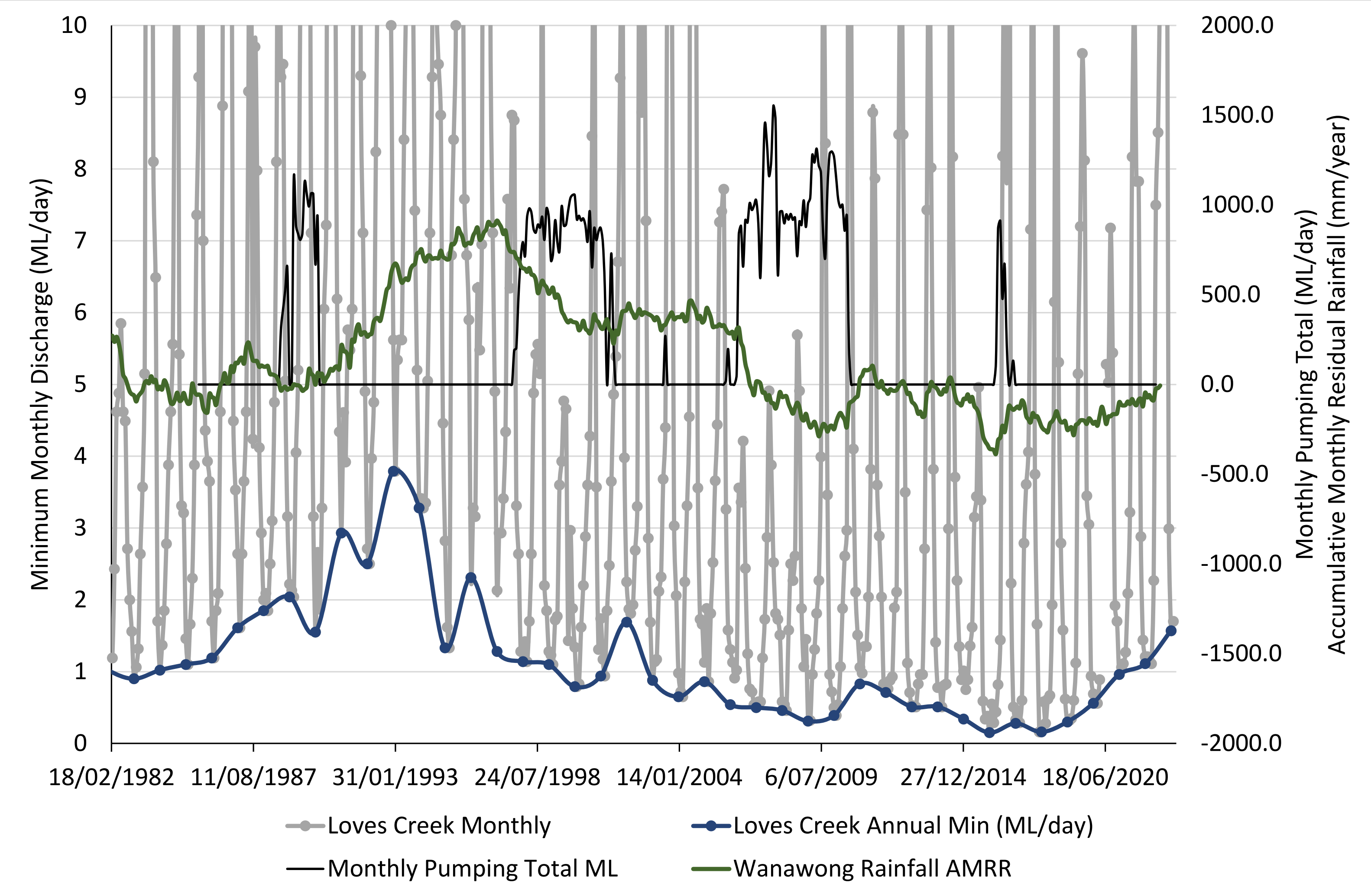

Figure 20 Minimum Monthly and Annual Streamflow Observations – Loves Creek

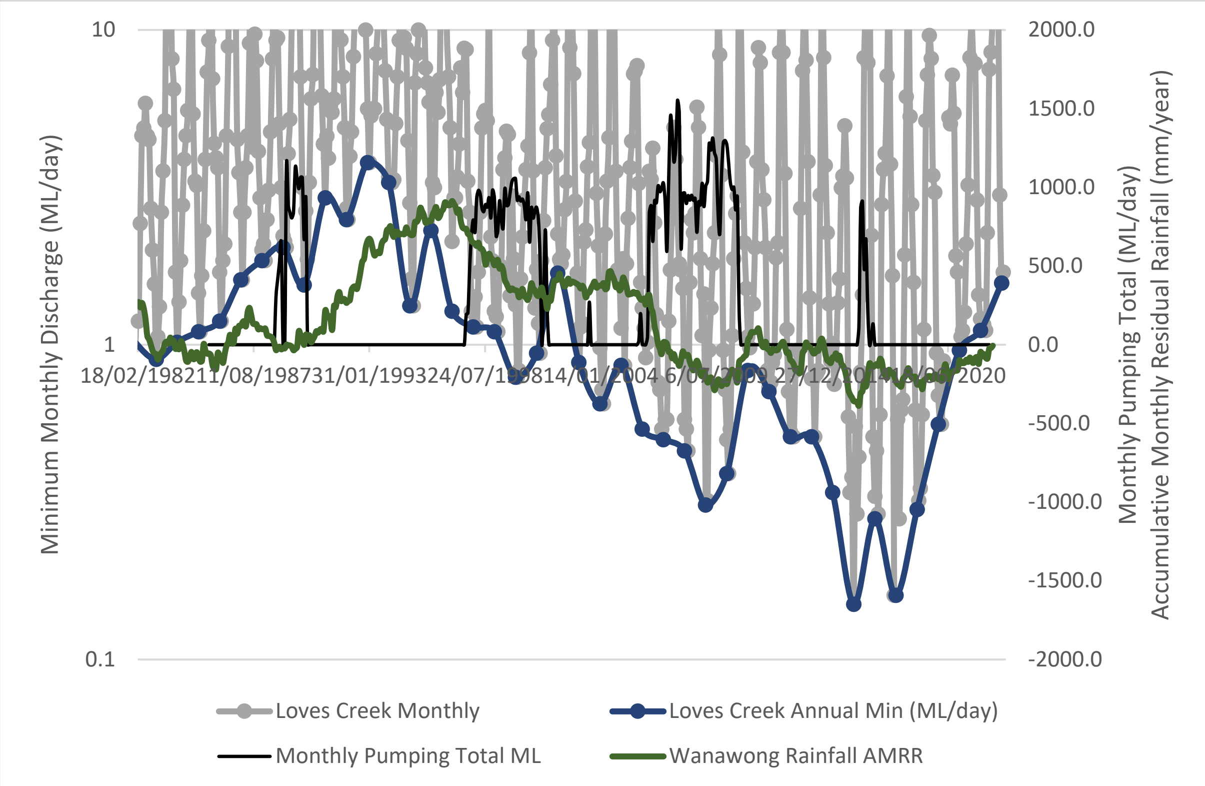

Figure 21 Minimum Monthly and Annual Streamflow Observations (Logarithmic) – Loves Creek

It is notable that the pre-1997 baseflow observed in Loves Creek (up to 1.02 ML/day) is less than the sum of baseflow in its upstream tributaries (Ten Mile Creek, Yahoo Creek and Porcupine Creek baseflows amount to 1.69 ML/day). This indicates that there are unaccounted for baseflow losses occurring between the stream gauges under the pre-extraction scenario and as such the relative contribution of the baseflow in each upstream creek to the baseflow in Loves Creek cannot be reliably estimated because it is not known from which stream the losses are occurring.

The unaccounted baseflow loss in Loves Creek under the pre-extraction scenario does not appear to be due to groundwater recharge to the LTA as the LTA is confined in this area. It could also be due to localised recharge occurring to one of the LMTA aquifers (e.g. there is Clifton Formation exposures proximal to Loves Creek) however there is a paucity of corroborating information. There is the potential that the discrepancy is due to surface water extraction; this is further discussed in **Section 5.4.3**.

5.3.2 Gellibrand River

Gellibrand River at Bunker Hill has shown a decrease in baseflow of 7.58 ML/day between <1997 and 1997-2009 (**Figure 22**). Flow rates have then shown an increase, corresponding to a net reduction of 4.66 ML/day. Apart from Loves Creek, the other tributaries of Gellibrand River including Lardner Creek and upstream monitoring locations in the Gellibrand River and have shown a slight overall increase in baseflow (up to 1.18 mL/day at Gellibrand River @ Upper Gellibrand) rather than a decrease. It is noted that the baseflow observed in the Gellibrand River at Bunker Hill in the period 1997-2009 is still above the minimum level of 13 ML/day recommended by EarthTech (2006).

Possible reasons for the observed decrease and apportionment are discussed in **Section 5.4**.

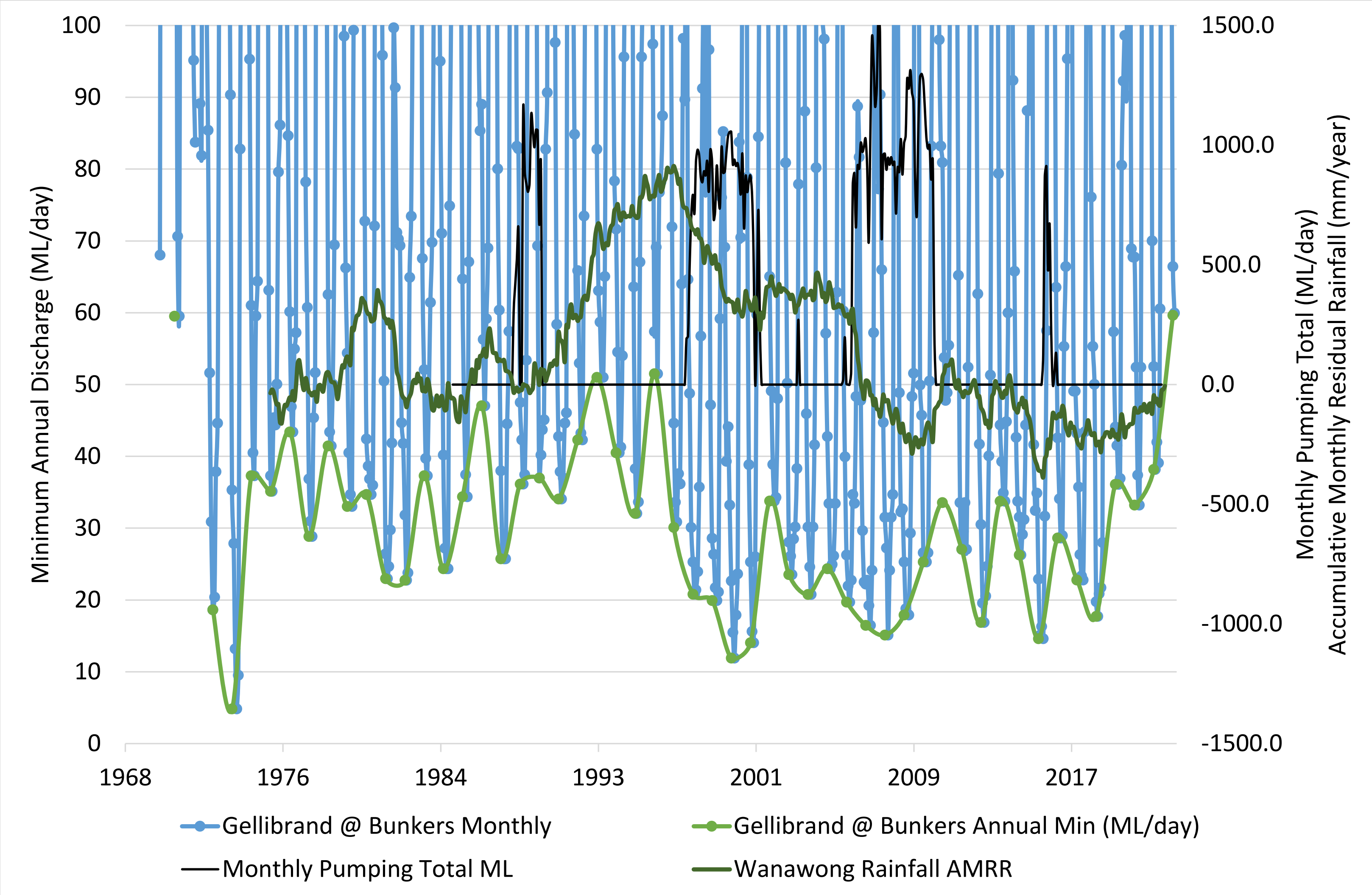

Figure 22 Minimum Monthly and Annual Streamflow Observations – Gellibrand River at Bunker Hill

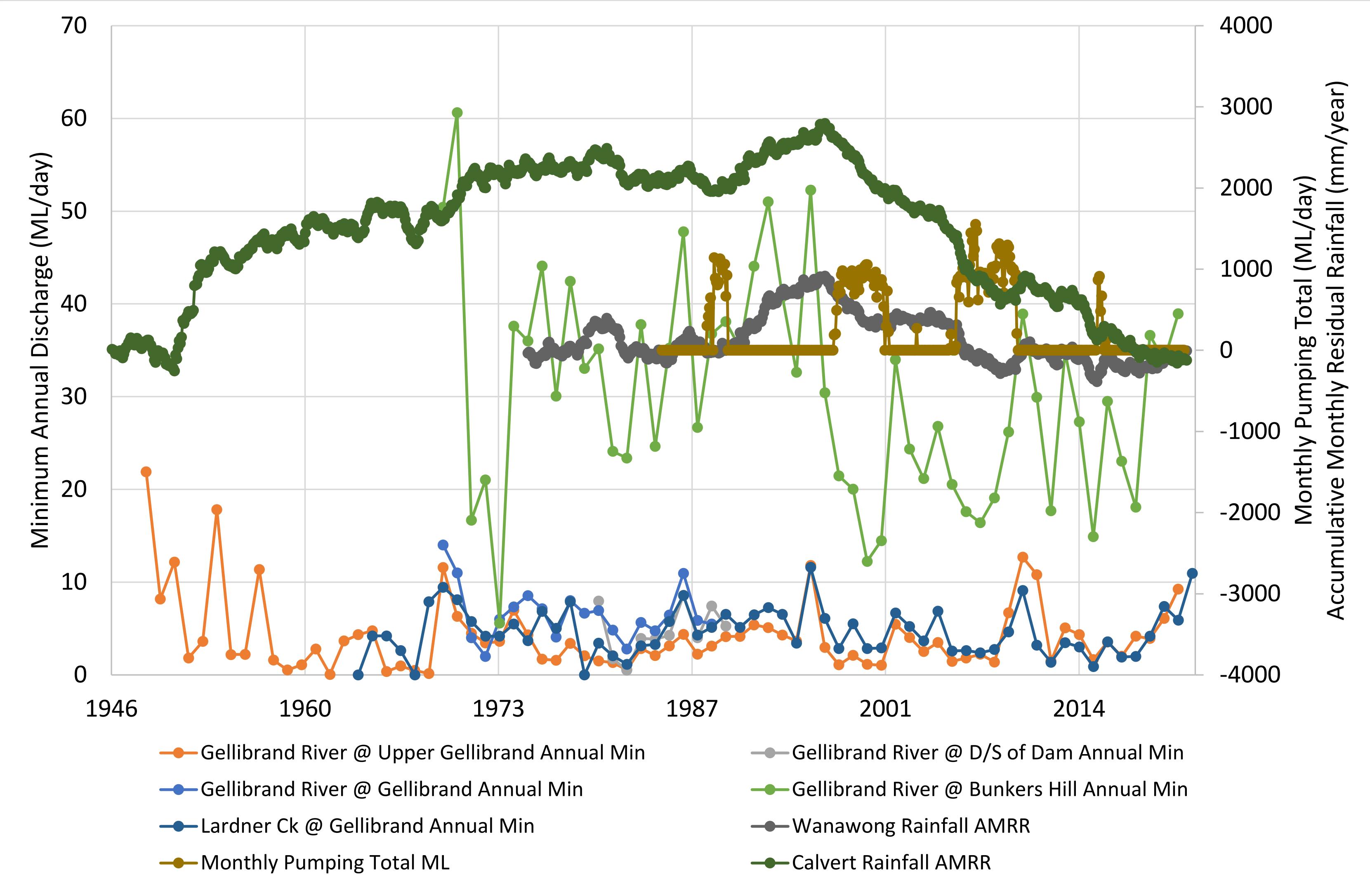

Figure 23 Minimum Monthly and Annual Streamflow Observations – Gellibrand River Tributaries (excluding Loves Creek)

5.4 Apportionment of Likely Influences on Observed Flow Trends

The declines in baseflow evident in the Gellibrand River (~7.58 ML/year between <1997 and 1997-2009), Yahoo Creek (0.74 ML/day between <1997 and >2019) and Loves Creek (0.47 ML/day between <1997 and 1997-2009), as described in **Section 5.3** are potentially due to a number of influences, including but not limited to:

- Long-term decreases in rainfall associated with the Millennium Drought, where deficits from annual average rainfall of between 66 mm/year to 148 mm/year have been recorded in the Kawarren Sub-Area (**Section 4.2.3.3**). This correlates to rainfall reduction of between 7% and 15% within the Kawarren Sub-Area. The effect on recharge to the LTA and subsequent discharge as baseflow to relevant stream has been considered in **Section 5.4.1**. The effect on the LMTA has not been considered as there is a paucity of information relating to the role those systems play, noting at a high level their overall contribution to baseflow is considered to be minor relative to LTA.
- The contribution from up-stream baseflow in the Gellibrand River has been considered to evaluate if the trends are potentially related to drivers occurring outside of the KIA. This is considered in **Section 5.4.2**.
- Local utilisation of surface water extraction, expected to be heightened during periods of drought. This is considered in **Section 5.4.3**.
- Groundwater extraction from the Barwon Downs borefield between 1982/83 and 2016, and particularly in the period 1997 to 2010 when approximately 77% of total extraction occurred (**Section 4.10.2.2**). This is considered further in Section **5.4.4**.
- Land use change, such as forestry which can alter recharge and runoff characteristics of the land. For example, higher recharge rates typically occur following clearing, and then reduce as young vegetation establishes. Forestry coupes are evident within the Yahoo Creek catchment (**Section 4.5**). This is discussed in **Section 5.4.5**.
- Establishment of surface water storages that potentially intersect groundwater springs. These largely intersect springs/soaks from the LMTA and not the LTA, and further, anecdotally the majority of these were established prior to groundwater pumping and are therefore considered to be subordinate. These have therefore not been considered further.
- Errors associated with stream gauges, including effects of sedimentation and scouring which can affect the water heights and subsequent calculation of flow rates from stage-flow relationship. For the purpose of this assessment the data are taken at face value.

The contribution of various factors has been estimated using high-level, 'back of the envelope' calculations to provide a sense of scale of influence of the various factors, where possible. There are a range of assumptions and potential errors, particularly at marginal values. The reader should therefore view the estimates as indicative only and ensure they are not taken out of context.

5.4.1 Long-term Rainfall Deficit on Recharge to LTA

Rainfall deficits were experienced across Victoria during the Millennium Drought, with DELWP estimating that 'more than half of the Victorian catchments analysed experienced an extra 20–40% decline in their annual streamflow due to the shift in rainfall– runoff relationships (DELWP, 2020).

In the KIA, rainfall deficits of between 66 mm/year and 148 mm/year have been recorded in the Kawarren Sub-Area between 1997 to 2009. Based on the maximum rainfall deficit of 148 mm/year, a 12 km^2 recharge area and recharge rate of 13% (HydroTechnology, 1994), a total recharge deficit to the LTA of 230 ML/year or 0.63 ML/day is calculated. The recharge deficit to the LTA based on the minimum rainfall deficit is 103 ML/year or 0.28 ML/day. The reduction in recharge to the LTA based on the rainfall deficit on the observed reductions in stream flow is discussed following.

It is important to note that long-term rainfall deficits can also affect general moisture within the soil profile, which in turn can influence baseflow contributions from bank storage, perched groundwater, local groundwater flow systems, wetland storage etc. The influence of these various factors have not been considered in the following calculations, consistent with the very high level nature of the calculations. Rather, just the potential role of rainfall deficit on groundwater discharges from the LTA has been considered. That is, it must be acknowledged that there are some data gaps, specifically in relation to the hydrology within the KIA.

5.4.1.1 Ten Mile Creek and Yahoo Creek

As outlined in **Section 4.9.5.6**, under average rainfall conditions approximately 27% of the total recharge to the Kawarren Avenue is estimated to contributed to baseflow in Ten Mile Creek approximately 18% to baseflow in Yahoo Creek (total ~45%). The remainder of the estimated recharge (~55%) is therefore considered to have transmitted into the deeper LTA aquifer.

Applying the proportion of recharge that would be expected to become baseflow (~45%) to the calculated total recharge deficits of between 0.28 ML/day and 0.63 ML/day equates to a reduction in baseflow contribution from the LTA of between 0.13 ML/day and 0.28 ML/day. That is, of the 0.74 ML/day baseflow reduction evident in Yahoo Creek, it is estimated that the long-term rainfall deficit associated with the Millennium Drought contributed between approximately 15% and 35% to the observed decline (note these deficits have been rounded to reflect the high level nature of the calculation).

It is noted that the decline observed in baseflow levels in Ten Mile Creek (0.07 ML/day) is slightly less than the calculated reduction in baseflow contribution from the LTA that is ascribed to long-term rainfall deficit (0.13 ML/day and 0.28 ML/day).

5.4.1.2 Loves Creek

The geology underlying Loves Creek comprises LMTA units; it does not directly receive any known groundwater discharge directly from the LTA. Rather, groundwater discharges from the LTA in upper Ten Mile Creek and Yahoo Creek contributes to baseflow in Loves Creek. As discussed in **Section 4.13.4**. Based on pre-1997 baseflow estimates as outlined in **Table 19**, Ten Mile Creek contributes approximately 0.84 ML/day of baseflow, Yahoo Creek approximately 0.76 ML/day and Porcupine Creek approximately 0.09 ML/day.

Based on the stream flow records, the overall baseflow reduction in Loves Creek observed between 1997 and 2020 prior to partial recovery is 0.82 ML/day. This total amount is approximately 90% of the decline observed in Yahoo Creek (0.74 ML/day) over the same time period.

As outlined in **Section 5.4.1.1**, the decrease observed in Yahoo Creek can only be partly explained (approximately 15% to 35%) by the rainfall recharge deficit to the LTA associated with the Millennium Drought. The rainfall deficits would equate to baseflow declines of between 0.12 ML/day (15%) and 0.29 ML/day (35%) based on the total observed decrease in Loves Creek. This is consistent with (Aquade 2019), who considered that the reduction in rainfall was not sufficient to explain the baseflow reduction observed in Loves Creek.

The balance of the observed decline in baseflow in Loves Creek (0.53 ML/day to 0.70 ML/day) is ascribed to other factors, which are described in **Section 5.4.3** noting that the role of the rainfall deficit on discharge from the LMTA has not been evaluated as there is a paucity of data to meaningfully evaluate this contribution.

5.4.1.3 Gellibrand River

Groundwater from the LTA discharges into the Gellibrand River across an approximately 15 km section of river (SKM, 2012). SKM estimated the baseflow in the Gellibrand River, based on the measured low flow in the river, to be between 0.05 ML/day/km (at gauging station 235236 in the period 2007-2009) and 1.40 ML/day/km (at gauging station 235227 in the 1980s). Station 235236 is on the up-stream end of the discharge zone and 235227 is on the down-stream end of the discharge zone. On this basis, the discharge rate of 1.40 ML/day/km is considered representative of overall baseflow associated with groundwater discharges associated with the LTA to the Gellibrand River.

A discharge rate of 1.40 ML/day/km equates to a baseflow of approximately 21 ML/day based on a 15 km discharge zone, which is consistent with the baseflow recorded in the period prior to 1997. Between 1997 and 2009 the baseflow in the Gellibrand River at Bunker Hill has been estimated to have reduced from 22.44 ML/day to 14.86 ML/day, a reduction of approximately 7.58 ML/day (**Section 5.3.2**).

As per **Section 5.4.1.2**, it is estimated that recharge has been reduced by between 0.28 ML/day (15%) and 0.63 ML/day (35%) due to long-term rainfall deficit associated with the Millennium Drought. Of this, approximately 55% of the recharge on the Barangarook High that feeds the Kawarren Sub-Area transmits to the deeper LTA and ultimately would discharge at the Gellibrand River. Based on this, transmission to the deeper LTA and thereon to Gellibrand River is estimated to have potentially been reduced by between 55 ML/year (0.15 ML/day) and 127 ML/year (0.35 ML/day). These reductions in groundwater discharge from the LTA due to the rainfall deficit amount to between approximately 2% and 4.6% of the observed baseflow reduction, which is minor.

In addition, groundwater flows through the Pipeline Restriction are estimated at 300 ML/year, which based on a 15% reduction in rainfall, would equate to a deficit through the Pipeline Restriction of approximately 0.12 ML/day. This is less than 2% of the observed flow reduction of 7.58 ML/day.

Interestingly the baseflow component at gauging station 235236, up-stream of the Gellibrand River discharge zone showed a reduction of from 0.25 ML/km/day to 0.05 ML/km/day, which is an 80% reduction. This would suggest that the rainfall deficit could contribute up to 20% of the observed losses. In any case, these calculations indicate that the rainfall deficit is minor to other factors.

5.4.1.4 Summary

The observed rainfall deficits between 1997 to 2009 are indicated to have reduced baseflow in Ten Mile Creek, Yahoo Creek and Loves Creek by between 15% and 35%, and in the Gellibrand River by up to ~6%.

5.4.2 Influence from Upstream Tributaries

The potential contribution from up-stream tributaries has specifically been considered in relation to the observed baseflow decline in the Gellibrand River at Bunker Hill. Of the total baseflow component measured in the Gellibrand River at Bunker Hill prior to 1997 (22.44 ML/day), 2.4% originates from the upper Gellibrand upstream of LTA influence, 5.9% from Lardner Creek and 4.5% from Loves Creek (refer to **Table 19**). The remaining approximately 87% of baseflow (approximately 19.5 ML/day) is generated between Gellibrand River at D/S of Dam Site (station 235236) and Gellibrand River at Bunker Hill (station 235227).

A decline in baseflow has been observed in Loves Creek (up to 0.47 ML/day between <1997 and 2009). This reduction represents approximately 6% of the observed baseflow reduction in Gellibrand River at Bunker Hill over the same time period (7.58 ML/day).

Evaluation of streamflow records at gauging stations up-stream within Gellibrand River together with Lardner Creek indicate that these are not contributing to the observed trends. In fact, increasing baseflow has been identified in Gellibrand River at Upper Gellibrand and in Lardner Creek.

5.4.3 Surface Water Extraction

There are no licenced surface water users in Yahoo Creek, therefore, licenced extraction does not appear to be contributing to the observed baseflow declined in the Yahoo Creek catchment.

As outlined in **Section 4.13.6** there are a number of surface water licences within Loves Creek amounting to 543.5 ML/year. Of these, 302.7 ML/year relates to licenced dams off the water course (which are not tradeable) and 240.8 ML/year which relate to direct extraction from the creek. The location of these extractions relative to the monitoring gauges has not been evaluated.

If it is assumed that all direct extraction users extract concurrently and utilise their full entitlement within the summer months only (i.e. 90 days), then this would amount to approximately 2.7 ML/day. If extraction was spread across the year then this would amount to a rate of approximately 0.65 ML/day.

These calculations indicate that licenced surface water extraction and the observed baseflow declines are within the same scale. However, without understanding specific usage patterns and the location of users relative to the gauges it is not possible to further discern the influence on baseflow levels.

Given that the baseflow decline observed in Loves Creek appears to be comparable in scale to the decline observed in Yahoo Creek, and given that there is no known licenced extraction in Yahoo Creek, it follows that licenced surface water extraction is not significant driver of the observed trends in Yahoo Creek, and in turn Loves Creek.

As highlighted in **Section 5.4.1.2**, in Loves Creek the sum of up-stream baseflows (approximately 1.69 ML/day) is greater than the subsequent baseflow in Loves Creek (1.02 ML/day), indicating there is a loss of baseflow of approximately 0.67 ML/day. Based on the known licences in the Loves Creek area, the observed losses could be explained by licenced surface water extraction.

In the Gellibrand River, there is extensive licenced surface water extraction, with 936 ML/year licenced comprising 853.3 ML/year relating to direct extraction from the river and 82.7 ML/year relating to licenced dams off the water course (which are not tradeable). The location of these extractions relative to the monitoring gauges has not been evaluated.

Again, if it is assumed that all direct extraction users extract concurrently and utilise their full entitlement within the summer months only (i.e. 90 days), then this would amount of approximately 9.5 ML/day. This is consistent with the baseflow decline observed in the Gellibrand River at Bunker Hill. That is not to say that it is the sole cause, but merely that surface water extraction has the potential to contribute to the observed trends. This is consistent with the reasonable expectation that users will more heavily utilise surface water resources when rainfall is lower than normal, such as was experienced in the Millennium Drought.

5.4.4 Groundwater Extraction from the LTA

In order to evaluate the potential influences that groundwater extraction from the LTA has on the observed baseflow reductions in Gellibrand River at Bunker Hill consideration has been given to the observed change in hydraulic gradient within the KIA. As per Darcy's Law, groundwater discharge through a cross sectional area reduces proportionally to the change in hydraulic gradient. It is important to note that this approach is conservative as not all groundwater discharge discharges into waterways; there is also expected to be a proportion of throughflow.

The hydraulic gradients within several sections of the groundwater flow system are provided **Table 20**. The sections where the hydraulic gradient was calculated are:

- Upper Kawarren Avenue flow path, following the alignment of Ten Mile Creek;
- Pipeline Restriction flow path;
- Gellibrand River East groundwater discharge zone, parallel to the Gellibrand River between Bambra Fault and Clancys Hill; and
- Gellibrand River West groundwater discharge zone, perpendicular to the Gellibrand River to the west of Clancys Hill.

Table 20 Hydraulic Gradient Estimates

	Upper Kawarren Avenue	Pipeline Restriction	Gellibrand River East	Gellibrand River West	Source
1983	0.023	0.006	0.005	0.010	(Leonard, Lakey, & Blake, 1983)
1991	0.022	0.008	0.007	0.011	(Stanley, 1991)
1994	0.026	0.008	NA	NA	(HydroTechnology, 1994)
2008	0.024	0.003	0.007	0.012	(SKM, 2012)
2010	0.018	0.005	0.001	0.015	**Figure F17**
2014	0.023	0.006	NA	NA	(Aquade Groundwater Services, 2015)
2021	0.023	0.007	0.013	0.014	**Figure F18**

- **Notes:** NA – not available
  ID – insufficient data

These data indicate that hydraulic gradients in the Upper Kawarren Avenue, Pipeline Restriction and in the vicinity of the Gellibrand River reduced in 2008-2010 compared to baseline levels.

The reduction in hydraulic gradient in the Upper Kawarren Avenue (~22%) is not dissimilar to the 12% reduction in baseflow observed in Ten Mile Creek, noting that the observed decline is also consistent with expected background variation and the influence of the observed rainfall deficit between 1997 and 2009. That is, such changes are not readily measurable within a natural system like this. A slight decrease was observed proximal to the Gellibrand River western discharge zone indicating that there does not appear to have been any change to the discharge in this portion of the river.

In Yahoo Creek it is possible that some of the observed reduction in baseflow (0.74 ML/day) is associated with the reduction in hydraulic gradient in the Upper Kawarren Avenue, noting there are no bores in this area to appraise the local response to pumping. It is postulated that the drawdown response in the Yahoo Creek catchment has been more pronounced that the Ten Mile Creek catchment due to its proximity to the central KIA where peak drawdowns of up to 4m have been recorded **Figure F25**. The potential contribution relating to groundwater extraction cannot be meaningfully calculated due to the paucity of data in this area. However, an estimate can be made through the process of exclusion.

Through the process of exclusion it is estimated that in Yahoo Creek between 65% to 85% (i.e. the proportion that cannot be explained by climate) is potentially due to a combination of extraction from the Barwon Downs Borefield, possibly exacerbated by the effects of forestry particularly since 2011 and climate driven baseflow reduction from outcrop of LMTA.

Of the baseflow decline observed in Yahoo Creek (0.74 ML/day) approximately 90% of the baseflow decline is represented in Loves Creek (0.82 ML/day). Therefore, the baseflow proportion that cannot be explained through long-term climate trends (between 0.12 ML/day and 0.29 ML/day) is explained through exclusion by a combination of extraction from the Barwon Downs Borefield, possibly exacerbated by the effects of forestry particularly since 2011 (refer to **Section 5.4.5**), and climate driven baseflow reduction from outcrop of LMTA (which has not been quantified but is expected to be minor relative to LTA contributions). These would amount to between 0.45 ML/day and 0.62 ML/day, which are between 55% and 75% of the observed baseflow decline in Loves Creek.

Proximal to the Gellibrand River eastern discharge zone (east of Clancys Hill), a reduction in hydraulic gradient was calculated between 1983 and 2010 (~80%). This is considered unreliable as the 2010 gradient is based on limited data points proximal to the Gellibrand River (**Figure F17**) and given the baseline hydraulic gradient is relatively flat (0.005). Nevertheless, it is apparent from the potentiometric contours that the hydraulic gradient in this area had flattened at this time. This appears to be due to the borefield intersecting groundwater flows that would have otherwise entered the KIA via the Pipeline Restriction.

In the vicinity of the Pipeline Restriction a 50% reduction in hydraulic gradient was observed between 1983 and 2008. Similarly, (Aquade 2019) calculated a reduction in hydraulic gradient in the across the Pipeline Restriction of approximately 32%. A 50% reduction in flux across the Pipeline Restriction could correspond to a daily rate reduction in throughflow of 0.4 ML/day, based on the previous pre-pumping through flow estimate of 300 ML/year (HydroTechnology 1994), and 0.7 ML/day based on a flow estimate of 500 ML/day (Aquade 2019). This is approximately 5-10% of the observed reduction in the Gellibrand River (7.58 ML/day), noting that this is based on the assumption that all of the reduction in groundwater discharge through the aquifer expresses into the Gellibrand River.

5.4.5 Land Use Change

Anecdotally there has been little land use change in the KIA, particularly during the period that a reduction in baseflows has been observed. The most significant land use change within the KIA appears to be forestry. There are forestry coupes in the Yahoo Creek catchment. As outlined in Section 4.5, Google Earth imagery indicates that land to the north and south of Gravel Pit Road and east of Yahoo Creek Track was cleared in 1982 and had again been cleared in 2011; by 2014 it appeared to have been replanted. During 2022 the area had again been cleared.

In Yahoo Creek the baseflow levels remained relatively uniform following clearing and re-establishment in the 1980s. There is a gap in the Yahoo Creek stream flow record between 1995 and 2019. However, the Loves Creek record does show a marked increase in baseflow in 2011 (2010 was an above average rainfall year), followed by a continued progressive decrease in baseflow until 2020. It was during this period that the plantation was re-establishing. Circumstantially this raises the possibility that there is a link with forestry in this latter part of the record, however, it cannot explain the proceeding baseflow reductions observed between 1997 and 2009.

5.4.6 Summary

A summary of the surface water impact assessment is provided in **Table 21**, and below.

A decline in baseflow of approximately 7.58 ML/day was observed in the Gellibrand River at Bunker Hill between 1997 and 2009. Of this:

- Approximately 0.47 ML/day (approximately 6%) is related to the baseflow decline in Loves Creek over the same time period. There are no contributions within the Gellibrand River up-stream of the LTA discharge zone and Lardner Creek to the observed decline.
- Long-term rainfall deficits have the potential to have reduced baseflow in the Gellibrand River by in the order of up to 6%.
- Potentially 5-10% of the observed reduction could be explained by groundwater extraction from the Barwon Downs Borefield (in addition to that potentially influencing Yahoo/Loves Creek) noting that this is based on the assumption that all of the reduction in groundwater discharge through the aquifer expresses into the Gellibrand River.
- The balance of the reduction observed in the Gellibrand River (approximately 78-83%) is potentially attributed to the effect of licenced surface water extraction during the Millennium Drought given extraction of that scale is possible based on licenced extractions.

Due to the confounding nature of these factors, these estimates should be approached with a degree of caution. Rather, they demonstrate the combined effects of various influences on available water.

The observed baseflow decline in Loves Creek between 1997 and 2009 appears to be predominantly related to a reduction in baseflow in Yahoo Creek, which emanates from areas of LTA outcrop. Interestingly a similar trend was not evident in Ten Mile Creek which also emanates from areas of LTA outcrop. Of the observed declines in Yahoo Creek and Loves Creek:

- Between 15% and 35% is attributed to the long-term rainfall deficit experienced during this time period, which would have reduced the volume of recharge to the LTA that becomes baseflow in Yahoo Creek and Ten Mile Creek.
- Through the process of exclusion it is estimated that in Yahoo Creek between 65% to 85% is potentially due to a combination of extraction from the Barwon Downs Borefield, possibly exacerbated by the effects of forestry particularly since 2011 and climate driven baseflow reduction from outcrop of LMTA. In Loves Creek, the contribution from these factors is estimated to be 55% and 75%. There is a paucity of data to establish a clear linkage nor to evaluate the relative contribution from these sources. However, based on the CSM for the LTA, a reduction in baseflow due to extraction from the Barwon Downs Borefield is not unexpected, however, the reasons why this has affected Yahoo Creek and not Ten Mile Creek is not known; this is a significant data gap.
- Licenced surface water extraction does not appear to be a significant driver given the reduction in Loves Creek appears to predominantly originate within Yahoo Creek and there is no licenced extraction in Yahoo Creek. Anecdotal information suggests that establishment of new dams within the Loves Creek catchment is also likely to be insignificant.

Whilst groundwater/surface water modelling could be conducted to refine the estimates above, it is BlueSphere's view that this would not change the outcome of this investigation, (i.e., that there has been hydraulic influence on waterways within the KIA due to historical extraction from the Barwon Downs Borefield, however, there is no observable environmentally significant impact).

Table 21 Summary of Surface Water Impact Assessment

Surface Water Body	Relationship with the LTA	Proportion of Baseflow to Total Flow (Hebblethwaite and James, 1990)	Climate Related Influences		Estimated Groundwater Pumping and other related influence	Other Influences (surface water harvesting etc.)
			Baseflow Reduction to LTA	Streamflow Reduction from Rainfall-Runoff Relationships		
Ten Mile Creek	Receives groundwater discharge from LTA in or adjacent to LTA outcrops	46%	15 – 35% of total baseflow or 7-16% of total streamflow	20 – 40% decline in annual streamflow (DELWP, 2020, amended 2021)	Nil	Nil
Yahoo Creek	Receives groundwater discharge from LTA in or adjacent to LTA outcrops	27%	15 – 35% of total baseflow or 4-9% of total streamflow		65 – 85% of total baseflow or 18-23% of total streamflow (range of factors)	Potential influences from forestry / logging activities and Climate driven baseflow reduction from outcrop of LMTA
Porcupine Creek	Does not receive groundwater discharge from the LTA	28%	Nil		Nil	Potential for influences from surface water harvesting in region
Loves Creek	Does not receive groundwater discharge from the LTA. However, is fed by Ten Mile and Yahoo Creeks that do receive groundwater discharge from the LTA	34%	15 – 35% of total baseflow or 5-12% of total streamflow		55 – 75% of total baseflow or 19-26% of total stream flow (range of factors)	Potential for influences from surface water harvesting in area, which may account for losses along Loves Creek. Loves Creek also receives discharge from the LMTA, which has not been considered in this assessment as it has not been impacted by pumping
Gellibrand River	Receives groundwater discharge from the LTA in or adjacent to LTA outcrops	~55%	Up to 6% of baseflow, or 3.3% of total streamflow		5 – 10% or 3-6% of total stream flow (pumping only)	38 – 63% of total baseflow reduction or 21-35% of total stream flow potentially due to surface water extraction based on process of exclusion

Notes: 1 Calculated based on proportion of typical summer baseflow to total flow from Hebblethwaite and James (1990) multiplied by estimated groundwater pumping related influence on baseflow.

5.5 Significance of Observed Hydraulic Influence

As outlined in **Section 5.4**, the impact assessment has identified that the historical groundwater pumping activities have had varying degrees of inferred influence on baseflow within several waterways in the KIA. The influence of factors such as climatic variability and licenced surface water usage, compounded during periods of drought, are also evident. The impact of baseflow reduction is most profound during periods of low rainfall (i.e. summer) when the waterways are typically sustained principally by groundwater inflows.

The anecdotal information summarised in **Section 4.6** did not reveal any consistent evidence to suggest that the extraction has had a demonstrable significant adverse impact on the environment within the KIA. Several local landholders raised specific concerns regarding potential acid sulfate soils, loss of stream flow and decline of native fish and platypus populations. There were also concerns expressed that the pumping from the Barwon Downs borefield had affected their springs, or that future extraction could have material impact on their water supply.

The concerns raised regarding a reduction in stream flow are supported by the streamflow records in Yahoo Creek, Ten Mile Creek and the Gellibrand River at least in so far as baseflow is concerned (this study has not examined other measures of stream flow). However, it is noted that the large majority of springs in the KIA are fed by the LMTA and not the LTA.

However, in this case there is a general paucity of data from which conclusions can be drawn regarding resultant environmentally significant impacts that can be associated with extraction from the Barwon Downs Borefield. For example, there does not appear to be any evidence of widespread vegetation decline/mortality in the KIA that is linked to the extraction based on vegetation surveys (e.g Jacobs, 2015, Jacobs, 2017) and there are no data available to assess aquatic biota populations pre-pumping. There was some evidence of vegetation decline at several swamp sites (outside of the KIA) during the early stages of the Millenium Drought which was considered to due a combination of below average rainfall and declining groundwater levels from pumping (Jacobs, 2019). However, there does not appear to be any obvious evidence of large scale vegetation die back along Ten Mile or Yahoo Creeks during pumping (see **Section 4.7**). Whilst it is well established that the waterways have been disturbed from their natural state, the extent to which pumping as opposed to other factors has contributed cannot be ascribed.

In the case of the Gellibrand River at Bunker Hill, the baseflow observed in the Gellibrand River at Bunker Hill in the period 1997-2009 was still above the minimum level of 13 ML/day recommended by (Earth Tech Engineering Pty Ltd, 2006) to maintain the ecological health of the waterway.

Acid sulfate soil impacts such as those realised in Big Swamp do not appear to be evident in the KIA. The available information suggests that ASS are not likely to be widespread in the KIA based on the limited extent of Quaternary swamp deposits which are liable to ASS formation (most likely limited to Porcupine and Serpentine Creeks which drain the LMTA).

5.6 Risk Assessment

The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (Department of Environment, Land, Water and Planning (DELWP), 2015) provide a framework for the classification of potential impacts of groundwater extraction on GDEs. This process is applied during the application stage for a new groundwater extraction. In this case the framework has been applied retrospectively here to provide a point of comparison to aid in future management and to categorise the susceptibility of GDEs in a consistent and transparent manner.

Importantly, the purpose of the risk assessment process is to in essence identify the susceptibility of the environment to an extraction proposal. The risk assessment does not provide that environmentally significant impacts have or will occur. Discussion regarding the significance of observed hydraulic influence in this particular case is provided in **Section 5.5**.

The risk assessment process includes the following key elements that are of relevance here:

- Evaluate if the aquifer is confined or unconfined, and therefore if it has the potential to interaction with high value ecosystems. In this case the CSM has established that the LTA has the potential to interact with high value ecosystems associated with Ten Mile Creek, Yahoo Creek, indirectly to Loves Creek and the Gellibrand River. It has been assumed that Ten Mile Creek, Yahoo Creek, Loves Creek and Gellibrand River are high value ecosystems as defined in the Ministerial Guidelines.

- Determine the likelihood that the proposed groundwater extraction will interact with a high value ecosystem.
- Determine the consequence of the proposed groundwater extraction on a high value ecosystem.
- Determine the risk to the high value ecosystems dependent on groundwater.

The risk assessment outcome is summarised in **Table 22**. In summary the risks to Ten Mile Creek, Yahoo Creek, Loves Creek and Gellibrand River are classified as 'high' under the framework. This is conservative as it has been assumed that the 100% of the baseflow that cannot be ascribed to other factors is entirely due to extraction from the Barwon Downs Borefield. Although conservative, this is considered reasonable in the absence of evidence to the contrary.

Note a 'high' risk has been adopted for Loves Creek on the basis that baseflow in Loves Creek is strongly linked to Ten Mile Creek and Yahoo Creek and not because there is a direct link between baseflow levels in Loves Creek and the LTA.

Table 22 Risk Assessment for Protection of GDEs

Waterway	Likelihood that groundwater will interact with waterway		Consequence – Depth to Water Table		Consequence – Surface Flow		Risk
	Rating[1]	Comment	Rating[1]	Comment	Rating[1]	Comment	
Ten Mile Creek	Certain	This is on the basis that the depth to watertable is <2 m from the surface and these streams are assessed as gaining or strongly gaining.	Significant	In the upper Ten Mile Creek the potentiometric surface in the LTA has been measured to have reduced up to 2.716 m. This would correspond to a 'significant' consequence	Minor	A baseflow reduction of ~0.07 ML/day was measured in Ten Mile Creek, which is consistent with expected background variation. The consequence is classified as 'minor'.	High (groundwater)/ Medium (surface flow)
Yahoo Creek	Certain		Significant	There are no data for groundwater in the LTA in the vicinity of Yahoo Creek. For the purpose of this assessment it is considered that a drawdown of >2 m is possible in this area and therefore a 'significant' consequence has been assigned.	Significant	A 97% reduction in baseflow is evident. Of this, between 65% and 85% is potentially due to a combination of extraction from the Barwon Downs Borefield possibly exacerbated by the effects of forestry particularly since 2011 and climate driven baseflow reduction from outcrop of LMTA. This corresponds to an overall reduction of between 63% and 82% of the baseflow decline, which is classified as 'significant'.	High
Loves Creek	Certain	See note 2 below	Significant	See note 2 below	Significant	See note 2 below	High
Gellibrand River	Certain	This is on the basis that the depth to watertable is <2 m from the surface and this waterway is assessed as gaining or strongly gaining.	Moderate	Proximal to the Gellibrand River, the peak drawdown is 0.6 m in bore 108903. This would correspond to a 'moderate' consequence.	Moderate	Between approximately 0.4 ML/day and 0.7 ML/day is potentially due to extraction from the borefield. These conservative estimates are between ~2% and ~3% of the pre-1997 baseflow (22.44 ML/day), which is classified as 'moderate'.	High

Notes: 1. Likelihood and consequence definitions adopted in accordance with Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).

2. The likelihood of a direct interaction between Loves Creek and the LTA is 'unlikely' given they do not appear in hydraulic connect. Whilst under the framework this would suggest a differing risk would apply to Loves Creek, given that baseflow in Loves Creek is strongly linked to Ten Mile Creek and Yahoo Creek in particular, it is considered that the same risk rating should apply to Ten Mile Creek and Yahoo Creek.

5.7 Overview of Changes Since Extraction Cessation

Water levels in the LTA have shown a recovery of approximately 80% in selected bores in the Barwon Downs sub-basin, since pumping ceased, as at July 2022 (Barwon Water, 2022). Recovery is considered to have been reached when water levels reach 90% of their pre-pumping levels.

In the KIA groundwater levels in the Upper Ten Mile Creek and Kawarren/Loves Creek areas have stabilised since 2012, however, they have not recovered to pre-pumping levels. It is noted that water levels furthest from the borefield are expected to take longer to recover than those closer to the borefield.

By 2021 the groundwater flow paths as shown by the potentiometric surface of the LTA (**Figure F18**) have largely returned to the 1983 system, noting however, that the groundwater elevations are below the 1983 groundwater elevations.

The surface water baseflow in Loves Creek and its tributaries since the cessation of pumping have varied as summarised below:

- The baseflow in Yahoo Creek has not recovered to the baseflow observed between the mid-1980s and early 1990s.
- The baseflow in Ten Mile Creek has largely remained consistent with the baseflow levels observed between the mid-1980s and the early 1990s.
- There is insufficient data to review changes in baseflow in Porcupine Creek since pumping ceased.
- The baseflow in Loves Creek has shown an increase in baseflow since the cessation of pumping to be comparable to baseflows of the early-1980s.
- The baseflow in Gellibrand River has shown an increase in baseflow since the cessation of pumping to be comparable to baseflows of the early-1980s.

6 Data Gaps

During the course of this report preparation a number of data gaps have been identified, which are summarised below:

- There are very few groundwater bores that are screened in the LMTA of which historical records are available to review. The LMTA is considered to be a significant local resource.
- The recharge area and groundwater flow direction for the Clifton Formation is not known.
- There are no bores in the shallow aquifers (e.g. Clifton Formation) in the KIA to understand the relationship with the LTA and also understand the role the Clifton Formation has in relation to groundwater-surface water interaction in Loves Creek.

In relation to the above dot points if information was available on the LMTA it would help to quantify its role in spring connectivity and baseflow contribution, as well as the connection with the LTA. This information would be useful for future management and understanding the implications of impacts of any future pumping of the resource.

- The extent of influence of land use on hydrology and hydrogeology is not well understood. As noted above there is circumstantial correlation between baseflow declines in Yahoo and Loves Creeks during a period of re-planting of forestry coupes, however, it is not definitive.
- The mechanism that is leading to a loss of baseflow between Loves Creek and its upper tributaries is not known. This pre-dates groundwater extraction from the Barwon Downs borefield and may be a natural phenomenon.
- Despite a long term record, the gap in data of stream flow along Yahoo and Ten Mile Creeks has meant that seasonal and spatial trends in streamflow have been difficult to assess. Further the reason why a reduction in baseflow has been identified in Yahoo Creek and not Ten Mile Creek is not well understood based on the available information.
- There are limited groundwater and surface water data particularly in Yahoo Creek with sufficient records from which the relative influence of groundwater extraction on streamflow can be estimated. Whilst groundwater/surface water modelling could be conducted, it is BlueSphere's view that this would not change the outcome of this investigation.
- Whilst the surface water licences are known, the surface water utilisation regime in the KIA is not well quantified (for both existing and potentially unregistered users). Licenced extraction is at a level that could materially affect baseflow levels in concert with other competing influences.

The continued collection of data will allow for a robust and continuous data set, as well as a baseline condition to facilitate the future management of the resource.

- The connectivity of the LTA sediments on the southern side of the Bambra Fault to the LTA sediments in the vicinity of the Gellibrand River is not well known; however some connectivity is expected. However in the context of the overall CSM this is not considered to represent a significant data gap, given any recharge would be expected to be insignificant compared to the Barongarook High recharge area.
- Groundwater and surface water interaction (in particular along Gellibrand River) is confounded by bank storage, which makes attribution to pumping influences challenging.
- The degree of interaction between the LTA and the LMTD and OTG has been established based on comparable data in adjacent areas and the observed lithologies. In the KIA it has not been directly investigated by way of geochemical studies nor physical hydrogeological data. However, based on the findings of this report it is expected that the degree of interaction is relatively minor.
- The nature and extent of LTA sediments across the Pipeline Restriction is not well defined. This underpins the estimates of throughflow across the Pipeline Restriction and subsequent sustainability of the aquifer. This data gap would be of importance for any future assessment of sustainability.

The potential shift of the groundwater divide in the Barongarook High area potentially due to groundwater extraction is not well defined.

7 Conclusions and Recommendations

7.1 Conclusions

BlueSphere has prepared this Hydrogeological Assessment (HA) report on behalf of Barwon Water in order to assist Barwon Water with meeting the requirements of the Section 78 Notice issued pursuant to the Water Act 1989. The objectives of the HA were to:

- Develop a robust CSM based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if any impacts that may have resulted from historical groundwater pumping activities at the Barwon Downs borefield have occurred.

The CSM was developed by desktop review of publicly available information in relation to the KIA setting including geology, hydrogeology, climate, topography, hydrology, GDEs and ASS. An inspection of the KIA and interview of knowledgeable landholders was also completed. The CSM has been developed with a focus on the LTA in the KIA, and is in large agreement with previous investigations including Lakey & Leonard (1983), Leonard, et al., (1983), Stanley (1991), HydroTechnology (1994) and Aquade (2019).

The CSM developed for the KIA was used to evaluate if impacts have resulted from historical groundwater pumping activities at the Barwon Downs borefield based on the current state of knowledge and the best available data. The evaluation has identified that the historical groundwater pumping activities have led to a decrease of water levels in the LTA of up to 4 m within the KIA. While there is a component of water level decrease that can be attributed to long term rainfall declines, this cannot account for all of the water level decreases observed. The water level reduction observed in the KIA in the LTA are not indicated to reflect the cone of depression associated with pumping, rather alteration of groundwater flow paths by pumping. The water levels in the LTA in the KIA would be expected to recover as baseline groundwater flow paths are re-established, although this has not yet occurred in bores in the upper Ten Mile Creek area or the central KIA.

Streamflow monitoring records indicate that there have been reductions in the baseflow (i.e. low flow conditions, when waterways are most reliant on groundwater inputs) observed in Yahoo Creek, Loves Creek and the Gellibrand River (summarised in **Table 21**) between 1997 and 2013. Despite this, baseflow continued during the peak pumping period. A minor reduction observed in Ten Mile Creek is consistent with expected natural variation.

Of the observed baseflow reductions in Yahoo Creek and Loves Creek, high level, 'back of the envelope' calculations, using best available data, indicate that 15% to 35% is attributed to long-term rainfall decline that occurred during the Millennium Drought. There are insufficient data to directly quantify the potential contribution from groundwater extraction to Yahoo Creek and Loves Creek, however, through a process of exclusion, the remaining 65% to 85% of observed baseflow reduction in Yahoo Creek (corresponding to 18 – 23% reduction relative to total flow) and 55% and 75% in Loves Creek (corresponding to 19 – 25% reduction relative to total flow) is potentially due to a combination of extraction from the Barwon Downs Borefield, possibly exacerbated by the effects of forestry particularly since 2011 and climate driven baseflow reduction from outcrop of LMTA.

In the Gellibrand River at Bunker Hill, which is located within the regional discharge zone for the LTA, groundwater extraction from the LTA can only account for potentially 5-10% of the observed reduction based on the current state of knowledge. Approximately 6% is attributed to long-term rainfall reductions, with the balance of the reduction observed in the Gellibrand River (approximately 80%) potentially explained by the effect of licenced surface water extraction during the Millennium Drought given extraction of that scale is possible based on licenced extractions. Importantly, the assessment highlights the cumulative influences of various competing demands on groundwater and surface water resources, particularly during periods of drought.

The framework documented in the Ministerial Guidelines for Groundwater Licensing of High Value GDEs was applied retrospectively to provide a point of comparison to aid in future management and to categorise the potential susceptibility in a consistent and transparent manner. The framework identified that Ten Mile Creek, Yahoo Creek, Loves Creek and Gellibrand River are categorised as being of 'high' potential susceptibility under the framework. This highlights the need for future management to consider the intimate relationship between the LTA and these GDEs, as well as the influences of climate, resource utilisation and land use.

Whilst the HA has established that there is evidence of varying degrees of hydraulic influence on groundwater and associated surface water features in the KIA due to the historical extraction from the Barwon Downs Borefield, there appears to be limited anecdotal evidence to suggest that the extraction has had a demonstrable impact on the environment within the KIA. One anecdotal observation indicated "severe stress" of vegetation in approximately 2010 along the Gellibrand River. Further, review of the available data has not identified any obvious evidence of environmental significant impacts in the KIA associated with groundwater extraction from the Barwon Downs Borefield. It should be noted however that there is a general paucity of data from which conclusions can be drawn regarding direct environmental significant impacts associated with groundwater extraction from the Barwon Downs Borefield.

One anecdotal observation indicated "severe stress" of vegetation in approximately 2010 along the Gellibrand River over areas of Quaternary Sediments and LTA outcrops.

The findings from this HA should be used to form the basis for the subsequent management decisions in the catchment. Future use of groundwater in the LTA in the KIA needs to consider cumulative effects of any pumping, climate change and land use within recharge zones where the LTA outcrops together with the role groundwater plays to surface water resources (e.g., Upper Ten Mile Creek, Yahoo Creek which feed Loves Creek, and Gellibrand River (key discharge feature of the LTA)). Additionally, the nature of the connectivity of the LTA in the KIA and Barwon Downs sub-basin is not well understood and this underpins any assessment of sustainable yield.

7.2 Recommendations

Based on the findings of the HA, the following recommendations are made for consideration by Barwon Water:

- Continued monitoring of groundwater and surface water assets in the KIA to monitor the recovery of groundwater levels in the LTA.

In addition to the recommendations listed above, the following recommendations are provided with regard to the future management of groundwater resources in the KIA:

- Future management decisions consider the cumulative effects and interconnectivity of surface water and groundwater resources; and
- The identified data gaps, particularly those in relation to the LMTA, the shallow aquifer systems and the LTA be addressed and data continue to be collected to allow for a robust and continuous data set, as well as a baseline condition as part of any proposed future extraction, should the PCV be raised in the future.

8 Limitations

This report was prepared for the sole use of Barwon Water and should not be relied upon by any other person. None of BlueSphere Environmental Pty Ltd or any of its related entities, employees or directors (each a BlueSphere Person) owes a duty of care (whether in contract, tort, statute or otherwise) to any third party with respect to or in connection with this report and no BlueSphere Person accepts any liability for any loss or damage suffered or costs incurred arising out of or in connection with the use this report by any third party.

The report has been prepared with the objectives and scope of work outlined in the proposal dated 12 August 2022. The work was carried out in accordance with the existing contract between BlueSphere and Barwon Water.

The conclusions and recommendations provided in this report are based on available information (including third party data and reports) and it is possible that different conclusions and recommendations could be made should new information become available, or with changing site conditions over time. These opinions, conclusions and recommendations are subject to uncertainty given the potentially complex nature of any subsurface environment. Variation in soil and groundwater conditions may vary significantly between the specific sampling and testing locations and other locations at the site.

The report will not be updated if anything occurs after the date of this report and BlueSphere Environmental Pty Ltd will not be obliged to inform any person of any matter arising or coming to its attention after that date.

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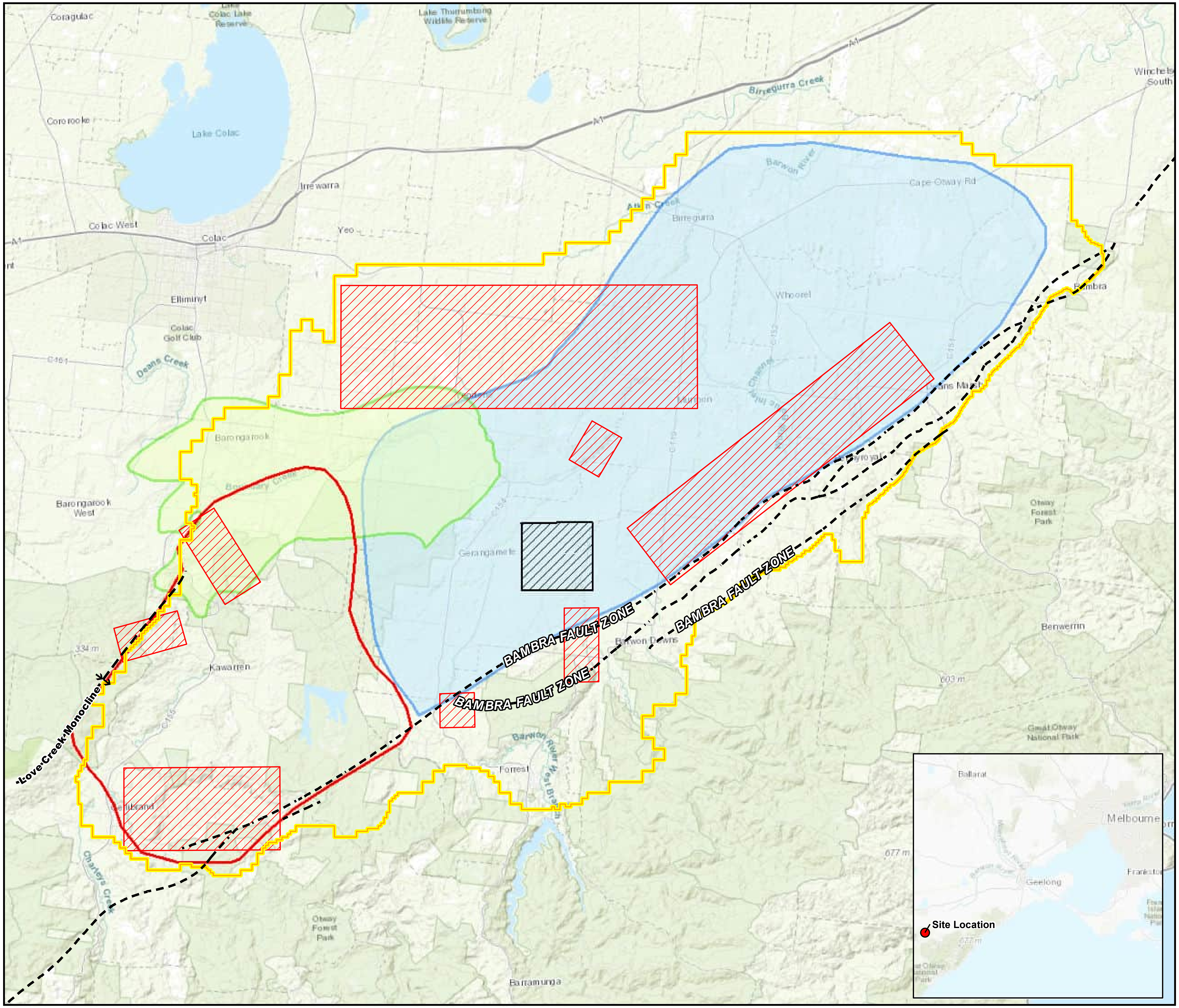
Figures



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DATE 27/06/2023
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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation Area
- Areas for Further Investigation
- Approximate Area of Barongarook High (Intake areas)
- Barwon Water Borefield

Structural Features

- Geological Faults
- Monocline

Service Layer Credits: 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

0 0.95 1.9 2.85 3.8 4.75
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55

REGIONAL SETTING

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F1

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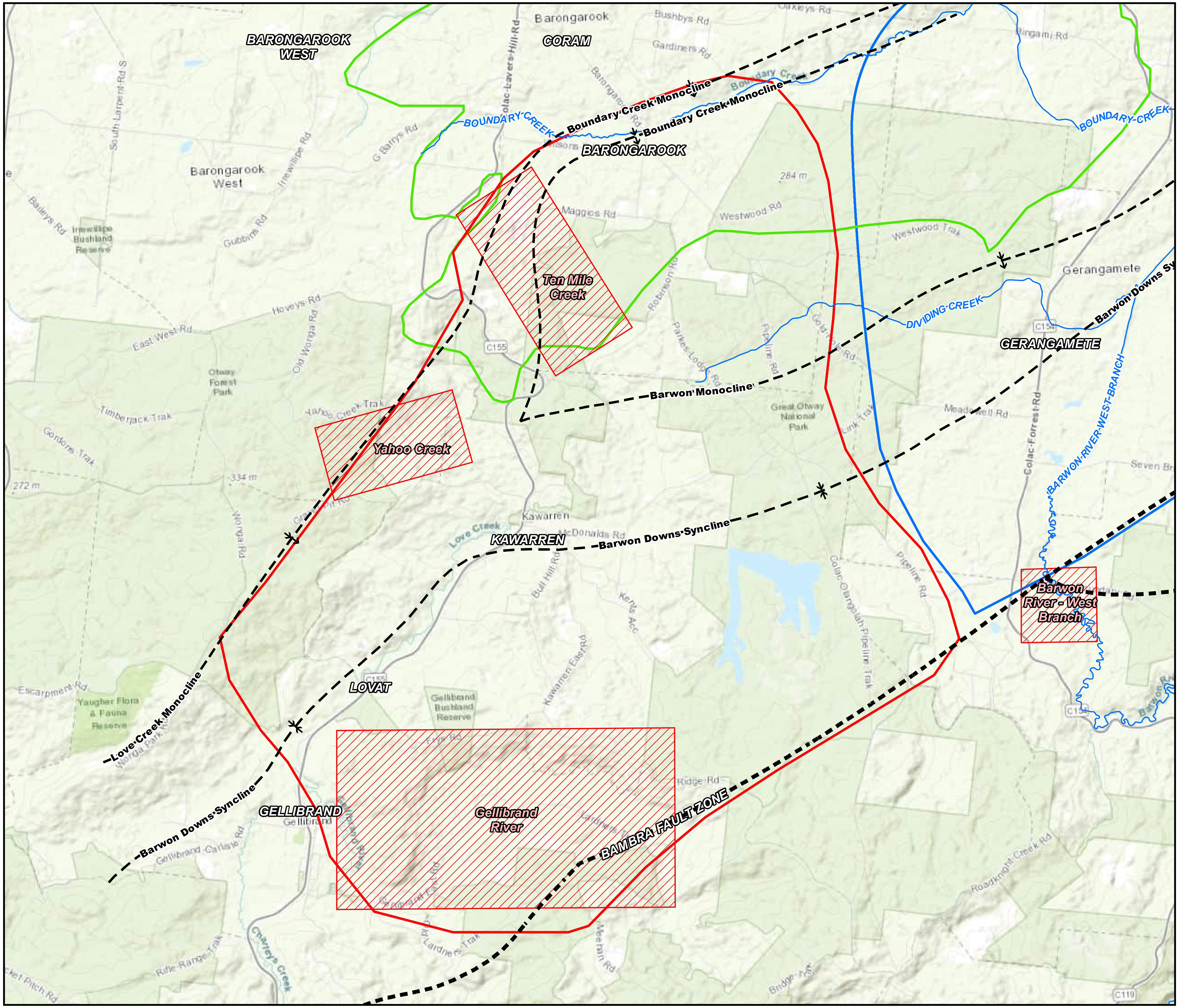

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Areas for Further Investigation
- Approximate Area of Barongarook High (Intake areas)
- Barwon Water Borefield
- Watercourse

Structural Features

- Monocline
- Syncline
- Geological Faults

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55

KAWARREN SUB-BASIN INVESTIGATION AREA

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin Area
Barwon Water

Figure **F2**

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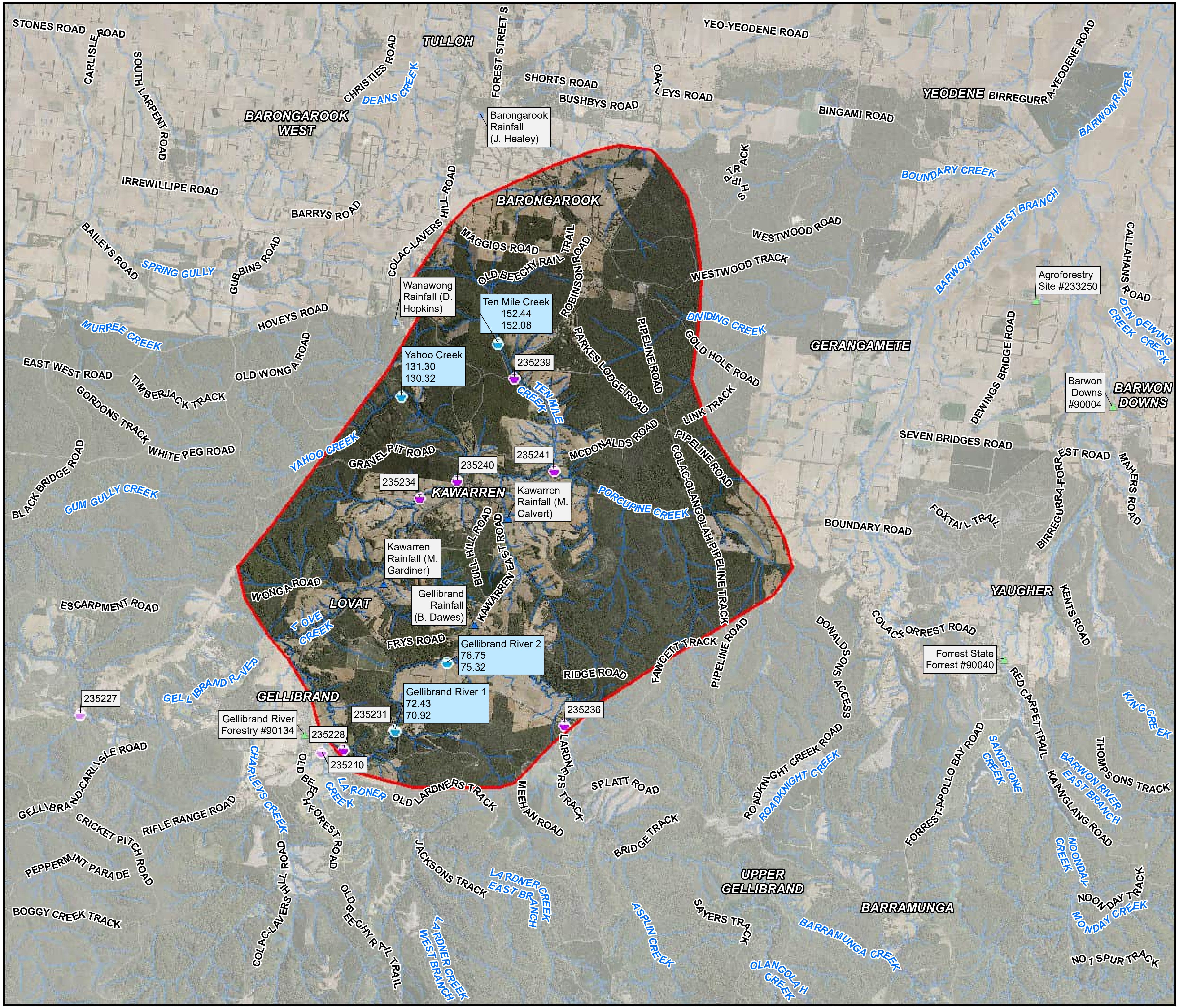

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

Hydrology

- Stream Gauges
- Stream Survey Locations

Rainfall Stations

- Formal Stations
- Community Gathered Rainfall Data

Location ID
Water Level (mAHD)
Invert Level (mAHD)

Note: Stream Survey provided by Barwon Water and collected between March and August 2022

N

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Kilometres
1:80,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 2019

HYDROLOGY AND RAINFALL STATIONS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F3

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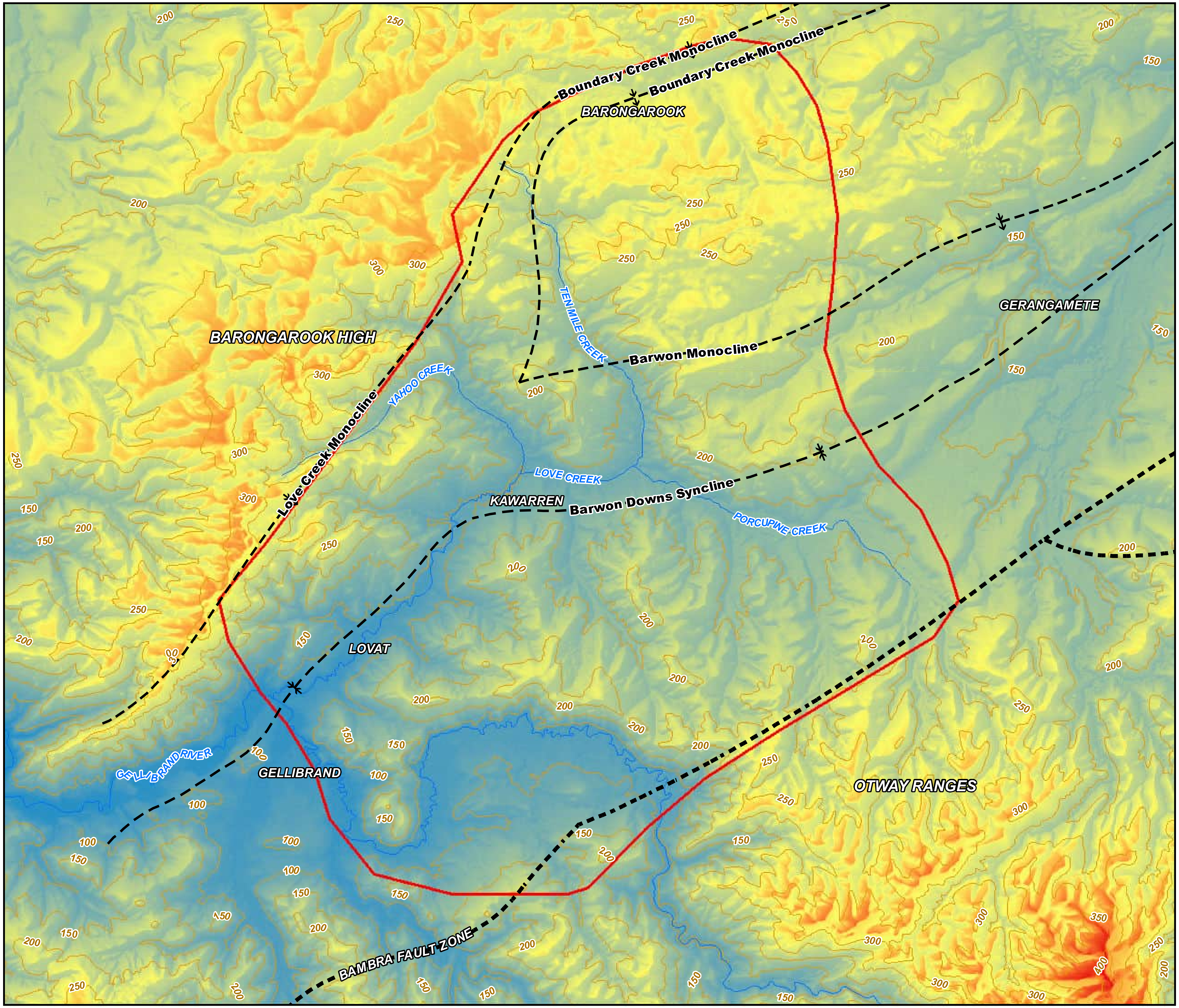

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BlueSphere ENVIRONMENTAL

Legend

Kawarren Sub-basin Investigation Area (approx. extent)

Regional Elevation Contours (mAHD)

Watercourse

Structual Features

Monocline

Syncline

Geological Faults

Elevation (mAHD)

High : 658.764

Low : 50

Note: Digital Elevation Model provided by Barwon Water

N

0 0.6 1.2 1.8 2.4 3

Kilometres

1:60,000 when printed at A3

GDA 1994 MGA Zone 55

TOPOGRAPHY

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F4

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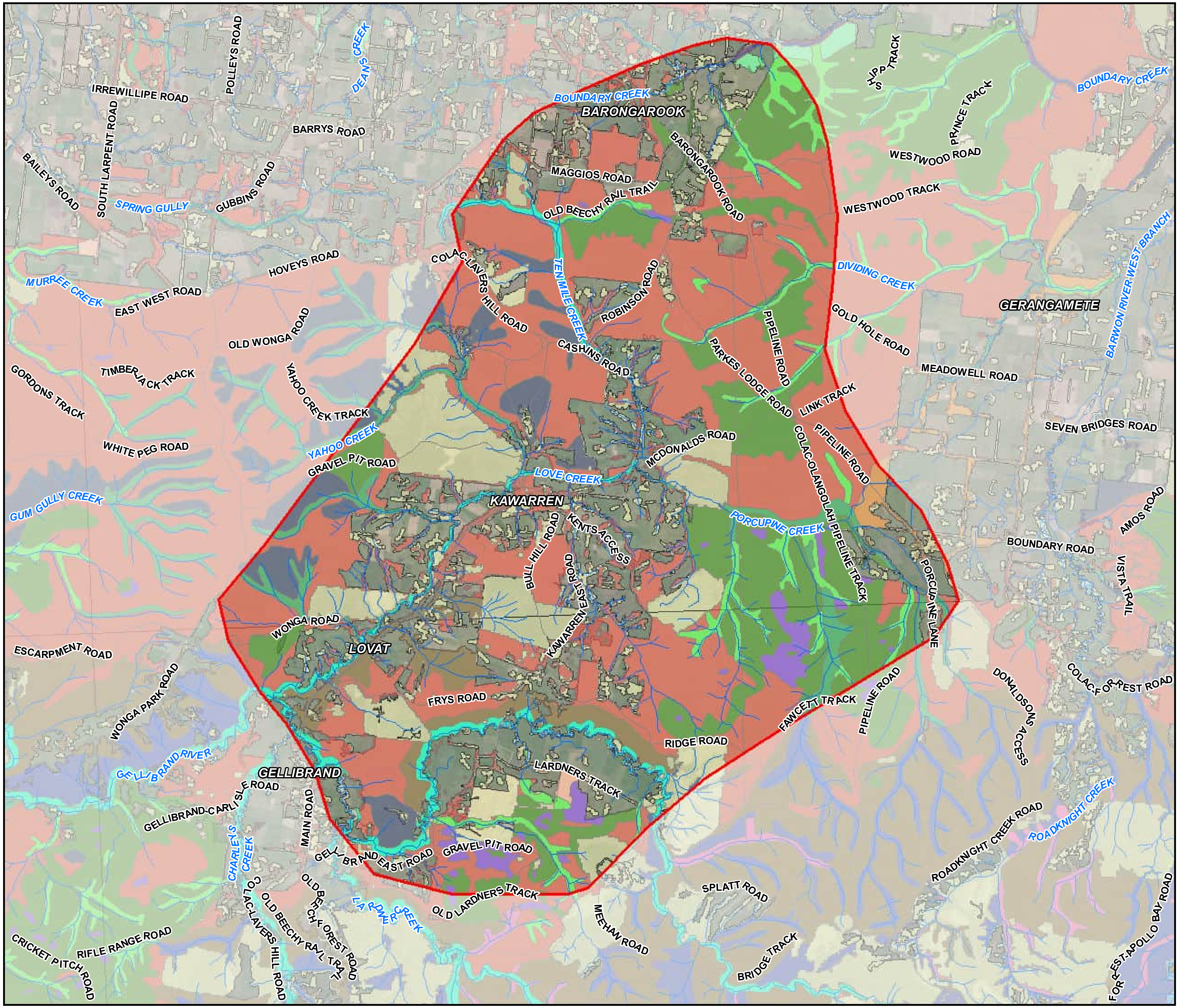

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

Ecological Vegetation Classes (NV2005, DELWP)

- 3, Damp Sands Herb-rich Woodland
- 8, Wet Heathland
- 16, Lowland Forest
- 17, Riparian Scrub/Swampy Riparian Woodland Complex
- 18, Riparian Forest
- 23, Herb-rich Foothill Forest
- 30, Wet Forest
- 45, Shrubby Foothill Forest
- 48, Heathy Woodland
- 83, Swampy Riparian Woodland
- 128, Grassy Forest
- 165, Damp Heath Scrub
- 175, Grassy Woodland
- 198, Sedgy Riparian Woodland
- 201, Shrubby Wet Forest
- 998, Water Body - man-made
- Non Native Tree Areas

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

N

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

ECOLOGICAL VEGETATION CLASSES

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F5

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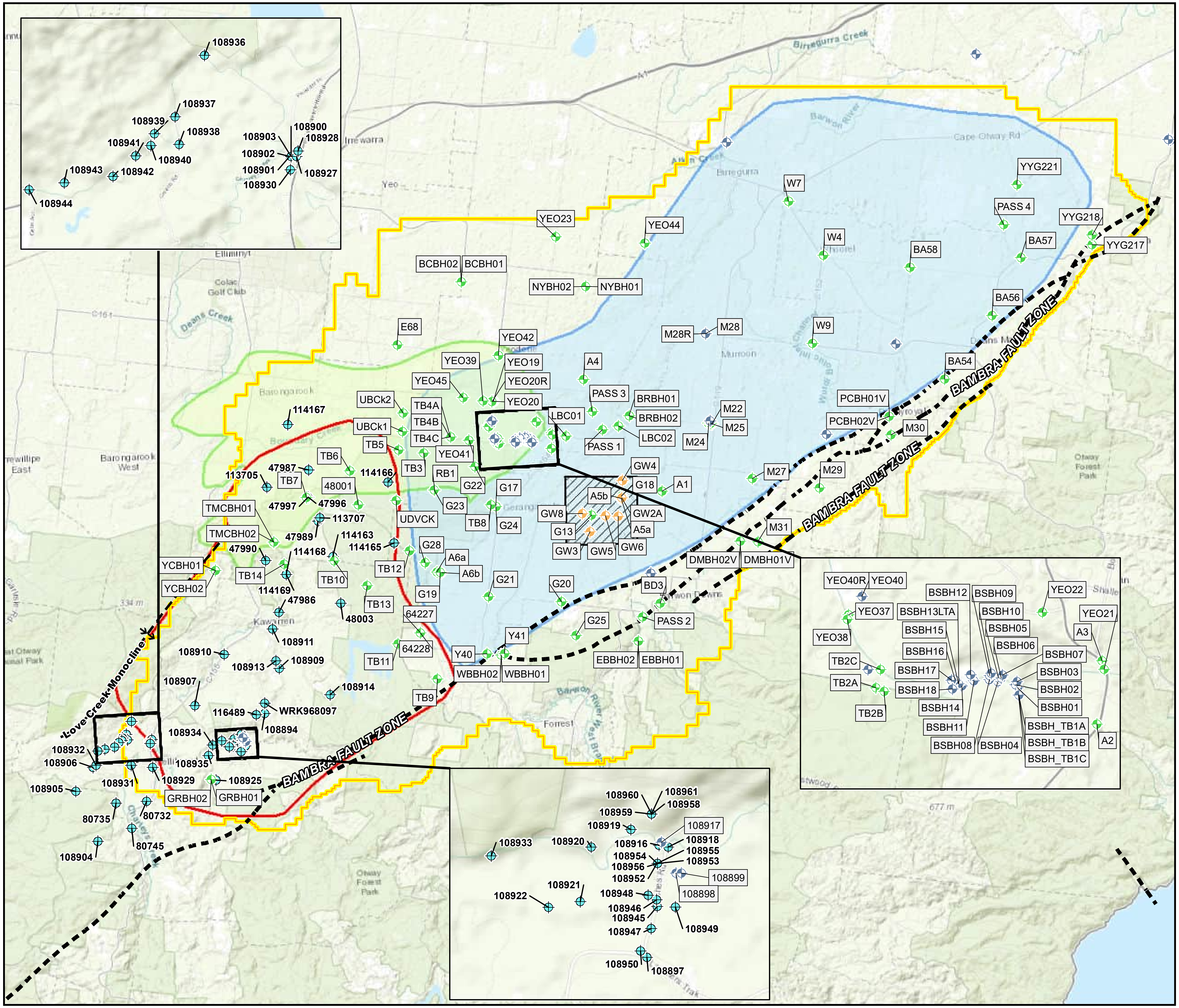

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation
- Approximate Area of Barongarook High (Intake areas)
- Barwon Water Borefield

Structural Features

- Monocline
- Geological Faults

Barwon Water Monitoring

- Production Bores
- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation

Service Layer Credits: 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

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Kilometres

1:130,000 when printed at A3

GDA 1994 MGA Zone 55

Imagery: Nearmap 19/02/2022

BARWON DOWNS MONITORING NETWORK

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F6

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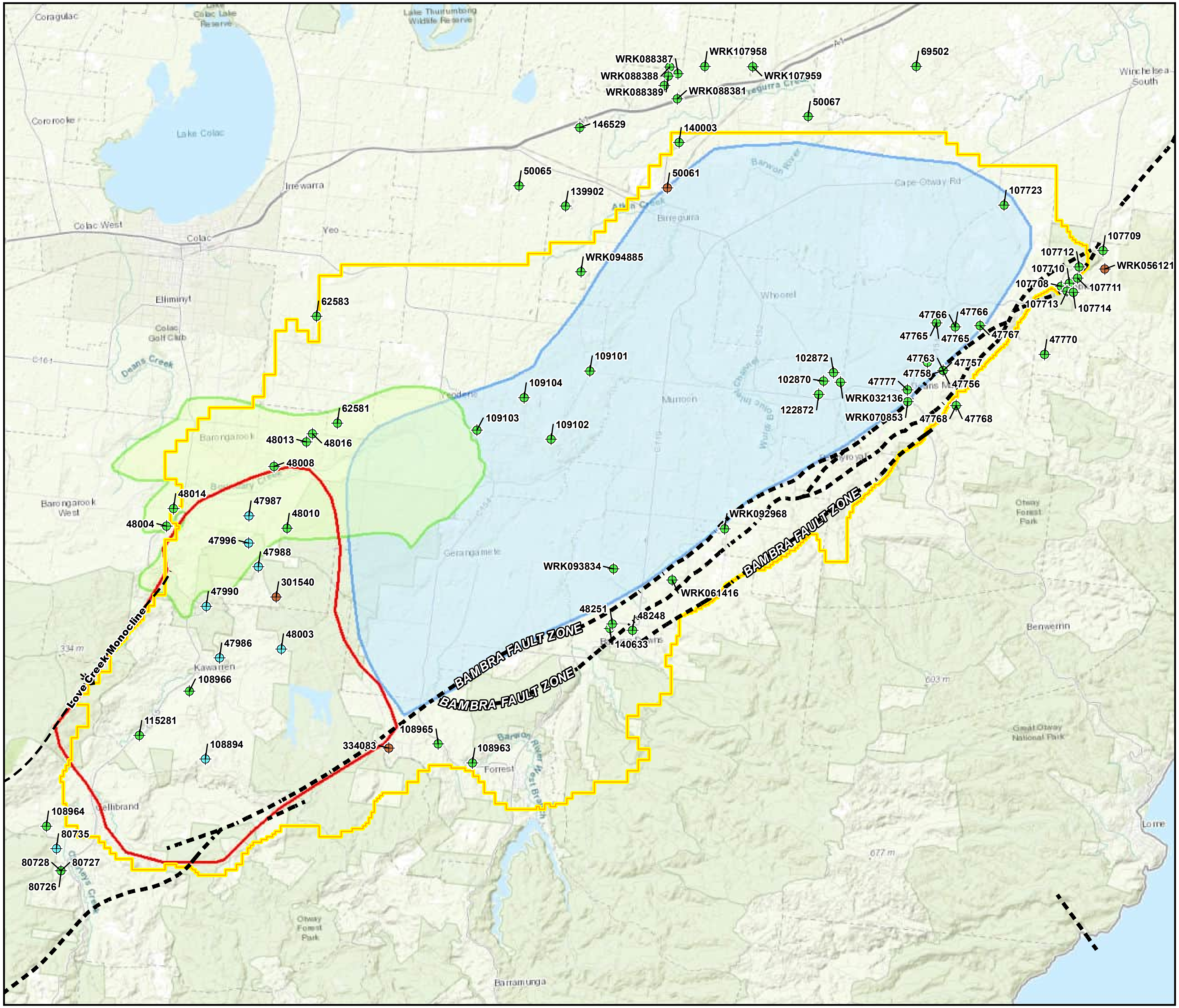

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Love Creek Monocline
- Geological Faults

Registered or Licenced Groundwater Bores

- Domestic/Stock
- Non Groundwater
- Observation
- Unknown

0 1 2 3 4 5
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

REGISTERED EXTRACTIVE USE BORES

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F7

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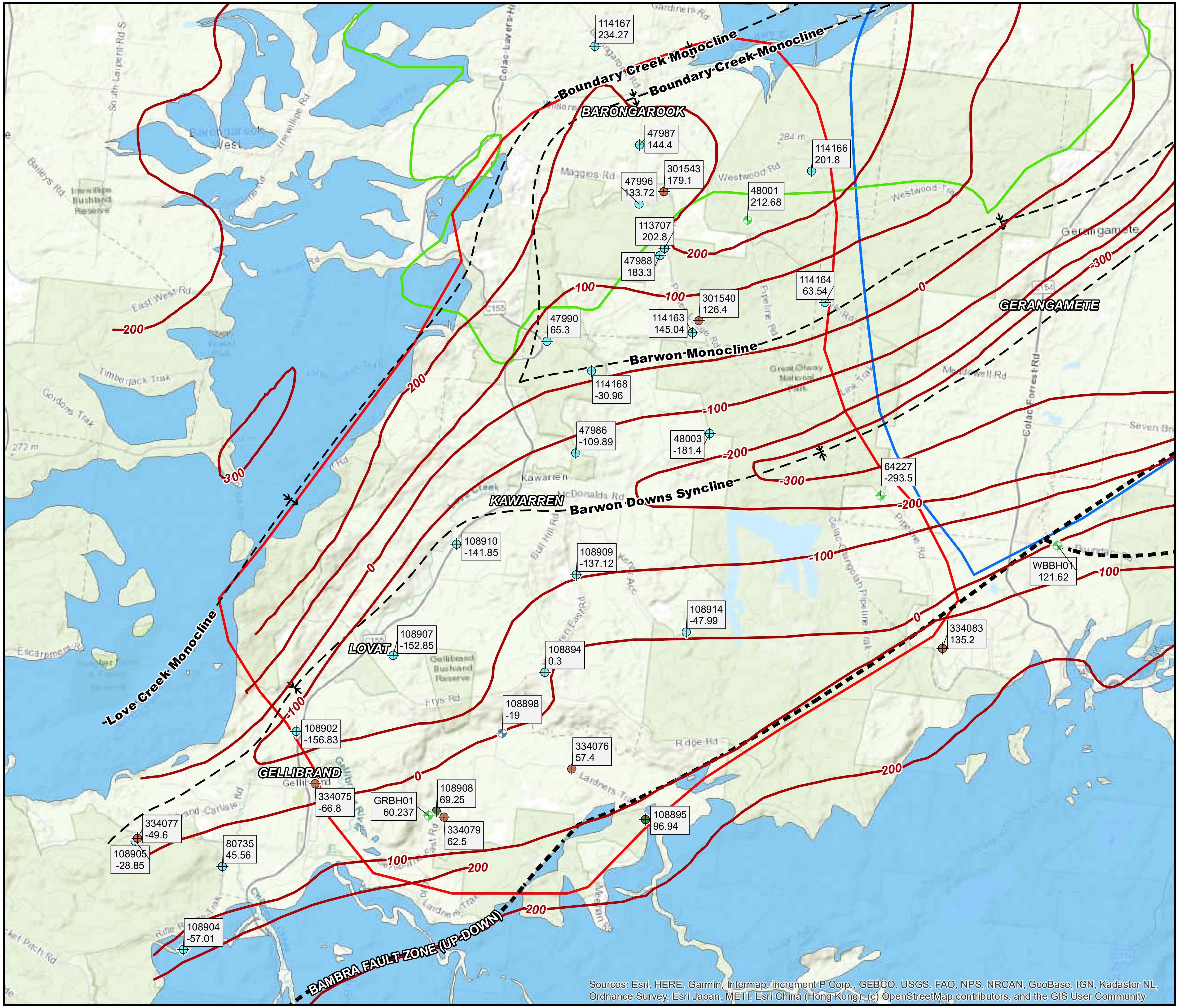

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Otway Group

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

Registered or Licenced Groundwater Bores

- Non Groundwater
- Observation
- Unknown
- Top of Otway Group Elevation Contours (mAHD)

Bore ID
Top of Otway Group Elevation (mAHD)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89

0 0.45 0.9 1.35 1.8 2.25
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

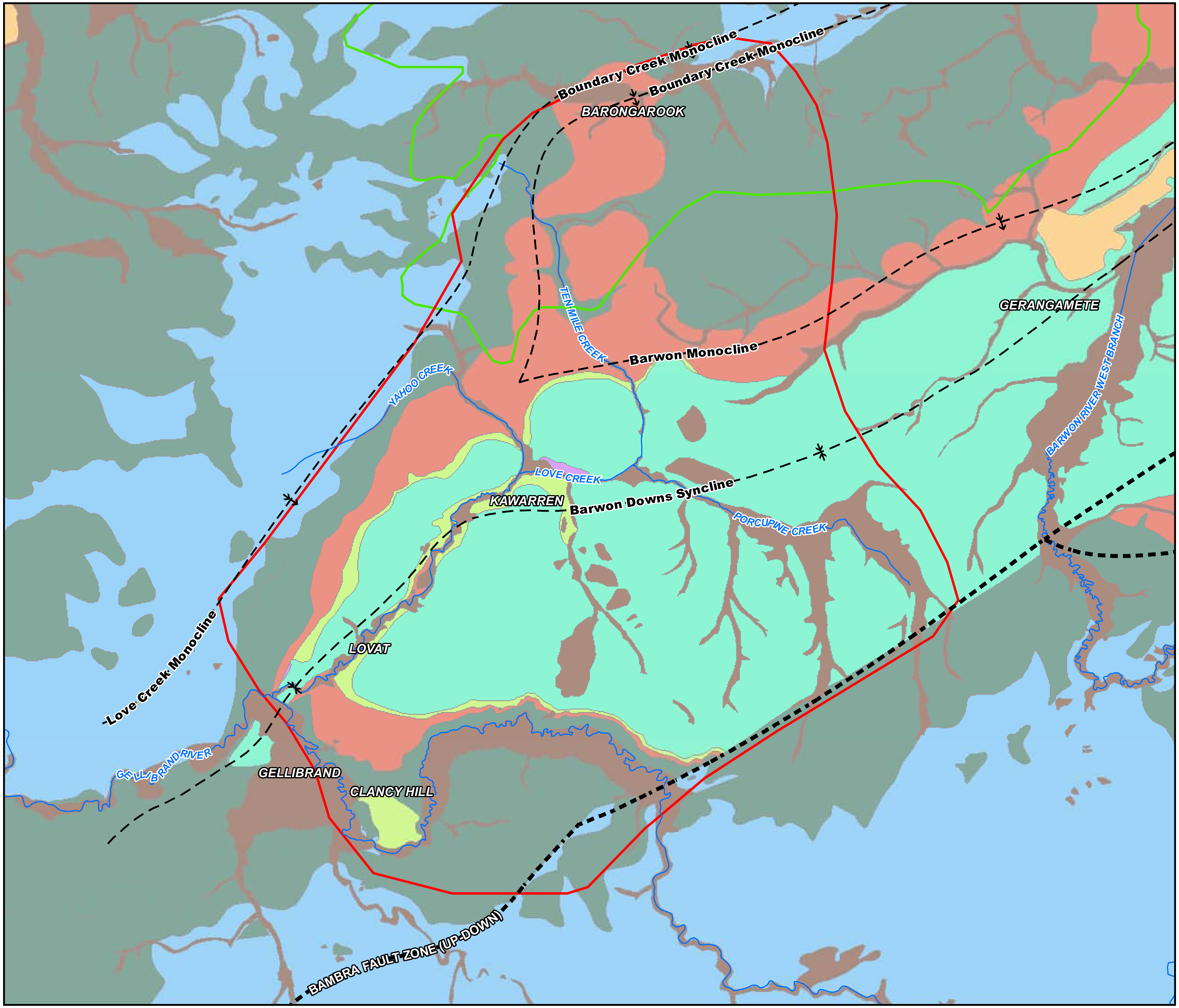
ELEVATION OF THE TOP OF THE OTWAY GROUP

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F8

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig08_OtwayGroup.mxd.mxd



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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Area of Barongarook High (Intake areas)
- Watercourse

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Sandringham Sandstone
- Gellibrand Marl Formation } Heytesbury Group
- Clifton Formation } Heytesbury Group
- Older Volcanics
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
- Otway Group

Note: Modified surface geology nomenclature.

N

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

SURFICIAL GEOLOGY

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F9

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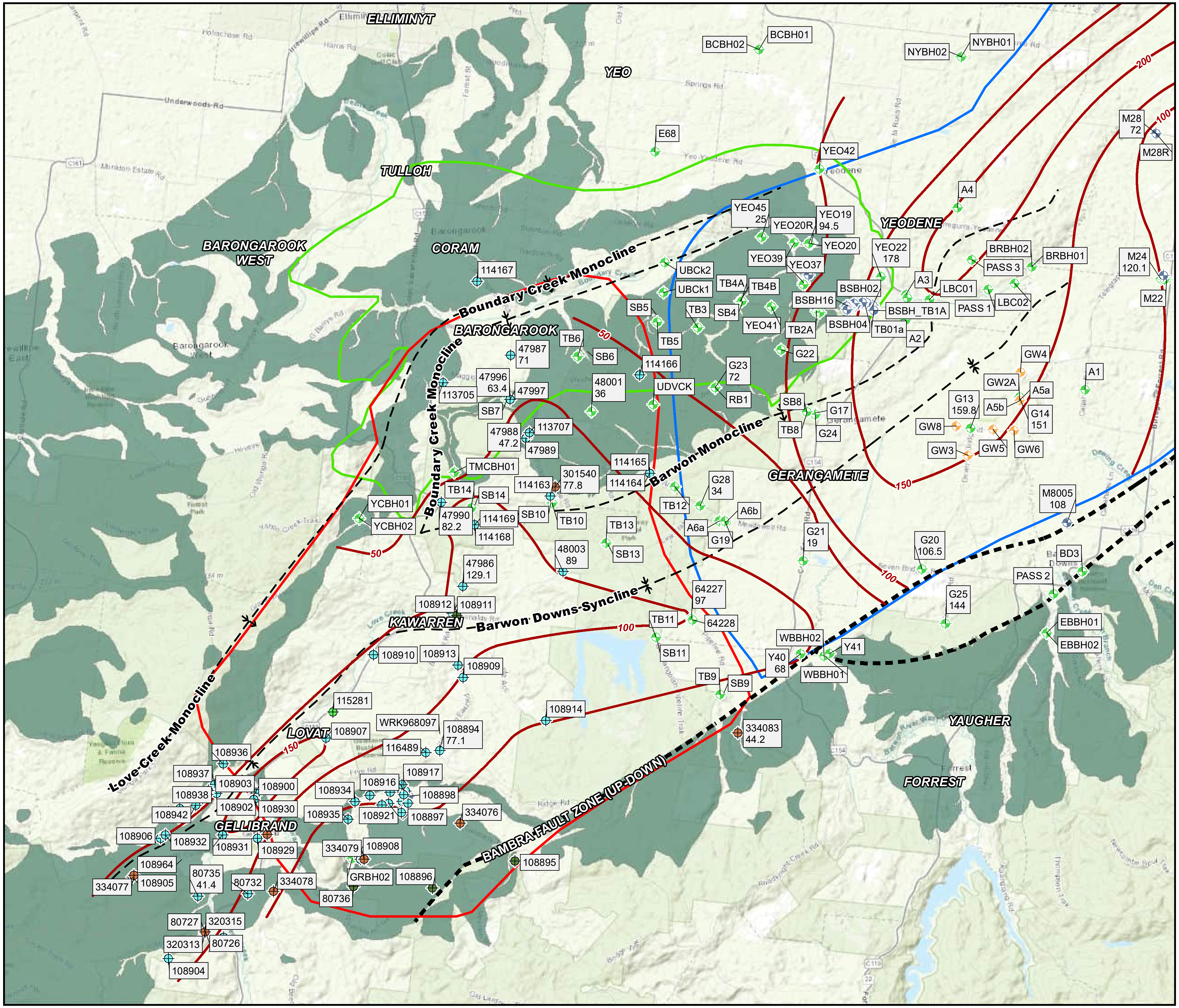

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)

Barwon Water Monitoring Assets

- Production Bores
- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Domestic/Stock
- Non Groundwater
- Observation
- Unknown
- Modified LTA Thickness Contours (m)

Bore ID
LTA Thickness (m)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89
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

0 0.8 1.6 2.4 3.2 4
Kilometres
1:80,000 when printed at A3
GDA 1994 MGA Zone 55

LTA THICKNESS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F10

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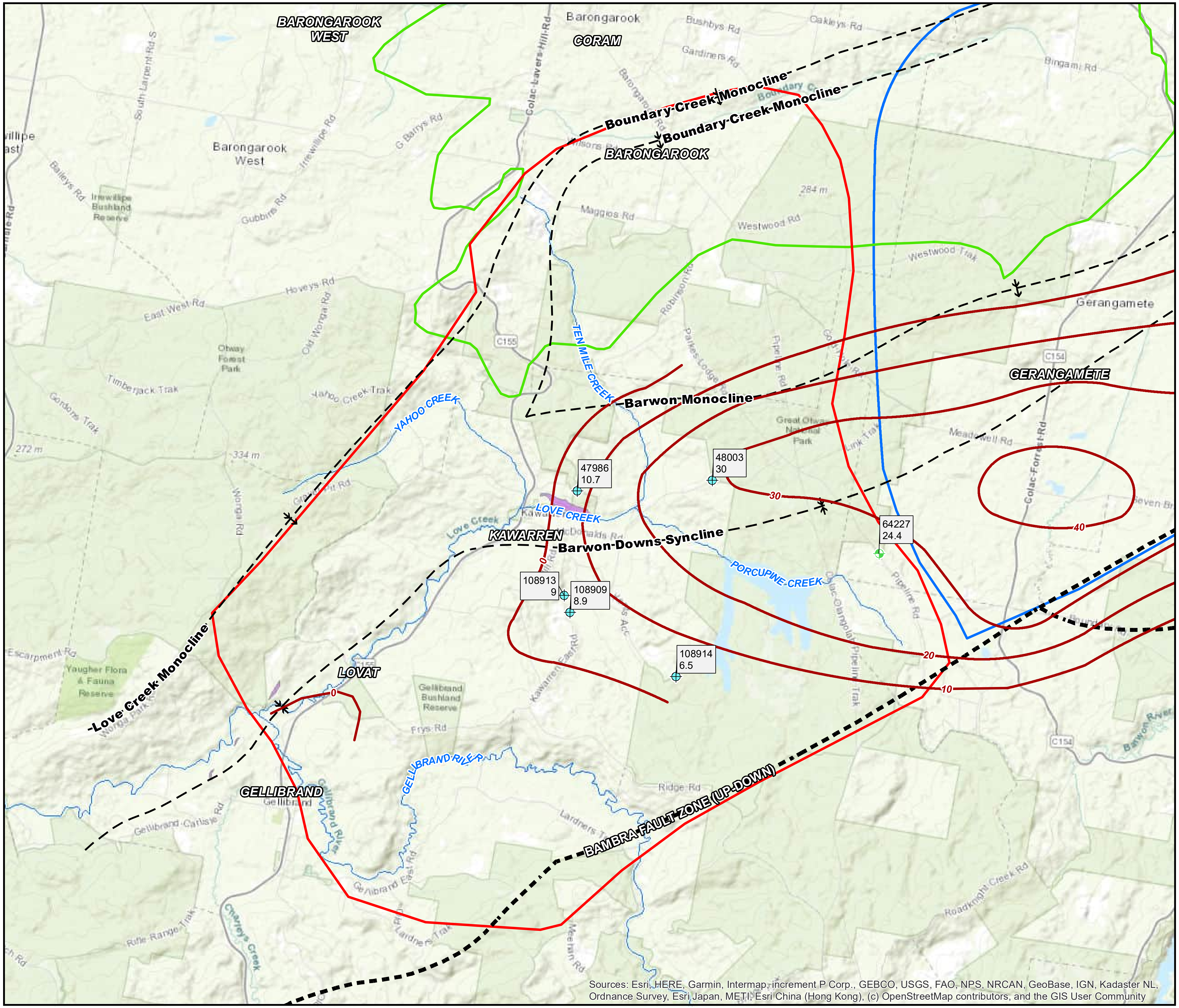

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BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Monocline
- Syncline
- Geological Faults
- Watercourse

Surface Geology (1:50,000) (DELWP)

- Clifton Formation

Barwon Water Monitoring Assets

- Groundwater Observation Bores

WMIS Groundwater Bores

- Observation
- Clifton Formation Contours (m) (modified from Tickell et al. 1991)

Bore ID
Clifton Formation Thickness (m)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89

0 0.55 1.1 1.65 2.2 2.75
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 54

CLIFTON FORMATION THICKNESS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F11

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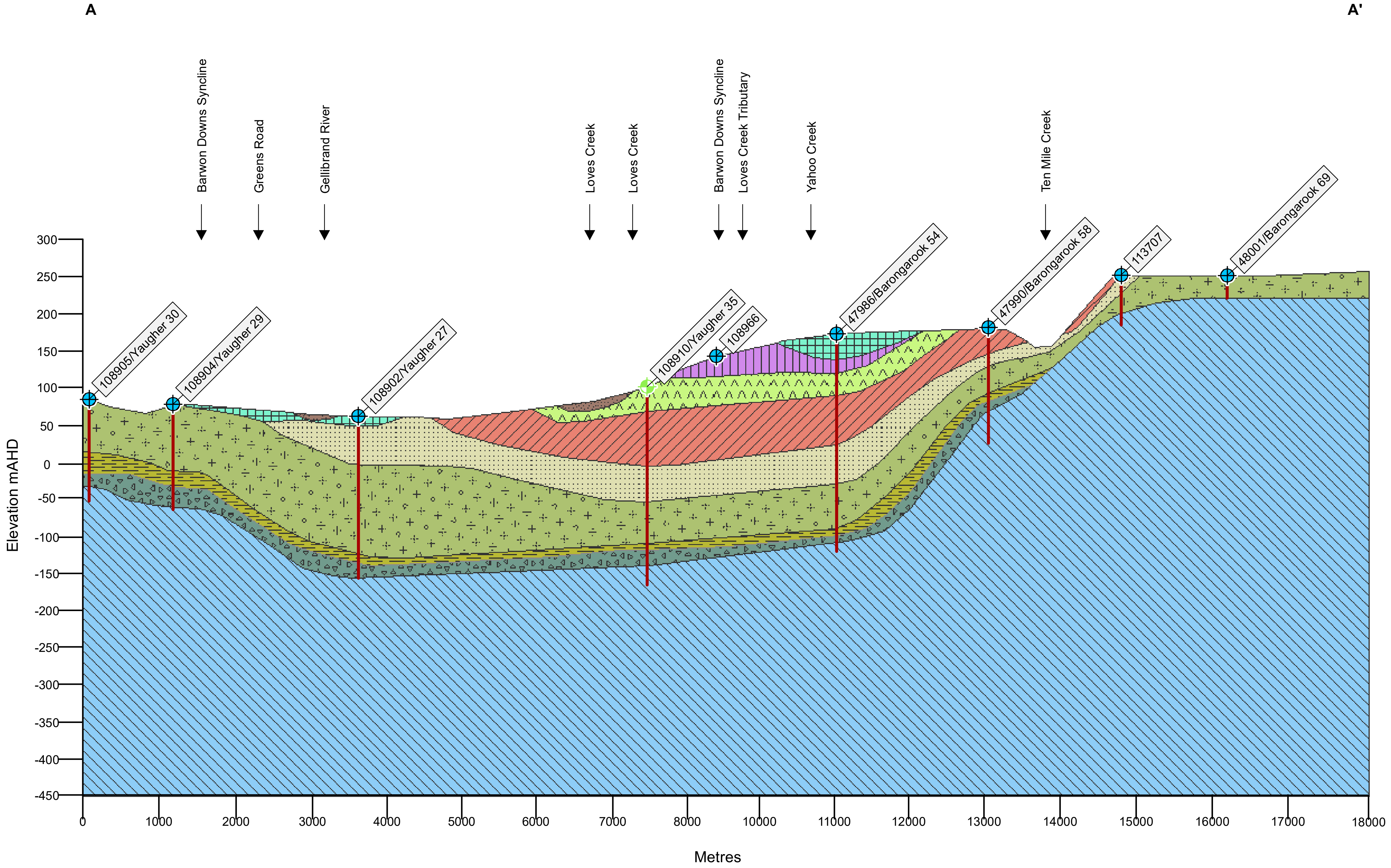


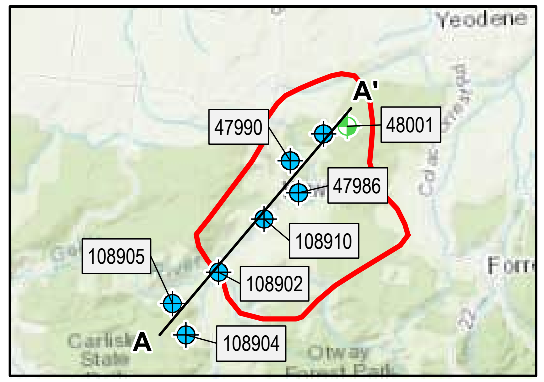
Legend

- Borehole
- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Mepunga Sands Formation
- Dilwyn Formation
- Pember Mudstone Formation
- Pebble Point Formation
- Otway Group

LTA (Mepunga Sands Formation, Dilwyn Formation, Pember Mudstone Formation, Pebble Point Formation)

Barwon Water Monitoring

- WMIS Groundwater Observation Bore
- Groundwater Observation Bores



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CONCEPTUALISED GEOLOGICAL CROSS SECTION A-A'

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F12

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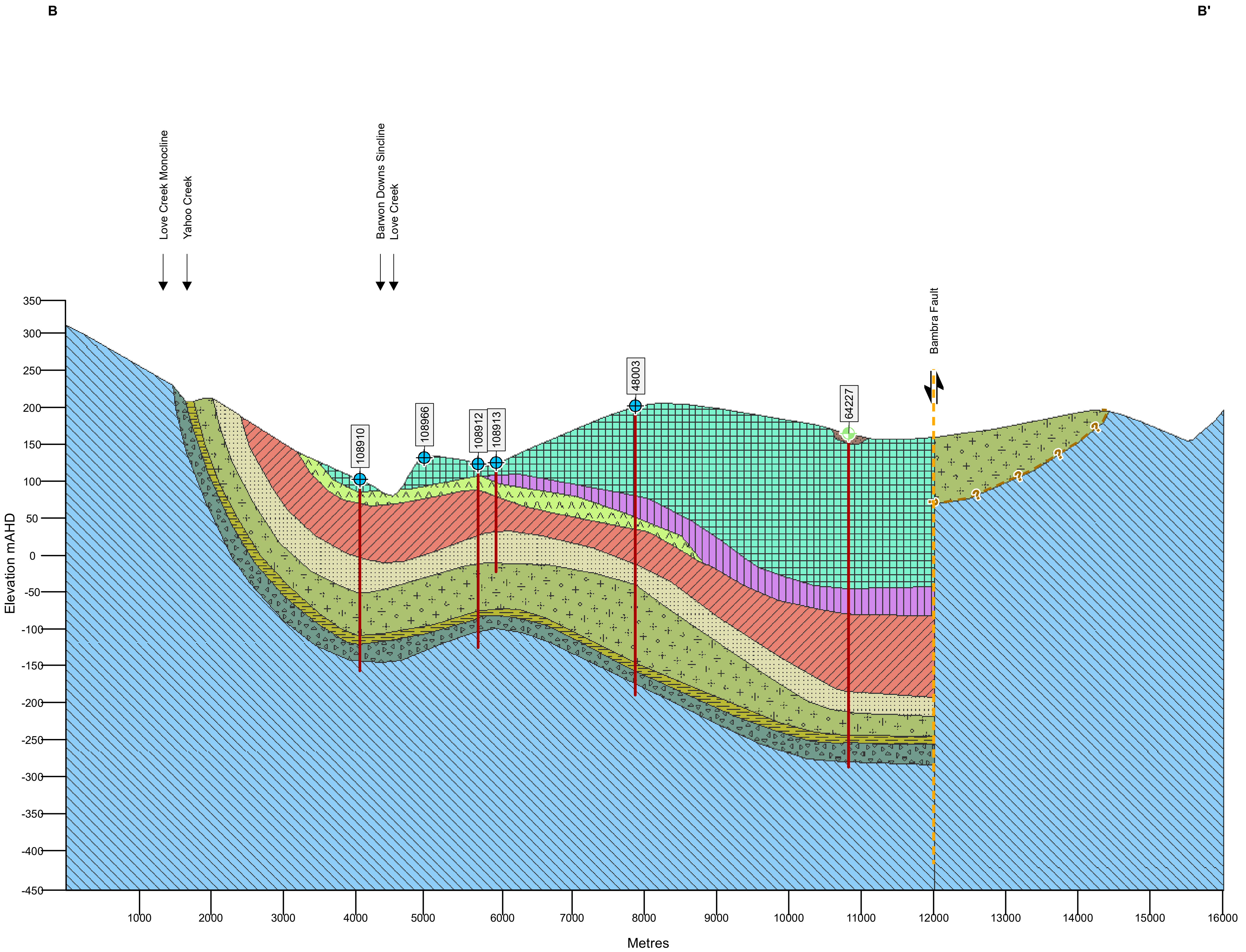


Legend

- Borehole
- Inferred Geology
- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Mepunga Sands Formation
- Dilwyn Formation
- Pember Mudstone Formation
- Pebble Point Formation
- Otway Group

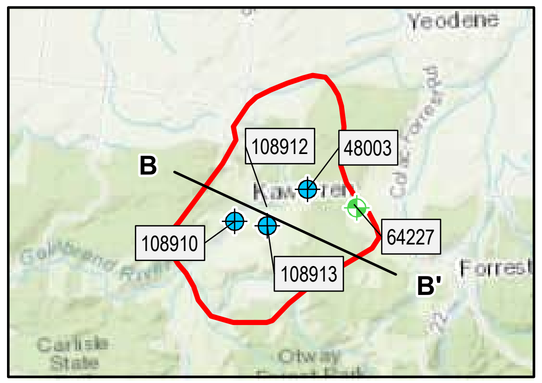
(Mepunga Sands Formation, Dilwyn Formation, Pember Mudstone Formation and Pebble Point Formation: LTA)

Structural Features

- Bambra Fault

Barwon Water Monitoring Assests

- Barwon Water Groundwater Monitoring Bore
- WMIS Groundwater Observation Bores



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CONCEPTUALISED GEOLOGICAL CROSS SECTION B-B'

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F13

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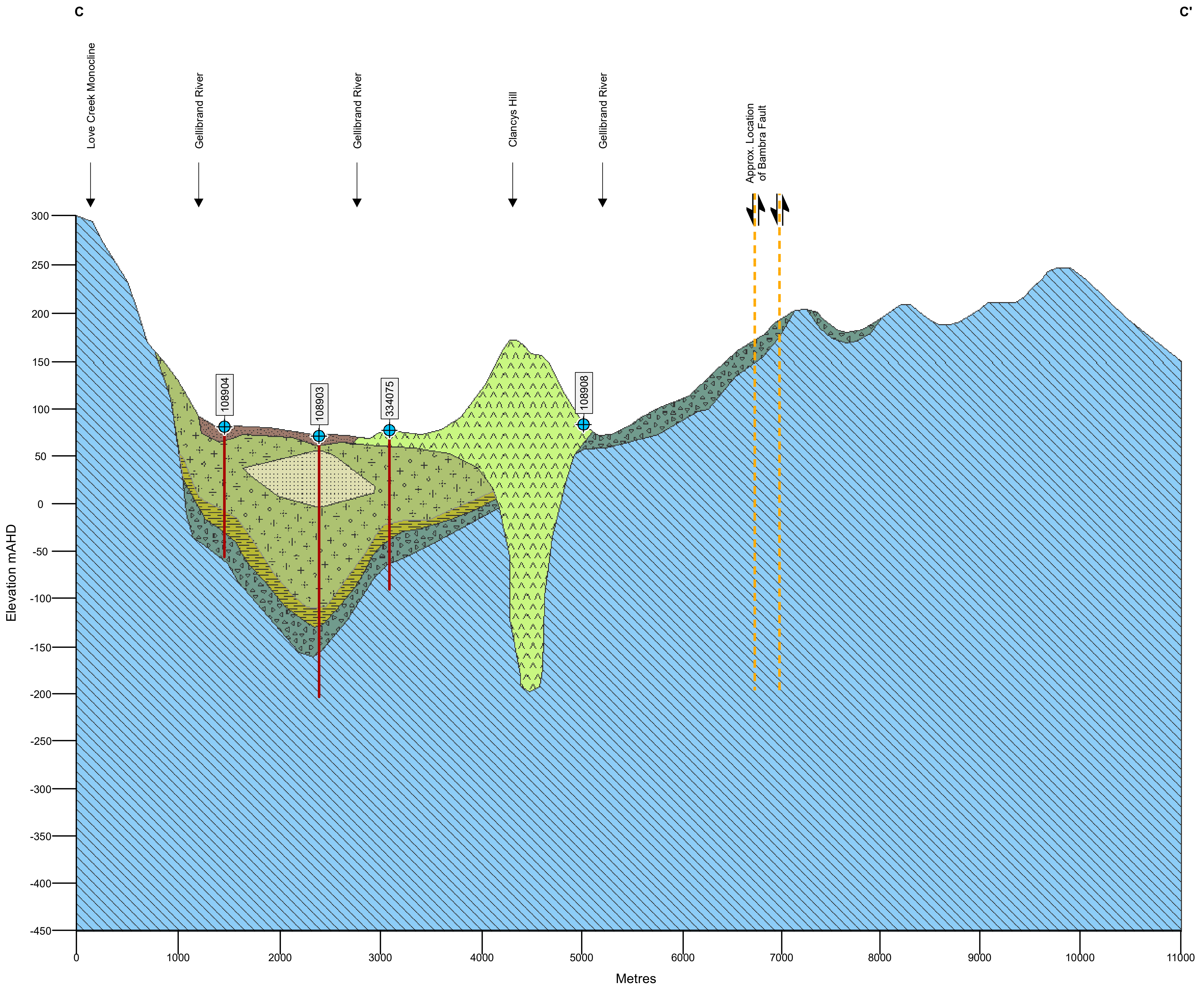


Legend

- Borehole
- Quaternary Sediments
- Yaugher Volcanics
- Mepunga Sands Formation
- Dilwyn Formation
- Pember Mudstone Formation
- Pebble Point Formation
- Otway Group

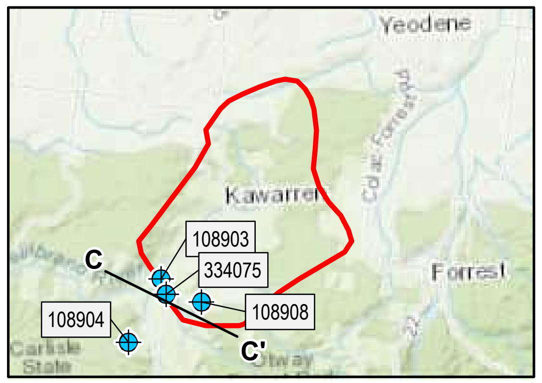
LTA

Structural Features

- Bambra Fault

Barwon Water Monitoring Assets

- WMIS Groundwater Observation Bore



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CONCEPTUALISED GEOLOGICAL CROSS SECTION C-C'

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F14

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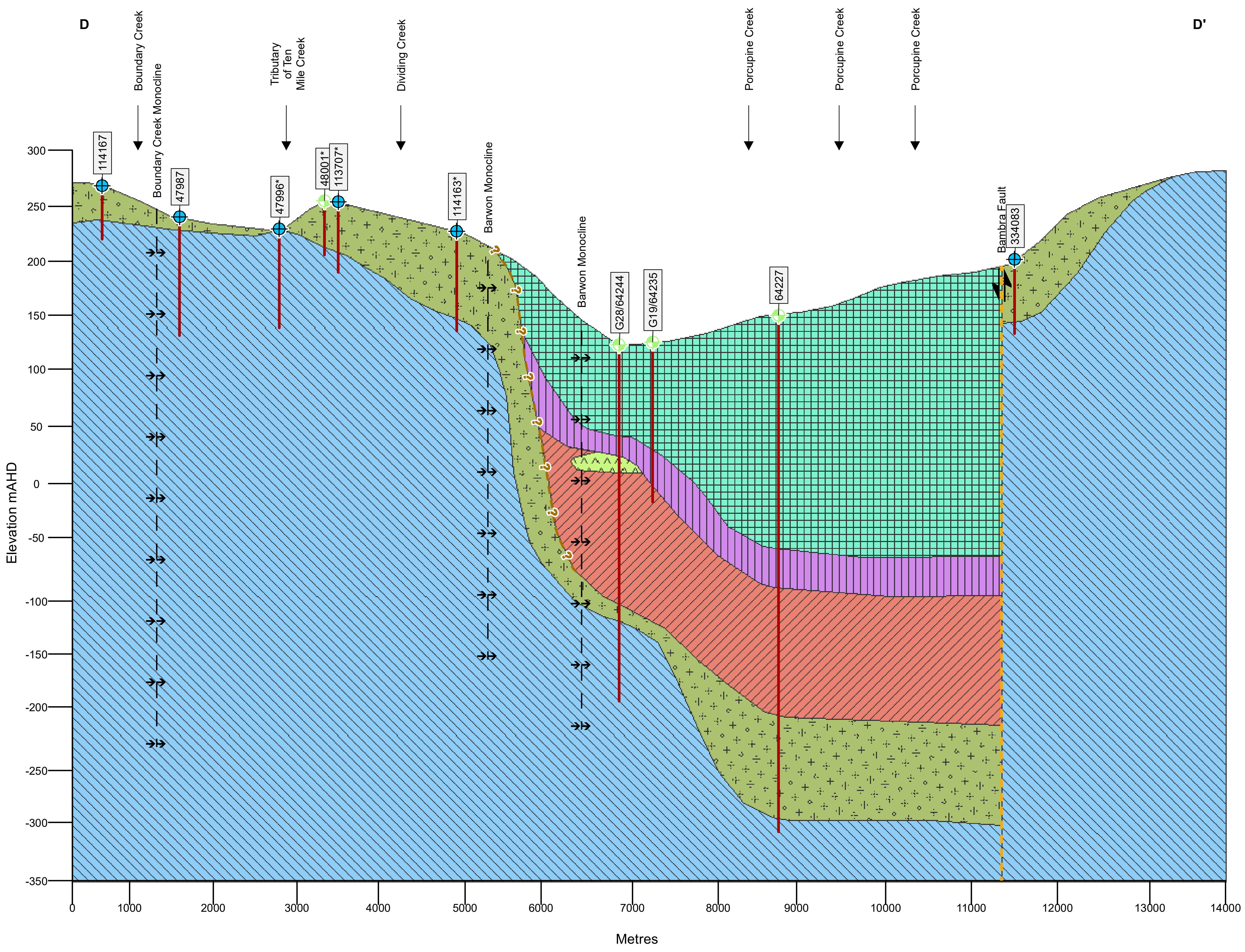


Legend

- Borehole
- Inferred Geology
- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Mepunga Sands Formation
- Dilwyn Formation#
- Pember Mudstone Formation
- Pebble Point Formation
- Otway Group

(Mepunga Sands Formation to Pebble Point Formation bracketed as: LTA)

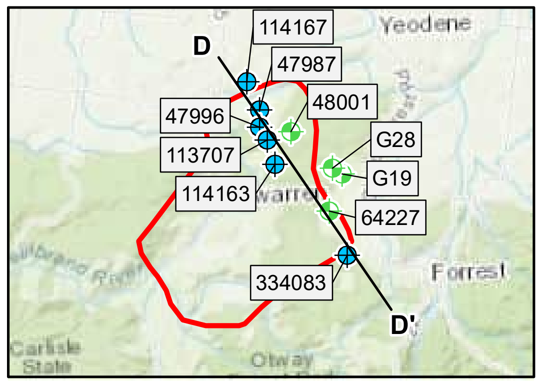
Structural Features

- Bambra Fault
- Monocline

Barwon Water Monitoring Assets

- WMIS Groundwater Observation Bore
- Groundwater Observation Bores

Notes:
* indicates bore offset from alignment
\# borelogs used for cross section did not differentiate between LTA units



Service Layer Credits: 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

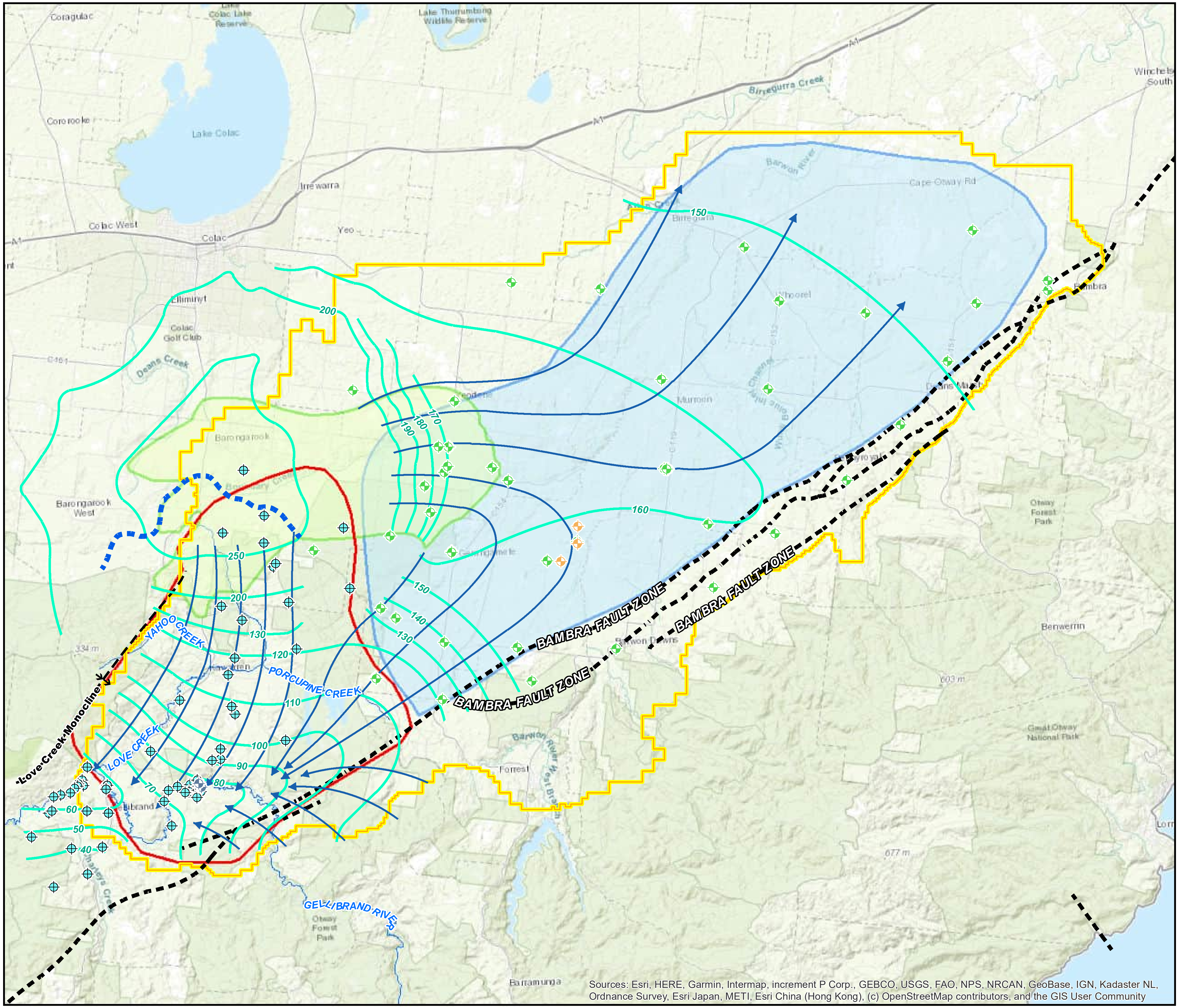
CONCEPTUALISED GEOLOGICAL CROSS SECTION D-D'

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F15

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig15_XSection_DD.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Watercourse

Structural Features

- Monocline
- Geological Faults

Barwon Water Monitoring Assets

- Production Bores
- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD) (Leonard, 1983)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Source Files: Leonard, J., Lakey, R., & Blake, R. (1983). Hydrogeological Investigation and Assessment, Barwon Down Graden, Otway Basin, Victoria. International Conference on Groundwater and Man Sydney, 1983. Unpublished.

N

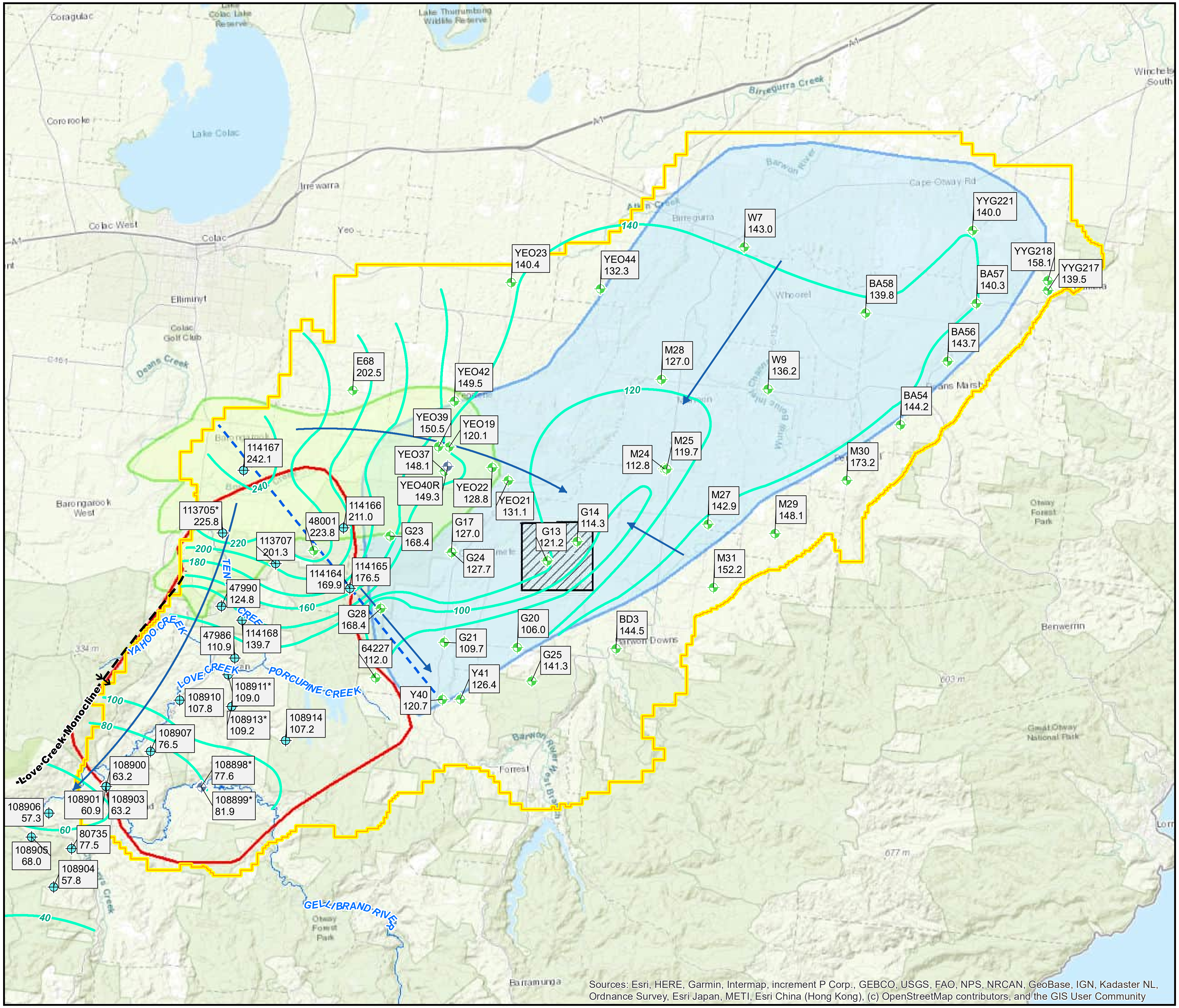
0 1 2 3 4 5
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55

POTENTIOMETRIC SURFACE CONTOURS - LTA (LEONARD, 1983)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F16



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Barwon Water Borefield
- Watercourse

Structural Features

- Monocline

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD)(May, 2010)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Well ID
RWL mAHD

Note:
* Indicates potentiometric surface value taken from nearest available date to May 2010

N

0 1 2 3 4 5
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55

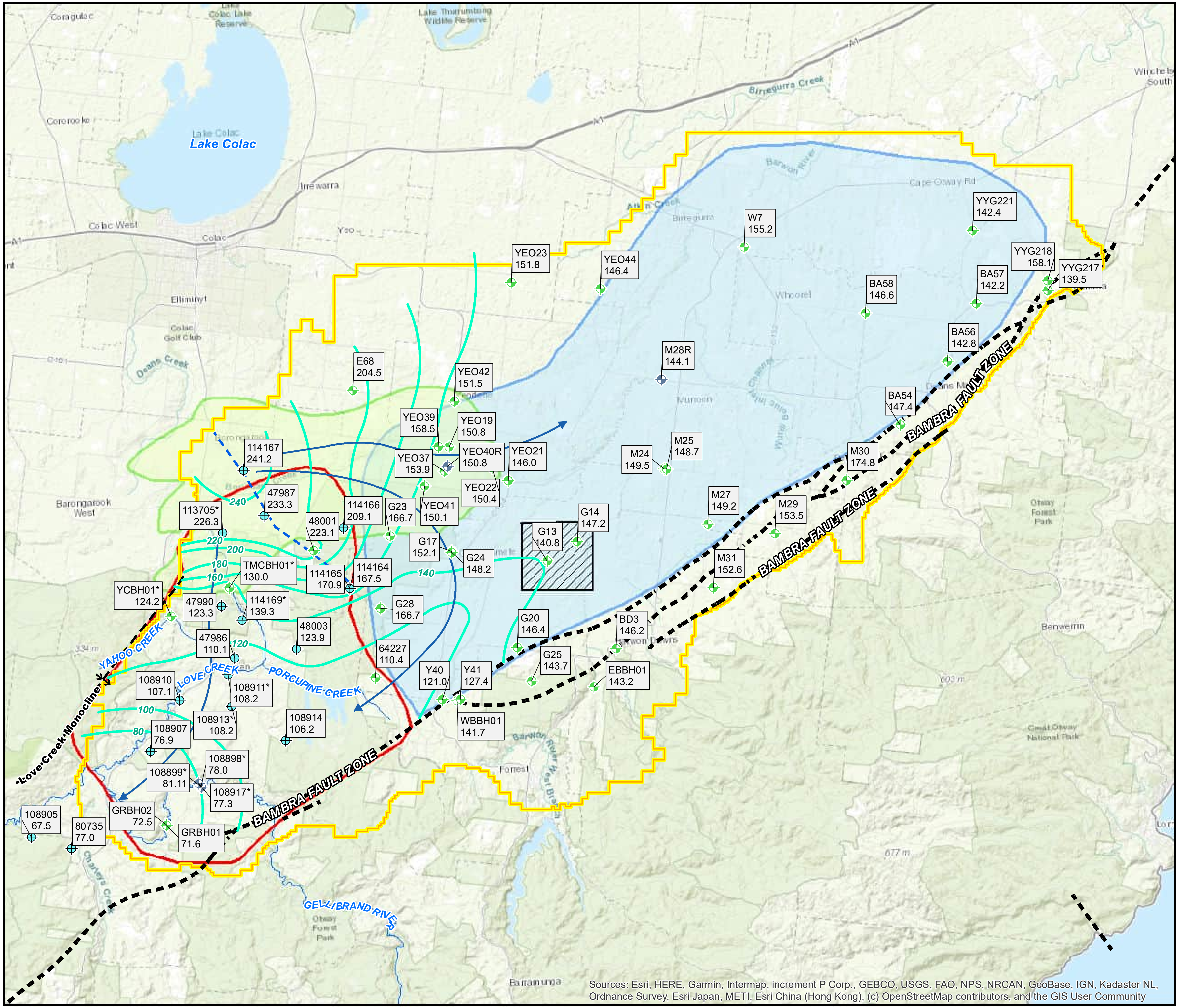
POTENTIOMETRIC SURFACE CONTOURS – LTA (MAY 2010)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F17

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig17_LTA_Surface_May2010.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Barwon Water Borefield
- Watercourse

Structural Features

- Monocline
- Geological Faults

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD)(May, 2022)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Well ID
RWL mAHD

Note:
* Indicates potentiometric surface value taken from nearest available date to May 2022

N

0 1 2 3 4 5
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

POTENTIOMETRIC SURFACE CONTOURS – LTA (MAY 2022)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F18

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig18_LTA_Surface_May2021.mxd.mxd

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Watercourse

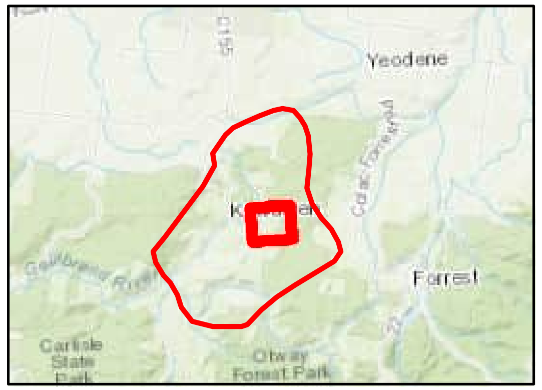
Spring Locations (surveyed and anecdotal)

- Private Spring Location (M. Calvert)
- Private Spring Location (community survey)
- Private Spring Location (SKM 2012)
- Surveyed Spring Location (SKM 2012)

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Gellibrand Marl Formation - Heytesbury Group

Note: Modified surface geology nomenclature.



Service Layer Credits: 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
M. Gardiner, Otway Book 53C, Local Knowledge of Springs (Draft)

N

0 80 160 240 320 400
Metres

1:8,000 when printed at A3
GDA 1994 MGA Zone 54
Imagery: Nearmap 2019

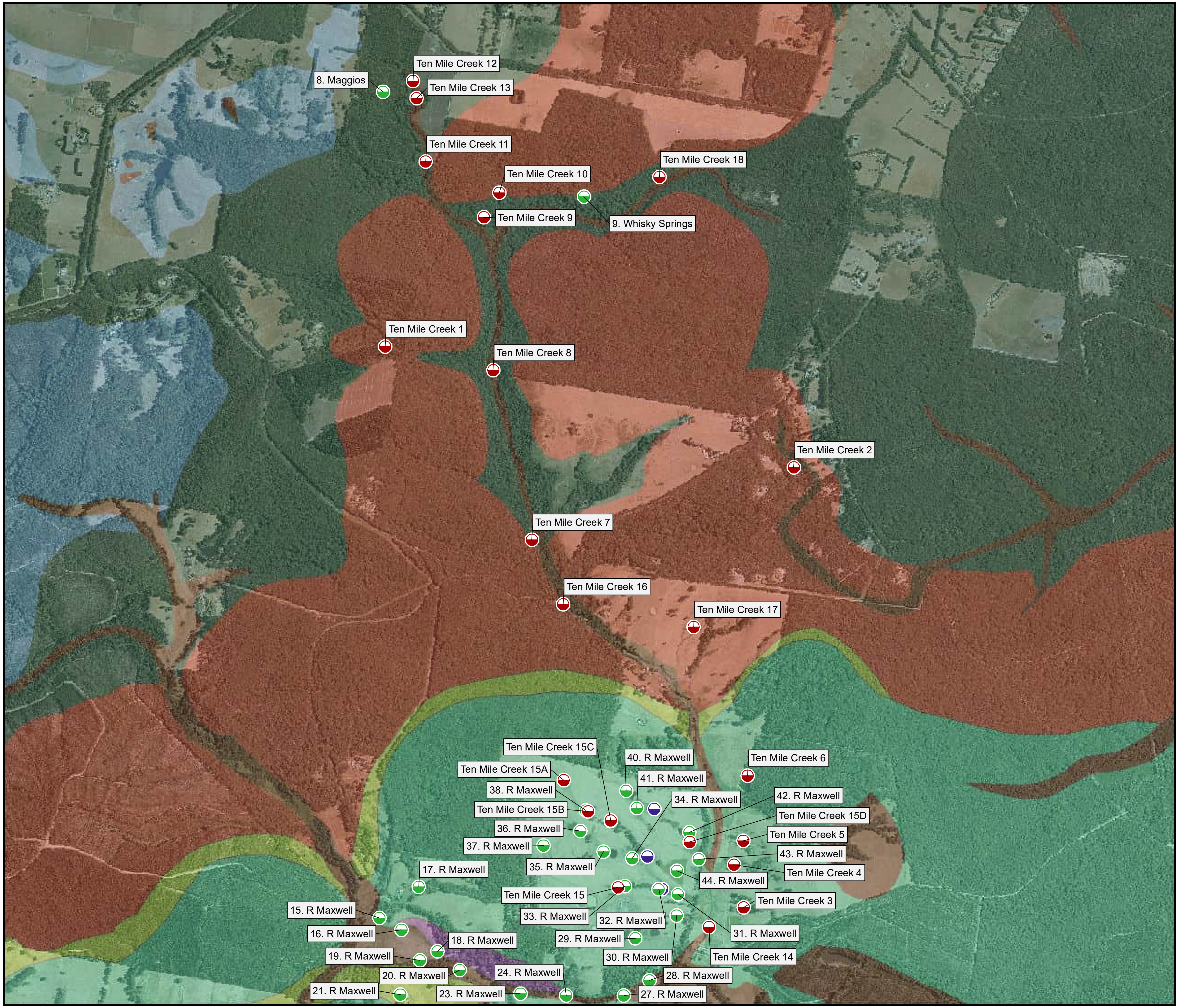
MAPPED SPRINGS (PORCUPINE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kawarren Sub-basin

Figure
F19

Kawarren Sub-basin
Barwon Water

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig19_Springs_PorcupineCrk.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Spring Locations (surveyed and anecdotal)

- Private Spring Location (community survey)
- Private Spring Location (SKM 2012)
- Surveyed Spring Location (SKM 2012)

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation } Heytesbury Group
- Older Volcanics } Heytesbury Group
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
- Otway Group

Note: Modified surface geology nomenclature.

Service Layer Credits: 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
M. Gardiner, Otway Book 53C, Local Knowledge of Springs (Draft)

N

0 200 400 600 800 1,000
Metres
1:20,000 when printed at A3
GDA 1994 MGA Zone 54
Imagery: Nearmap 2019

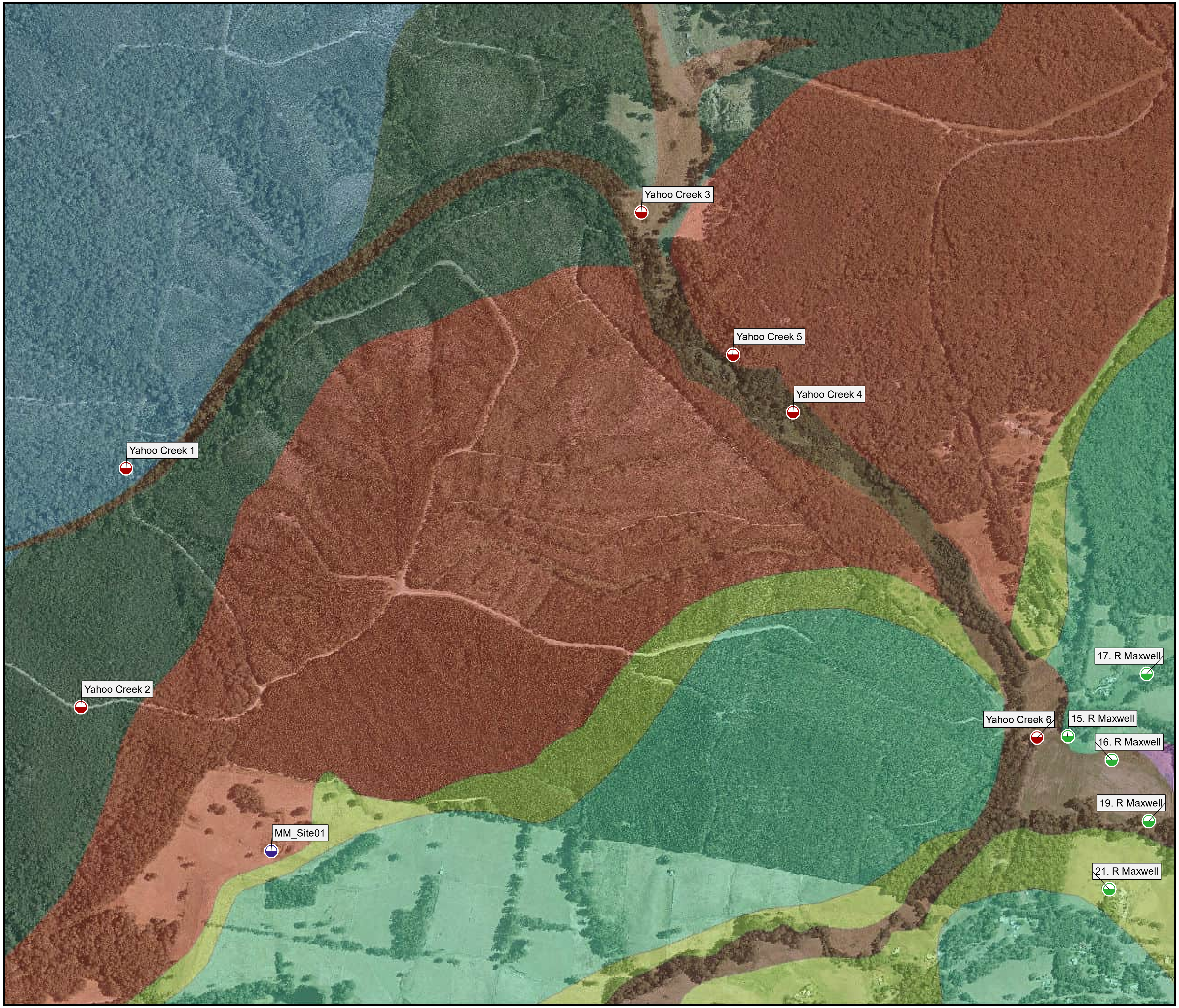
MAPPED SPRINGS (TEN MILE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F20

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig20_Springs_TenMileCrk.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

Legend

Spring Locations (surveyed and anecdotal)

- Private Spring Location (community survey)
- Private Spring Location (SKM 2012)
- Surveyed Spring Location (SKM 2012)

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation } Heytesbury Group
- Older Volcanics } Heytesbury Group
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
- Otway Group

Note: Modified surface geology nomenclature.

Service Layer Credits: 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
M. Gardiner, Otway Book 53C, Local Knowledge of Springs (Draft)

N

0 100 200 300 400 500
Metres

1:10,000 when printed at A3
GDA 1994 MGA Zone 54
Imagery: Nearmap 2019

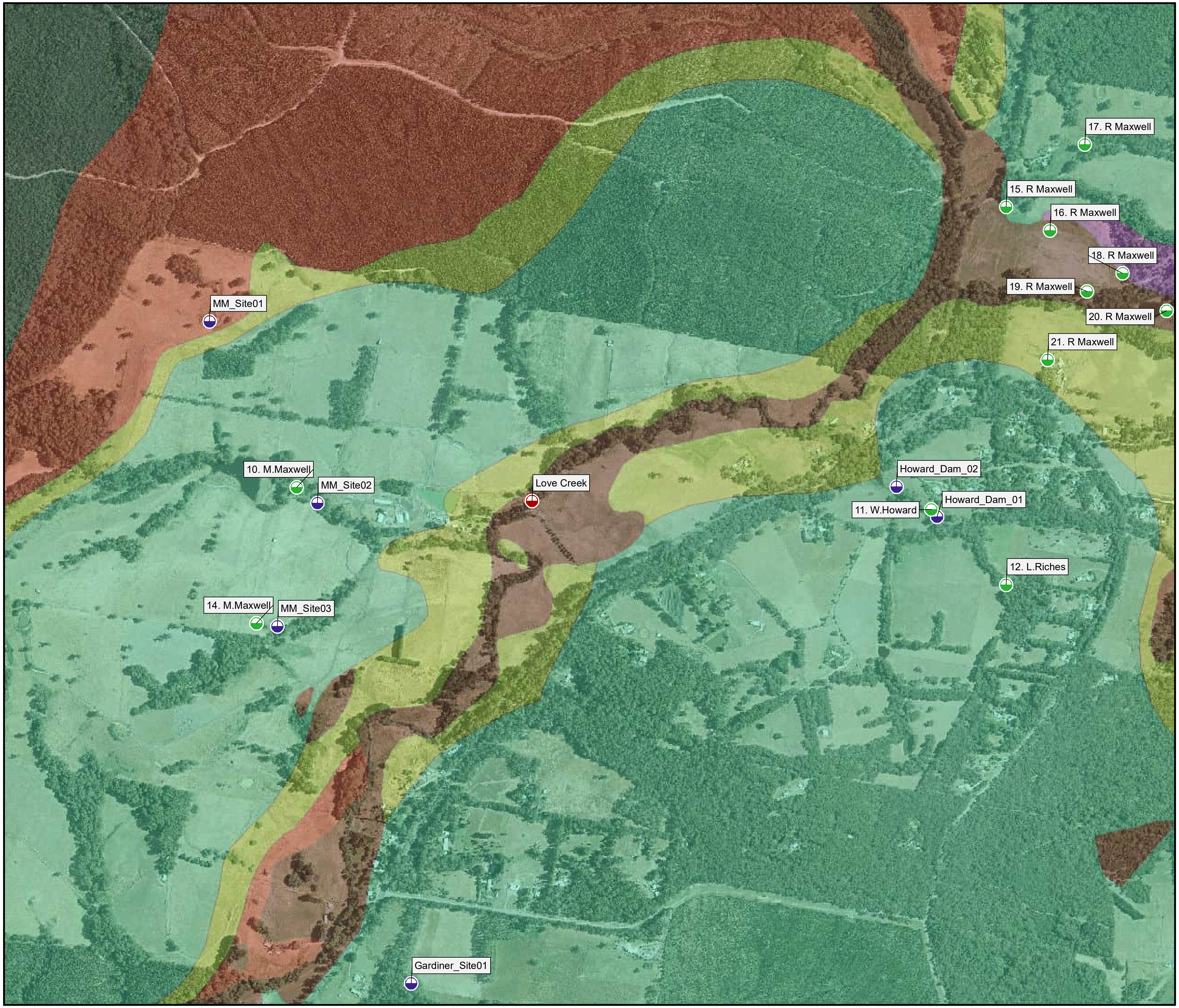
MAPPED SPRINGS (YAHOO CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F21

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig21_Springs_YahooCrk.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Spring Locations (surveyed and anecdotal)

- Private Spring Location (community survey)
- Private Spring Location (SKM 2012)
- Surveyed Spring Location (SKM 2012)

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation } Heytesbury Group
- Older Volcanics } Heytesbury Group
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)

Note: Modified surface geology nomenclature.

Service Layer Credits: 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
M. Gardiner, Otway Book 53C, Local Knowledge of Springs (Draft)

N

0 100 200 300 400 500
Metres
1:10,000 when printed at A3
GDA 1994 MGA Zone 54
Imagery: Nearmap 2019

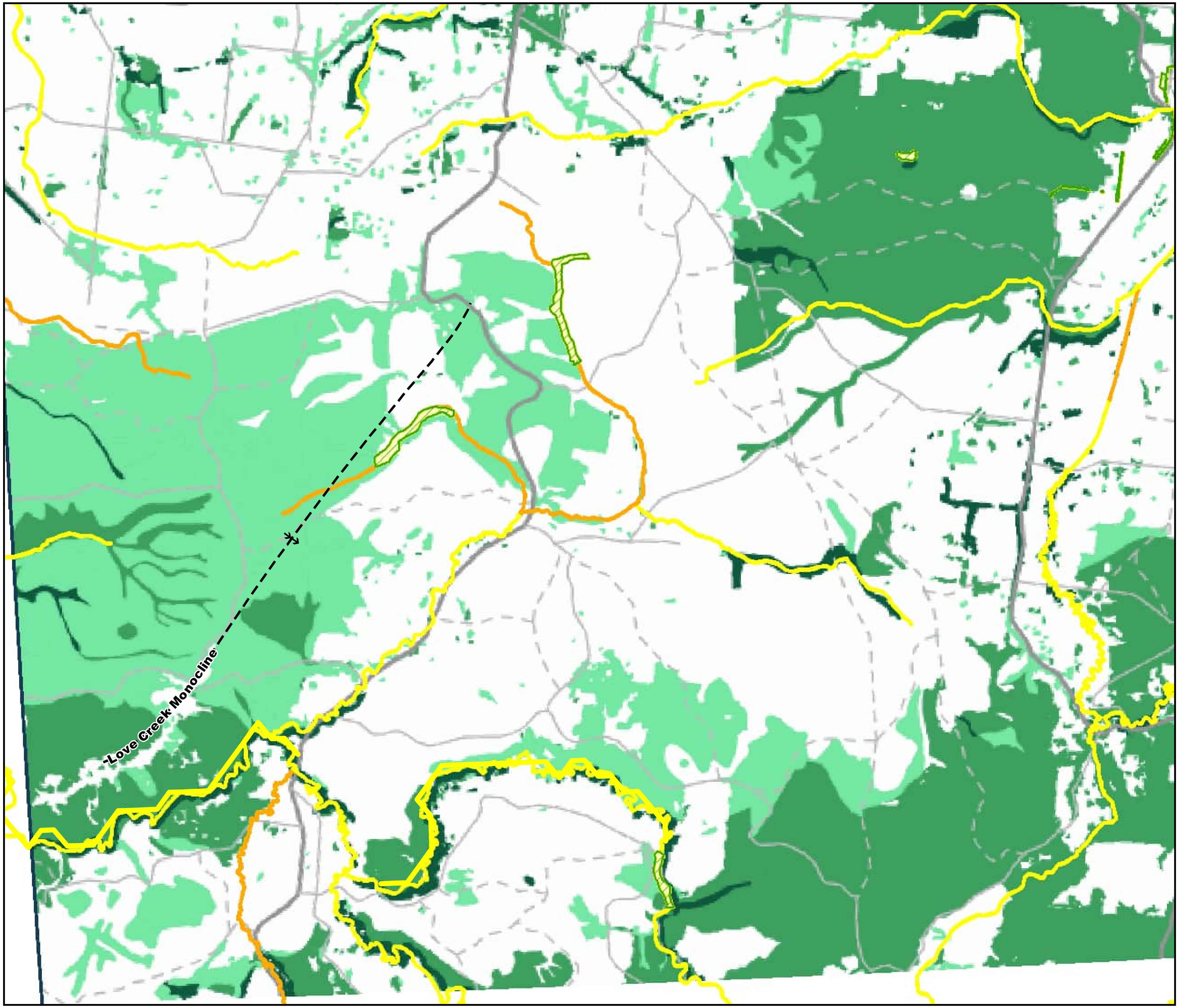
MAPPED SPRINGS (LOVE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F22

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig22_Springs_LoveCrk.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Structural Features
Monocline

Validated Vegetation
Native - remnant

GDE Likelihood of Vegetation
High

Likelihood of Groundwater Interaction (DELWP 2018b)
High
Moderate

Terrestrial GDE
Known GDE (regional study)
High potential GDE (regional study)
Moderate potential GDE (regional study)
Low potential GDE (regional study)
Unclassified potential GDE (regional study)
High potential GDE (national assessment)
Moderate potential GDE (national assessment)
Low potential GDE (national assessment)
Unclassified potential GDE (national assessment)

Service Layer Credits: Bureau of Meteorology, Geoscience Australia and State/Territory lead water agencies.

N

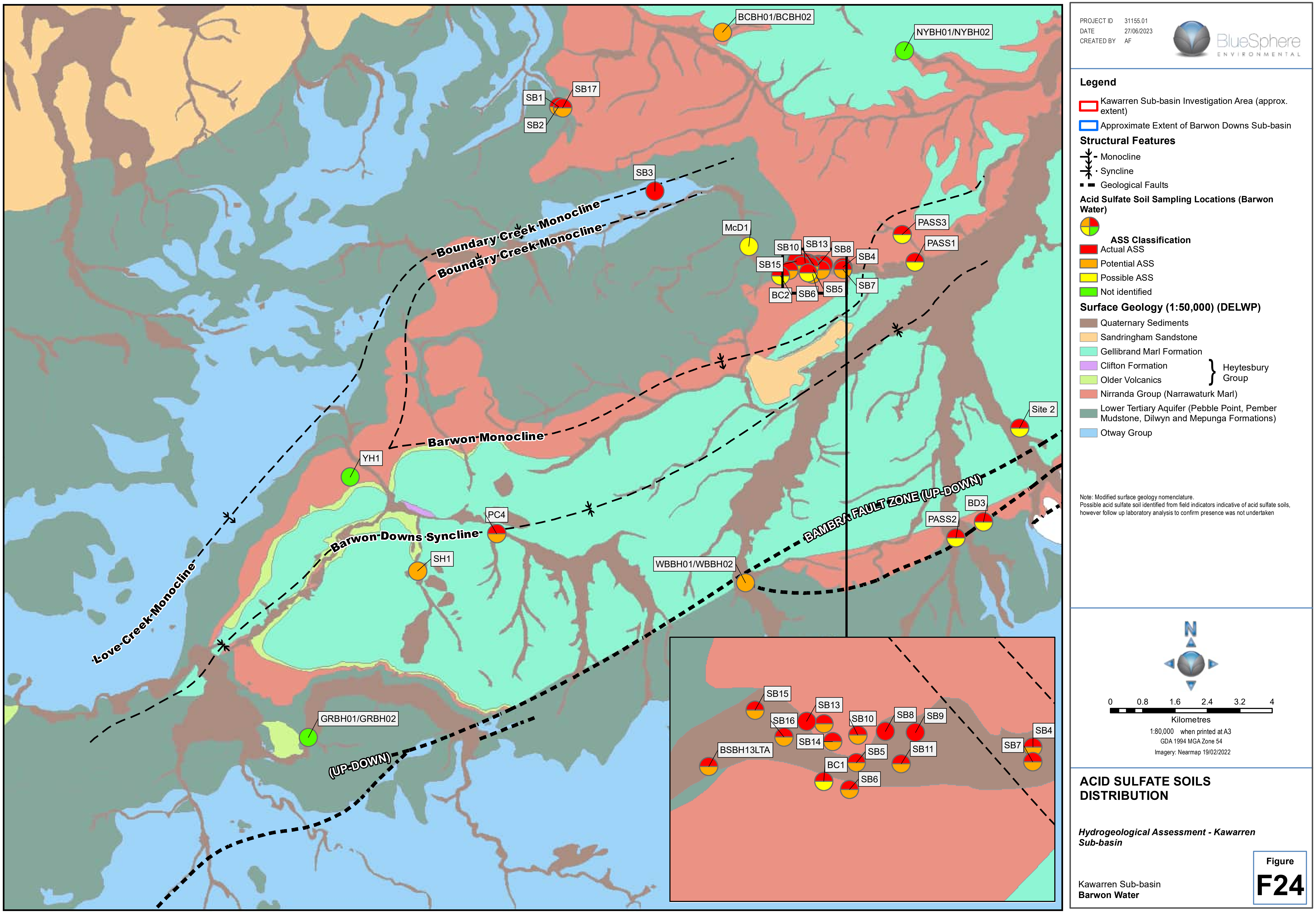
0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

GROUNDWATER DEPENDENT ECOSYSTEMS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F23



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

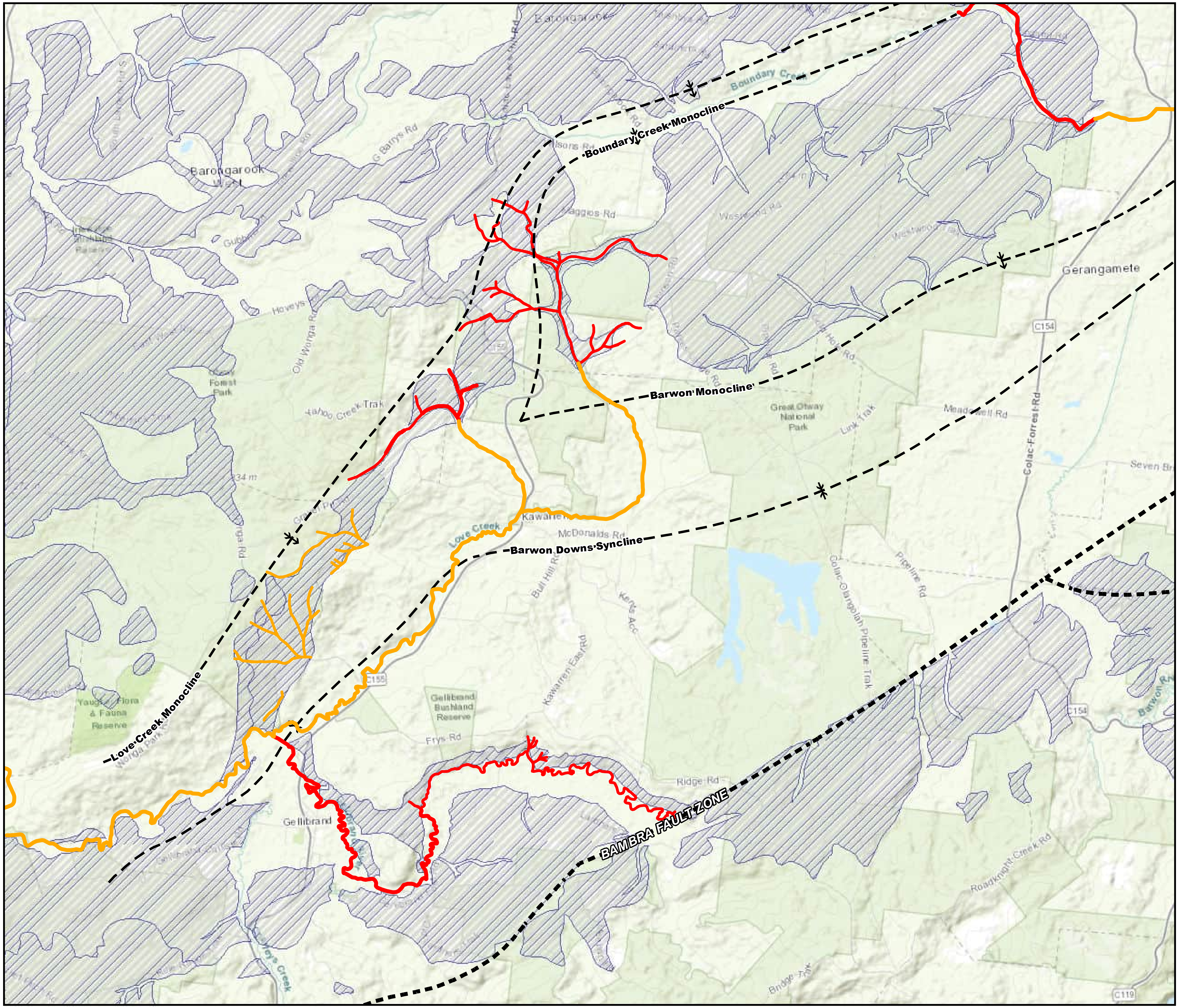
ACID SULFATE SOILS DISTRIBUTION

Hydrogeological Assessment - Kawarren Sub-basin

Figure **F24**

Kawarren Sub-basin
Barwon Water

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig24_ASS.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- LTA (Pebble Point, Dilywn and Mepunga Sands Formations)
- Primary Susceptible Water Features
- Secondary Susceptible Water Features

Structural Features

- Monocline
- Syncline
- Geological Faults

Site Code
Change in WL (Nov 1997-Nov2013)

N

0 0.6 1.2 1.8 2.4 3
Kilometres

1:60,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

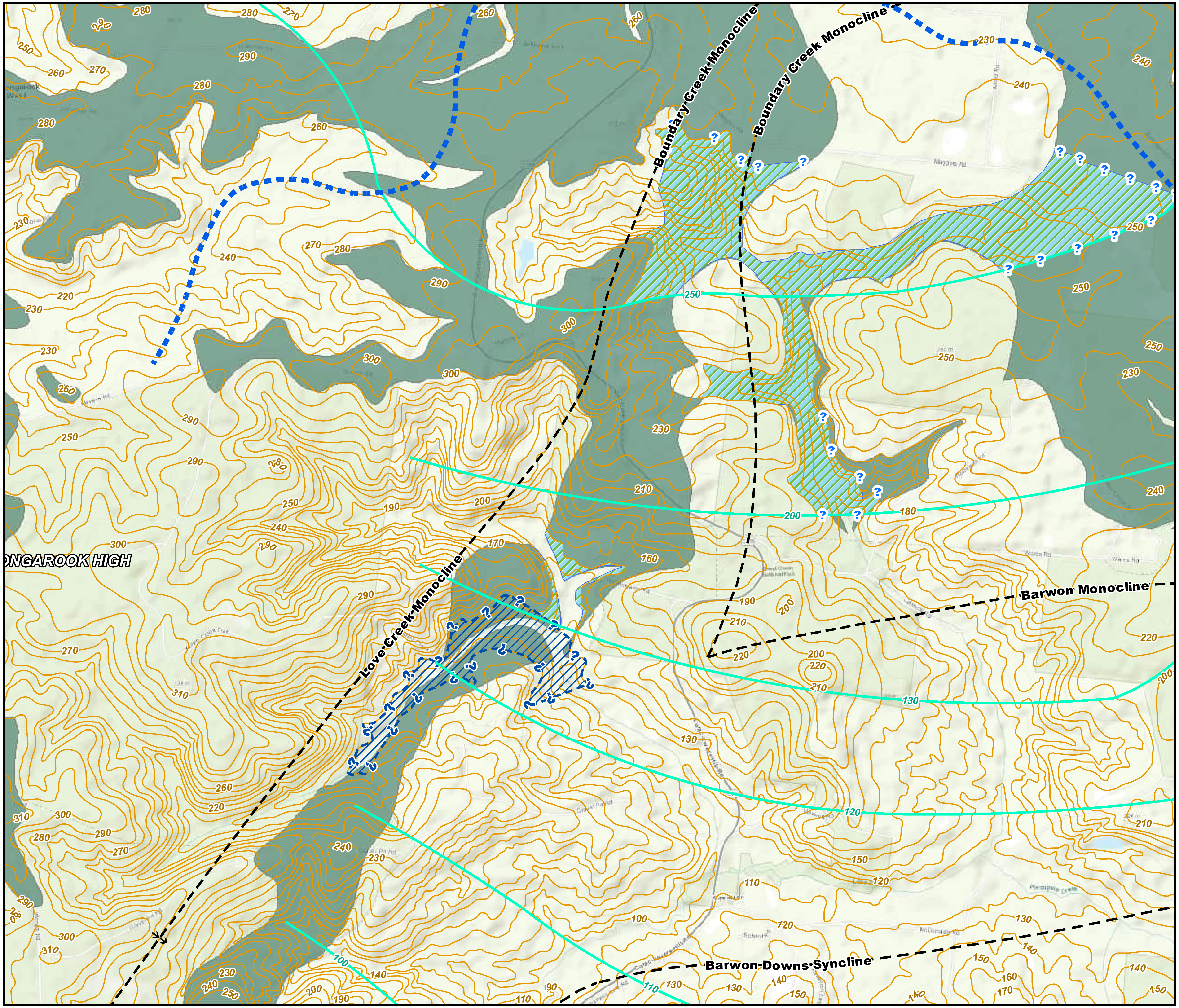
WATER LEVEL CHANGE IN KAWARREN SUB-BASIN INVESTIGATION AREA: 1997 - 2013

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F25

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig25_HydroReview.mxd.mxd



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Expected Groundwater Discharge (LTA)
- Expected Groundwater Discharge (LTA) (Low certainty as to extent)
- LTA Outcrops - Expected LTA Recharge
- Regional Elevation Contours (mAHD)
- LTA Potentiometric Surface (m AHD) (Leonard, 1983)
- Groundwater Divide

Structual Features

- Monocline
- Syncline

Service Layer Credits: 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

N

0 0.25 0.5 0.75 1 1.25
Kilometres
1:25,000 when printed at A3
GDA 1994 MGA Zone 55

EXPECTED RECHARGE AND DISCHARGE AREAS - LTA

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F26

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_Fig26_Discharge.mxd.mxd

Appendix A

Section 78 Notice

Southern Rural Water
Managing Water. Serving Communities.

MINISTERIAL NOTICE

Issued pursuant to Section 78 of the Water Act 1989

<table>
<tr><td>Issued to:</td><td>Barwon Region Water Corporation (Barwon Water)</td></tr>
<tr><td>Property Address (the Property):</td><td>
<table>
<tr><td>BW asset name</td><td>Bore ID</td><td>Address</td></tr>
<tr><td>GW4</td><td>64248</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
<tr><td>GW2a</td><td>64246</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
<tr><td>GW6</td><td>S56301/01</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
<tr><td>GW5</td><td>64245</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
<tr><td>GW8</td><td>S56301/02</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
<tr><td>GW3</td><td>64247</td><td>Dewing Bridge Road, Gerangamete VIC 3243</td></tr>
</table>
</td></tr>
<tr><td>Property Description:</td><td>Gerangamete Groundwater Field</td></tr>
<tr><td>Licence Number:</td><td>BEE032496</td></tr>
<tr><td>Legal Reference:</td><td>Water Act 1989 (Vic) s.78</td></tr>
</table>

Trevor McDevitt (Delegate)
Manager Applications
Groundwater & Rivers

11/9/2018.
Date Notice Issued

Preamble

Who we are: Southern Rural Water (SRW) is a government-owned statutory Corporation, governed by a skill based Board appointed by the Minister for Water as outlined in "Water Corporations and Former Water Authorities" outlined in Column 1 Schedule 1 of the *Water Act 1989* (Vic).

Our purpose: The Groundwater & Rivers Group within SRW services over 8,000 groundwater and river users across southern Victoria in a region stretching from the SA border to the NSW border south of the Dividing Range. This function includes managing licences and ensuring compliance to protect the resource, the environment and other users as outlined in the purposes of the *Water Act 1989* (Vic).

Why we serve Section 78 directions: SRW is acting as a delegate of the Minister for Water. The Minister for Water may, by notice in writing direct the occupier of any works on a waterway or of a bore-

- To operate or alter those works in compliance with the conditions specified in the notice;
- To take measures specified in the notice; being measures that the Minister thinks necessary to protect the environment, including the riverine and riparian environment

What happens if you do not comply: The occupier of works or of a bore must comply with any direction given under section 78. Penalty provisions are described in Section 3 of this notice.

What to do if you need more time: Make a formal request to SRW giving reasons for any extension and providing at least 7 days notice prior to the compliance date.

What are your appeal rights: If you feel you are affected by a decision under the *Water Act 1989* (Vic) an application for review of the decision can be made to the Victorian Civil and Administrative Tribunal (VCAT) within 28 days of receipt of the decision.

Southern Rural Water
Managing Water. Serving Communities.

Notice structure

1. Background and reasoning

This section outlines background and reasoning that led to the issuing of the s78 notice.

2. Requirements of the notice

Considering the view that has been formed, this section lists the requirements or actions to address the environmental risk(s) or impact(s).

3. Penalty Provisions

Outlines the penalty provisions should there be failure to comply.

1. Background and reasoning

1.1 The Minister for Water, the Hon Lisa Neville wrote to SRW on 7 August 2018 requiring SRW, as a delegate, issue a notice (under Section 78 of the *Water Act 1989* (Vic)) requiring Barwon Water to:

a) continue no extraction, other than for maintenance and emergency response, and
b) prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and
c) describe the environmental outcomes for the waterways to be achieved by the remediation plan.

1.2 It is acknowledged that:

a) Barwon Water has operated the Barwon Downs Borefield under groundwater extraction licence BEE032496. Barwon Water has undertaken a monitoring and assessment program over the past six years, with input from a Community Reference Group, to improve the understanding of the impacts of operation of the borefield.
b) Barwon Water has been working to address confirmed impacts and has commenced the development of a remediation plan for Boundary Creek and Big Swamp with input from community, stakeholders and independent technical experts nominated by the community and stakeholders.

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

1.4 A further report commissioned by Barwon Water titled "*2016-2017 Technical Works Program Yeodene Swamp Study*" (Jacobs, November 2017) found that the current groundwater licence condition requiring the release of the 2 ML/d of supplementary flow into Boundary Creek has not been effective at offsetting the impacts of operation of the borefield on groundwater base flows in Boundary Creek.

1.5 This led to the swamp drying, acid sulphate soils being generated and the release of acid water downstream of the swamp and impacting the downstream environment.

1.6 On this basis, and considering the observations previously stated, I have formed a view and I am satisfied that a process or activity which is being/or has been carried out at the property has caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment and legal enforcement of protective works is required under s78(1).

2. Requirements of the notice

Barwon Water must undertake the following requirements.

2.1 Barwon Water must not extract from the works for any purpose other than maintenance or emergency access until this notice is rescinded (as defined by the requirements outlined in section 2.11 of this notice).

For the purpose of this notice, emergency access is defined as circumstances resulting in the need for Barwon Water to declare a water shortage under s33AAA of the Water Act 1989. Under these circumstances Barwon Water should notify SRW of their intention to make this application to the Minister.

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

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

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

2.5 By 20 December 2019 Barwon Water must submit to SRW the Plan which includes:

a) A description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment; this will include:
- Hydrogeological conditions (groundwater levels and quality)
- Hydrology (Surface water quality and flow monitoring)
- Ecological assessment
- LIDAR topographic mapping
- Results of soil sampling program (Soil chemistry, peat profile, incubation tests)
- Additional matters arising from the scope contemplated in Item 2.4.

b) An outline and risk assessment of the processes/activities on the Property which may impact on Boundary Creek, Big Swamp and the surrounding environment (including, but not limited to hydrogeology, hydrology and soil chemistry);
c) A range of controls and actions that could be practicably carried out to protect and improve the condition of Boundary Creek and Big Swamp and the surrounding environment, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;
d) A comprehensive risk assessment of proposed controls and actions documented in c);
e) The controls and actions to be implemented, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;
f) A monitoring program to check the controls and actions documented in e);
g) Contingency measures designed to address any issues identified from monitoring results;
h) A schedule of timeframes by which the controls and actions documented in e) will be carried out; and
i) A reporting schedule, whereby Barwon Water will provide a minimum of quarterly updates to SRW which report on the progress of the Plan, as well as an Annual Report. The Annual Report must be submitted to SRW and made publicly available by 30 September each year.

2.6 In preparing both the scope of works and the Plan, Barwon Water must:
a) Identify all appropriate hydrogeological, hydrological and geochemical assessments to support the development of the Plan (during the scope of works process);
b) Carry out appropriate hydrogeological, hydrological and geochemical assessments to support the assumptions, controls, actions and targets described in the scope of works (during the development of the Plan);
c) Provide quarterly updates on progress to SRW;
d) Consult with the Corangamite Catchment Management Authority;
e) Consult with the SRW appointed Expert Reviewer;
f) Engage with the local community to seek their ideas and feedback;
g) Ensure the State Environmental Protection Policy (Victorian Waters) are considered and;
h) Present each of the points in 2.5 under separate headings (in the Plan).

2.7 Barwon Water must submit the scope of works and the Plan prepared in accordance with this notice to SRW for review by the independent expert or panel of experts (Expert Reviewer) appointed by SRW. SRW will consider the advice provided by the Expert Reviewer in order to:
a) Confirm any changes to the Plan that are required to be made by Barwon Water;
b) Confirm and accept the scientific methodology used to prepare the Plan; and
c) Verify and accept the preferred controls and actions presented in the Plan.

2.8 If requested under Section 2.7(a), Barwon Water shall update the Plan and resubmit it under Section 2.7 for review by the Expert Reviewer appointed by SRW. Note that this resubmission process can occur on more than one occasion until it is accepted by SRW under Section 2.9.

2.9 Upon acceptance of the Plan by SRW, Barwon Water must finalise the Plan (Including any changes required by SRW) by 1 March 2020 and implement the Plan. Nothing in this clause prevents earlier implementation.

2.10 Timelines may be varied by SRW, at our discretion or upon request, in order to achieve compliance with the nominated objectives.

2.11 This notice will remain in effect until such time that Barwon Water can demonstrate to the satisfaction of SRW that the Plan has been implemented and the measures and outcomes have been achieved as outlined in section 2.5.

2.12 Further to Section 2.11 in order to resume extracting groundwater pursuant to the conditions on Licence Number BEE032496 Barwon Water must:

a) seek express written permission from SRW; and
b) provide sufficient scientific evidence to support the request.

3. Penalty Provisions

3.1 Failure to comply with this notice is an offence – 20 penalty units, calculated at the time of the offence.

3.2 If you fail to comply with this direction the Minister may arrange to carry out the works and recover costs from the occupier.

Appendix B

Previous Investigation Report Summaries

Item	Details
Ministerial Notice, Issued pursuant to Section 78 of the Water Act 1989, Licence Number: BEE032496, 11 September 2018	
Scope of Work	N/A
Key Findings	On 7 August 2018 the notice was issued requiring Barwon Water to: *a) Continue no extraction, other than for maintenance and emergency response, and* *b) Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and* c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.* • A report (Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts, Jacobs June, 2017) found that the operation of the borefield over 30 years was responsible for 2/3 of the reduction of groundwater base flow into Boundary Creek. • An additional report (2016-2017 Technical Works Program Yeodene Swamp Study, Jacobs, November 2017) indicated the licence condition requiring the release of 2 ML/d of supplementary flow into Boundary Creek had not been effective at off setting the impacts of the borefield operation on groundwater base flows in Boundary Creek. This resulted in the creek drying out, generation of acid sulfate soils and release of acid water into downstream systems. • SRW (acting on behalf of the Minister) formed the view that the borefield had caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment. • Barwon Water was required to prepare and implement the '*Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan*'. Which was to (among others) include: – Identification of appropriate hydrogeological, hydrological and geochemical assessments to support the plan; – Consult with CCMA; – Consult with SRW appointed expert reviewer; and – Engage with the local community and seek ideas and feedback. • The notice remains in effect until Barwon Water can demonstrate to satisfaction of SRW that the plan has been implemented and measures and outcomes (per Section 2.5 of the document) have been achieved.
Barwon Water, 2019, Boundary Creek, Big Swamp and surrounding environment – Remediation and Environmental Protection Plan, December 2019	
Scope of Work	Preparation of REPP to address and meet the requirements of the section 78 Ministerial Notice.
Key Findings	The following findings were noted regarding Boundary Creek and Big Swamp. • Barwon Water was issued with a groundwater extraction license in 1975. Groundwater extraction did not occur until 1982. The borefield was used intermittently to supplement water supply during dry periods between 1982 and 2016. Pumping primarily between 1998-1989, 1997 – 2001, 2005 – 2010 and 2016 – 2017. ~119,000 ML extracted from borefield between 1982 and 2016/17. • Licence renewal process in 2002. Amended in 2004 to accommodate environmental provisions such as release of 2 ML/day of supplementary flows. • 2017 Barwon Water acknowledged groundwater pumping activities had resulted in environmentally significant impacts to the Boundary Creek catchment. BW withdrew application to extend groundwater extraction licence.

Item	Details
	• May 2018 a community and stakeholder working group was established by Barwon Water to participate in the development of the REPP. • Two objectives working in parallel: – Boundary Creek & Big Swamp RP – address remediation of confirmed impact in Boundary Creek Catchment. – Surrounding Environment Investigation – to investigate if other areas within regional groundwater system have been impacted by extraction. • Permissive Consumptive Volume set for Gerangamete and Gellibrand Groundwater Management Areas by Minister for Water. • Numerical groundwater model initially developed in 1994 by BW which has evolved. 2019 the model was used to assess historical impacts of pumping and identify potential high risk areas. The layers modelled included: Layer 1: Gellibrand Marl; Layer 2: Clifton Formation; Layer 3: Narrawaturk Marl; Layer 4: Dilwyn Formation; Layer 5: Pember Mudstone; Layer 6: Pebble Point Formation; Layer 7: Basement. Model had a Scaled Root Mean Square error of 4.9%. • Resulted in identifying eight high risk areas: – Boundary Creek b/w McDonalds Dam and Big Swamp; – Barwon River (East branch); – Barwon River (downstream of the confluence); – Gellibrand River and associated GDEs; – Ten Mile Creek; – Yahoo Creek; – GDEs west of the Barwon River (near Yeodene); and – GDEs east of the Barwon River (b/w Barwon Downs and Yeodene). • Big Swamp is also known as Yeodene Swamp covers an area of ~11 hectares and is understood to be a GDE. • Boundary Creek was divided into three reaches as shown on Figure 6 (Barwon Water, 2019). Reach 1 includes a private dam on-stream (160 ML) constructed in 1979. Reach 2 downstream of the private dam and the end of Big Swamp. Reach 3 is downstream of Big Swamp to the confluence of Boundary Creek and Barwon River. • Investigations have confirmed that drawdown associated with pumping from the Barwon Downs borefield was the main cause of reduction of stream flows within Boundary Creek and Big Swamp. This resulted in a reduction of surface water and groundwater interaction, evaporation and dewatering of Big Swamp and Boundary Creek and oxidation of naturally occurring acid sulfate soils. Reaches 2a, 2b and 2c of Boundary Creek Catchment are only areas at this stage that have shown impacts. • The pumping of groundwater from the borefield contributed to the frequency and duration of no flow periods in Boundary Creek, further the passing flow conditions was not managed effectively. Overall the impacts identified (focus of REPP) were reduction in surface water/groundwater levels; increased occurrence of 'no flow' events; progressive loss of wetland species and increase of other vegetation classes; and oxidation of naturally occurring Acid Sulfate Soil (ASS) (see Figure 8 from (Barwon Water, 2019)). • Remedial actions for Boundary Creek and Big Swamp included: – Cessation of groundwater pumping in LTA; – Use of supplementary flows to maintain minimum flow of 0.5 ML/day in Reach 3 of Boundary Creek; – Construction of hydraulic barriers to distribute flows across swamp to prevent wet-dry cycling; – Infilling of fire trenches and agricultural drain to allow swamp to retain more water over winter months; and

Item	Details
	– Prevent encroachment of dry vegetation classes (e.g. Swamp Gump in the Big Swamp area. • Monitoring plan in Appendix A of REPP. • Investigating approaches to neutralise pH and remove metal and acidity loads including Upstream treatment option involving a semi-passive treatment system using caustic magnesia rock to increase soluble alkalinity; and Downstream treatment option using a sodium hydroxide dosing plant. Completed Surrounding Environment Investigation findings: • Limited data sets for each of the 8 areas. • Information gaps: – *Has historic groundwater pumping activities caused a reduction in baseflow to rivers from the Lower Tertiary Aquifer system (either directly or indirectly)? If so, how much and is it significant?* – *Has historic groundwater pumping caused a decline in water levels in areas where there are high value GDEs? And if so, how much and is it significant?* • Installation of site specific monitoring assets including 212 groundwater bores, 5 stream gauges and 6 new vegetation monitoring sites. • Outcomes of the Surrounding Environment Investigation provided to SRW by 31 July 2023. Technical Response to Notice: • Climatic setting indicates several periods of drought. • High modification of land use in the Boundary Creek catchment has occurred. • Main stratigraphic groups in the area are: – Quaternary sediments; – Sandringham Sandstone; – Heytesbury Group; – Demons Bluff Group; – Nirranda Group (Narrawaturk Marl; Mepunga Fm); – Wangerrip Group (Dilwyn Fm, Eastern View Fm; Wiridjil Gravel; Moomowroong Sand; Pebble Point Fm) and – Otway Group. • Key Aquifers: – Upper Aquifer system (Quaternary alluvium; Sandringham Sandstone; Gellibrand Marl & Clifton Fm); – Lower mid-Tertiary Aquitard: (Demons Bluff Group & Narrawaturk Marl); – Lower Tertiary Aquifer (Mepunga Fm & Wangerrip Group – primarily Mepunga, Dilwyn and Pebble Point formations; and – Basement (Otway Group). • Water levels in Reach 2a and Reach 2b of Boundary Creek (underlain by LTA) dropped by up to 14.7 m b/w 1987 and 2012. • Model considered to overestimate losses associated with impact of pumping. • Aquifer properties of bores installed in and around Big Swamp presented in Table 13 of REPP. • Acid sulfate soils within Big Swamp are variable. Elevated concentrations of existing acidity are relatively high in the upper soil profile (2 m >0.5%) while the potential acidity are low (0.1%S) in the upper profile but increase with depth (>2%S below 1.5 m). Table 15 in REPP provides potential acidity with depth of soils from installed groundwater bores.

Item	Details
	• Big Swamp has had a significant reduction/change in vegetation cover and type over the past 30 years.
Blake, W.J.R., 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area (unpublished)	
Scope	Study of the groundwater resources of the Otway Ranges. Study of the recharge areas of the Lower Tertiary Aquifers on flanks of the Otway Ranges to potentially develop the area as a water supply supplement for Geelong Waterworks and Sewerage Trust (now Barwon Water). Works included: • Drilling bores for both stratigraphic and hydrogeologic purposes (15 bores); and • Interpretation of magnetic, gravity and seismic data.

Key Findings	• Barwon Downs basin is the area between the Otway uplifted block and the Barongarook uplifted block in the eastern end of the Otway Basin. The Otway basin is delineated by a series of North-East/South-West trending faults.
	• Barwon Downs graben has a sediment thickness (based on gravity data) of approximately 12,000' (~3,658 m). Faulting took place while sediments were being deposited.
	• Four sedimentary cycles occurred between Upper Cretaceous to Middle Miocene. First two characterised by *quartz-clastic, deltaic sedimentation separated by a marine transgression in the middle Paleocene* (i.e. Wangerrip Group). Third and fourth characterised by limestone-marl shelf deposition, separated by a minor regression-transgression in upper Oligocene (ie. Nirranda Group and Heytesbury Group.
	• Pebble Point Formation (upper cretaceous deltaic sediments) absent in Barwon Downs.
	• Barwon Downs basin ~196 square miles, with approximately 46 sq. miles identified as intake or potential intake area – defined by outcrop of Dilwyn Formation. ~150 sq. miles is the estimated area of confined aquifer.
	• The Dilwyn Formation was considered main aquifer, within the sands. Sands are described as fine to medium grained, poorly to moderately sorted with moderate permeability (based on pump test). Thickest section of Dilwyn Fm. encountered at Yeo 16 bore (~600' / 183 m), with coarser sands than at Barwon Downs graben. Dilwyn Fm thicker on north western edge of graben than on south eastern edge.
	• Mepunga Formation – unlikely to exceed 100' (30.5 m) thickness.
	• Main recharge (intake) area was on Barongarook High where Dilwyn Fm outcrops, in areas where sands outcropped. Dilwyn Fm also comprised of silts, ligneous clays, clays and minor coals.
	• Recharge also occurs along southern edge of graben from Barwon downs – Forrest area to Gellibrand.
	• Groundwater flows in two directions:
	  – Southwest to Gellibrand River.
	  – East and north east towards Bambra Fault
	• Estimated to be ~4 mill. gals/day flowing through aquifer in SW direction. Estimated to be 1-2 mill.gals/day flowing through aquifer in north /north east direction.
	• Salinity of GW in Dilwyn Fm ranged between 250 mg/L – 350 mg/L. Total iron concentration ~20 mg/L (although samples sat for several weeks before analysis).
	• Mepunga Fm salinity ~201 mg/L, iron ~34 mg/L.

Leonard, J.G., Lakey, R.C., and Blake, W.R., 1983, Hydrogeological Investigation and Assessment, Barwon Downs Graben, Otway Basin, Victoria, Unpublished.	

<table>
<tr><th>Item</th><th>Details</th></tr>
<tr><td>Scope</td><td></td></tr>
<tr><td>Key Findings</td><td>
Seismic and gravity data indicated the Otway Group basement is block faulted and tilted to form half grabens. Some faults extend subsurface. The faults are often expressed as monoclines. The Barwon Downs Graben contains major aquifers.
Major aquifers occur in basal Tertiary units including Pebble Point, Dilwyn and Mepunga Formations. Pebble Point Fm is confined between the Otway Grp and Pember Mudstone.
Dilwyn and Mepunga Formations considered to be in direct connection and referred to as one aquifer. Vary between confined to semi-confined aquifer. Unconfined where it outcrops at Barongarook High.
Drill findings indicated presence of valley like features either side of the Yeo Dome. Valleys have been infilled by Tertiary aged sediments. On the western side of the Yeo Dome, the valley runs approximately south-north from Kawarren to Barongarook (identified as Kawarren recharge avenue). Considered to provide important recharge pathways from outcropping of aquifer on Barongarook High to the confined aquifer system.
Potentiometric surface for the TA showed the outcrops of Dilwyn Fm acted as a recharge area. Groundwater flows to the south west from the Barongarook High towards Gellibrand River.
Estimations indicated ~14,800 ML/annum flow off the Barongarook High into the TA in Barwon Downs Graben, split Kawarren recharge avenue ~8,500 ML and Yeodene recharge avenue (6,300 ML). Combined the recharge avenues provide ~12,000 ML/annum of recharge to Gellibrand River Catchment.
Effective infiltration rate of 27.4 cm/annum on the Barongarook High was considered too high a rate. Works indicated a structural or stratigraphic barrier within Barwon Downs graben between the borefield and Kawarren which reduced the south-westerly flow from the Yeodene recharge area.
Elastic storage calculated to be ~15,000 ML.
Unconfined storage calculated to be ~5,920,000 ML.
Additional sources of recharge (outside of Barongarook High) to borefield after development included:

Enhanced natural recharge as a result of lowered water levels;
Induced stream bed infiltration as water levels fall below stream level;
Leakage form overlying marl members;
Leakage from clay and silt layers within the TA;
Leakage from Otway Group rocks underlying and flanking grabens; and
Natural recharge from possible (not delineated) recharge zones along Bambra Fault and other structures.

Pumping of borefield projected to start February 1983. Consisted of three bores, combined daily extraction of 35 ML. with a maximum of 12,500 ML in any one year and up to 80,000 ML over a 10 year period.
A second borefield proposed/under consideration pending further pumping test results.
If recharge calculations were correct the annual extraction allowance would exceed the recharge from Yeodene recharge avenue.
</td></tr>
<tr><th colspan="2">Lakey 1983, GSV Gellibrand Groundwater Investigation – Kawarren Pumping Test Report</th></tr>
<tr><td>Scope</td><td>Pumping test on Yaugher 51 bore to determine hydraulic characteristics of Dilwyn Formation and Mepunga Formation to inform possible construction of borefield in Kawarren area.</td></tr>
<tr><td>Key Findings</td><td>Yaugher 51 bore not installed within the Pebble Point Formation.</td></tr>
</table>

Item	Details
	• Both Dilwyn and Mepunga Formations were found to not comprise a homogeneous aquifer. Slow and incomplete recovery considered due to '*partial and permanent collapse of aquifer skeleton resulting from depressurising the system from its pristine and possibly slightly over-pressured system*'. Similar residual drawdowns observed in Barwon Downs borefield – potentially due to same issue. • An area of concern in relation to the development of a borefield in the Kawarren area was the impact of reduced water levels on stream flow in Ten Mile Creek and Yahoo Creek, and discharge on the natural springs in the area. Many springs in Kawarren area are fed by the Clifton Formation. • Pumping test indicated that drawdowns will initially stabilise upon recharge from the Gellibrand River and reduction in unconfined storage on the Barongarook high. If pumping exceeds the mean annual recharge of the aquifer then substantial of the unconfined aquifer and further reduction of the confined aquifer storage was considered likely to occur. Although this could be offset by increased streambed infiltration from Gellibrand River. • Recommended installation of stream gauges on Yahoo and Ten Mile Creeks, comprehensive survey of springs in the area and completion of additional pumping tests.
Gellibrand Groundwater Investigation – Stage II Report – August 1983, R Lakey & J Leonard (PDF pg 35 of (Lakey R. , 1984)	
Scope	Draws together all geological and hydrogeological information form investigations completed along western flanks of the Otway Ranges. Investigations completed included geological mapping, geophysical surveys, borehole drilling, wireline logging, aquifer tests, water level monitoring and water quality analysis.
Key Findings	• Determined that there is a faulted contact between the Tertiary sediments and the basement rock (Otway Group). • The Barwon Downs graben pinches out to the south west around Bunker Hill. The graben deepens in the Gellibrand-Kawarren East area due to half grabens associated with Loves Creek and Kawarren Faults (referred to as Gellibrand Depression). Gellibrand Depression forms a corridor which provides interconnection between the Tertiary sediments in the Barwon Downs and Gellibrand areas. • Pebble Point Formation is divided into a lower shaley unit and an upper sandy unit based on gamma ray log interpretation. • Pember Mudstone overlies the Pebble Point Fm. Dominant carbonaceous muds are considered a sub-unit of Dilwyn Fm. • Considered to be vertical leakage given hydraulic head of Pebble Point Fm higher than the Dilwyn-Mepunga Fms. • Basal Tertiary Aquifer (Pebble Point, Dilwyn and Mepunga Fms) thickest along toe of Barwon and Loves Creek faults. Thickest (324m) of the Tertiary aquifer at bore Yeo 5 (south west of Yeodene). • Main sources of recharge to the aquifer in the Barwon Downs graben are from the Barongarook High via Yeodene to the north east and Yeodene to the south west, via Karwarren. Recharge to the aquifer occurs along all outcrop except the component to the north east which is expected to discharge to the Gellibrand River.
HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area, Kawarren Groundwater Resource Evaluation, May 1994.	
Key Findings	• Investigation into the Kawarren Groundwater sub-basin of Barwon Downs graben considered as an area to construct a borefield. • 12 km^2 of the outcropping aquifer material on the Barongarook High acts as a recharge area (out of 28 km^2 outcropping area total).

Item	Details
	• Groundwater primarily moves through a narrow paleo-valley extending northwards from the extracting site at Kawarren towards Barongarook. Approximately 1.5 km wide and 5 km in length, with a thickness of over 100 m of basal Tertiary Eastern View Formation Sediments. • Prominent groundwater divide controls groundwater flow from Barongarook High into the Barwon Downs graben. Local discharge occurs to streams draining the high including Boundary and Ten Mile Creeks. • Considered that sustained pumping would result in reduction of water levels across the high, the groundwater divide would shift and the amount of rejected recharge to the surface water systems, streams and springs would decrease. • Further investigation into the environmental significance of the wetlands and stream was recommended to be completed to establish baseline conditions. • Both Boundary Creek and Ten Mile creek identified as gaining streams.
Dalhaus Environmental Geology Pty Ltd, 2002, Groundwater Flow Systems of the Corangamite Catchment Management Authority Region, May 2002 (Report No. CCMA 02/02).	
Scope	• Corangamite Catchment Management Authority Region identified as a high risk salinity area. • Purpose to the report was to consolidate information based on data and advice from a workshop.
Key Findings	• Wiridjil Gravels considered an intermediate flow system; Dilwyn Fm considered a regional flow system.
Petrides, B., Cartwright, I., 2006, The hydrogeology and hydrogeochemistry of the Barwon Downs Graben aquifer, southwestern Victoria, Australia	
Key Findings	• Recharge rates to the aquifer were low (based on Carbon 14 age dating) and that the aquifer could be impacted by over extraction. • Localised flow system, lack of regular spatial variation in groundwater chemistry. • Stable isotopic data indicated that groundwater was recharged under similar climatic conditions of the day. • Barongarook High recharges/provides base flow to Boundary Creek and other surface water bodies. • The Clifton Fm and Gellibrand Marl are not hydraulically connected to LTA, however, Narrawaturk Marl shows minor response to borefield pumping indicating it acts as a leaky aquitard. • Carbon dating indicates the resource is not finite, with long groundwater residence times. • Heterogeneous hydraulic conductivities are present in Dilwyn Mepunga and Pebble Point Fm due to discontinuous beds of sand, gravel, silt and clay. • Concluded that groundwater was mainly extracted during periods of low rainfall and most likely the changes to surface water bodies was reflective of the lack of recent rains that lower water tables in near surface systems.
SKM, 2012, Newlingrook Groundwater Investigation, Gellibrand River Streambed and Baseflow Assessment, 21 December 2012.	
Scope	• Groundwater level data collection; • River elevation and EC collection; • Spring discharge estimates and water quality sampling; and • Surface water and groundwater sampling.

<table>
<tr><th>Item</th><th>Details</th></tr>
<tr><td>Key Findings</td><td>In 2007 Barwon Water was investigating an additional water supply option during a long drought period. One of these was a borefield installed in the Newlingrook Aquifer.
Investigation found that Gellibrand River was highly connected to the groundwater system and was found to be both currently and historically gaining along the reaches studies.
Pumping may induce greater leakage from the Clifton Fm (aquitard) which had potential to impact springs fed from the formation (presumed the report meant Clifton Fm). Springs derived from shallow groundwater and contribute to generation of tributaries to Love Creek (Porcupine Creek, Yahoo Creek, Serpentine Creek, Ten Mile Creek, and others). Other springs derived from the bedrock or LTA (Eastern View Fm in this report) around margins of the basin.
Consideration of other natural influences such as periods of drought and other climatic factors also have the potential to impact groundwater baseflow to the Gellibrand River and other streams.
Recommended a Permissible Consumptive Volume (PCV) be developed for the Gellibrand GMA that takes into account the likely strong connection between groundwater pumping and stream flow.</td></tr>
<tr><td colspan="2">Aquade, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area (Completed for LAWROC)</td></tr>
<tr><td>Scope</td><td>Review of previous reports and publicly available information to consider if groundwater extraction at Barwon Downs was affecting groundwater recharge and groundwater flow rates including to creeks in the Kawarren/Gellibrand System.
Consideration if the groundwater divide had moved as a result of the Barwon Downs borefield operation.</td></tr>
<tr><td>Key Findings</td><td>The changes in groundwater levels and gradients in the Kawarren sub-basin indicate changes in groundwater flow and resulting changes in flux between streams and groundwater.
The reduction in groundwater discharge rate to Gellibrand River as a result of drawdowns in Kawarren is not considered to be significant. It wasn’t thought to follow that the reduction in groundwater levels in the Kawarren systems has or will have a measurable effect on streamflow in Love Creek catchment. This was due to the very low permeability confining layers that separate the LTA from the surface water system.
In areas where the creeks directly interact with the aquifer and groundwater levels were lowered there was likely to be a reduction in net flux from groundwater to surface water. The Love Creek catchment area was considered to have the greatest potential for significant impact on stream baseflow.
Ten Mile Creek was considered by previous reports to be sourced from springs discharging from the EVF aquifer (LTA).</td></tr>
<tr><td colspan="2">Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/16 – Recharge Rate Assessment, 16 September 2016.</td></tr>
<tr><td>Scope</td><td>Objective was to provide estimated recharge rates of LTA in Barwon Downs region.
Adopted tritium method – using natural levels of tritium in water to calculate age of groundwater. Three approaches used: independent estimates at each site; differential estimates between bores; and interface method to identify spike present in natural tritium levels in the 1960s.
Adopted chloride mass balance method.</td></tr>
<tr><td>Key Findings</td><td>Results found that the ‘best representation of current/modern recharge to the LTA on the Barongarook High are derived from the application of independent and interface methods’. Modern recharge rates are most likely around 9 – 11% of average annual rainfall in the area of aquifer outcrop.</td></tr>
</table>

Item	Details
	• Recharge over a longer term was considered to be about half of modern day estimates. • Recommended an updated numerical model use the recharges rates as a starting point for calibration.
Aquade, 2017, Impacts of Barwon Downs Extraction on Groundwater and Surface Water in the Kawarren Area, 27 January 2017 (prepared for LAWROC).	
Scope	• Updated previous report (Aquade, 2014) incorporating additional groundwater data. • Estimated the baseline flux through Kawarren sub-basin and into Gellibrand River. • Assessment of whether there is evidence from creek flows of a reduction in baseflow in Love Creek. • Consideration of whether there is potential for increased impacts including cease to flow of Love Creek due to future extraction from the borefield.
Key Findings	• The Barwon Downs graben has two sub-basins – Barwon Downs and Kawarren sub-basins aligned approximately NE-SW. Groundwater flow from Barwon Downs to Kawarren sub-basin is restricted by a low transmissivity area. • Love Creek is dominated by groundwater discharge to upper reach tributaries of Ten Mile Creek. • Groundwater extraction in the area has resulted in drawdown of the LTA in the Kawarren area, reducing by 4 m below their baseline levels after the last period of extended pumping in 2010. • A significant reduction in baseflow of Love Creek has been observed. Between 1979 and 1997 the lowest minimum daily flow rate was 1.0 ML/day. Post 1997 there have been a number of years where minimum average daily flow rate was <1.0 ML/day. The minimum flow in Love Creek has reduced by approximately 50%. • An assessment of the aquatic ecosystem in Love Creek was recommended to appreciate the effect of reduced baseflows on the ecosystem.
Jacobs, 2018, Barwon Downs Technical Works Program: Potential impacts and risks from future operation of the Barwon Downs Borefield. 7 December 2018.	
Scope	• Inform Barwon Wwater licence application via groundwater model to predict potential impacts of pumping to environmental indicators in Gerangamete region. • Assess level of risk of pumping.
Key Findings	• Numerical groundwater model was used to run predictive scenarios under varying climate scenarios and under varying pumping scenarios. • Proposed groundwater extraction rates were not considered to exceed recharge. • When pumping ceases groundwater levels were predicted to recover in the future, with the aquifer returning to pre-development condition when pumping ceases. • Groundwater extraction was not considered to impact on the aquifer matrix subsidence. • Groundwater extraction was not considered to have an adverse impact on the groundwater quality (salinity). • Risks to receptors indicated that several areas in the catchment (Boundary Creek and Big Swamp) had a high risk to vegetation in areas where the regional aquifer outcrops and there are no alluvial aquifers. • Potential acid sulfate soils: high risks in Reach 2 of Boundary Creek and Barwon River East Branch. • The risk to Gellibrand River (key discharge area for regional aquifer) was considered to be medium. The alluvial aquifer was considered to be buffered from drawdowns predicted in the regional aquifer. Small areas of high risk where the LTA outcrops at the surface.

Item	Details
	• Ten Mile Creek considered to be medium risk. Creek is considered to be a gaining creek. • Yahoo Creek considered to be a medium risk in small areas where there is an absence of alluvial aquifer. • Loves Creek considered to flow over aquitard, however, there are small outcrops of the LTA near the confluence of Gellibrand River. Risk considered to be low. • Several trigger levels set including for Ten Mile Creek and Gellibrand River .
Aquade, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment	
Scope	• Assess apparent connection between Barwon Downs pumping and drawdown in the Barongarook Creek Catchment.
Key Findings	• It was understood (based on previous reports) that; – In the 1980s 22.7 GL was extracted; – Between 1997 and 2001 36.8 GL – Between 2006 and 2010 52.7 GL; and – Between 2015 and 2017 3.5 GL. • The drawdown induced by the groundwater extracted extends at least as far as 15 km in the LTA. • Drawdown in an observation bore along Ten Mile Creek has been in the order of 1.2 m. The groundwater level has not recovered to original level
Jacobs, 2019, Technical support for Section 78 Scope of Works: Historical Pumping Risk Assessment Method and Results, 24 September 2019	
Scope	• Renew and update existing numerical model to assess historic impacts associated with groundwater extraction.
Key Findings	• Reduction in baseflow of Gellibrand River since mid-1990s. Considered that the change in total baseflow was ~6% reduction. Shallow sediments were considered to collect local recharge and hold local groundwater flow cells that contribute to local discharge to the river. • Estimated maximum impact associated with historical pumping on Gellibrand River baseflow was ~0.3 ML/day (~2% of low flow) • Maximum impact associated with historical pumping on Ten Mile Creek was 0.2 ML/day (~15% low flow). • Estimated maximum impact associated with historical pumping on Yahoo Creek was 0.08 ML/day (~8% of low flow) • Estimated maximum impact associated with historical pumping on Loves Creek was 0.02 ML/day (~1% low flow)
Otway Water Book 21: An aquifer divide shift and Study of the EVF aquifers in the Gerangamete and Gellibrand Groundwater Management Areas, 2013	
Key Findings	• Timeline of extractions from Barwon Downs Borefield. • Three Groundwater Management Aareas – Newlingrook, Gellibrand and Gerangamete. Newlingrook separated from Gellibrand by Gellibrand Saddle, while Yeo Dome separates Gellibrand and Gerangamete. • Aquifer divide between Barwon Downs sub-basin and Kawarren sub-basin due to Yeo Dome. • Yeo 40 (obs bore 109131 – new/replacement bore installed around 2001/2002) – important bore with a trigger level of 158.5 m AHD whereby supplementary flows released into Boundary Creek

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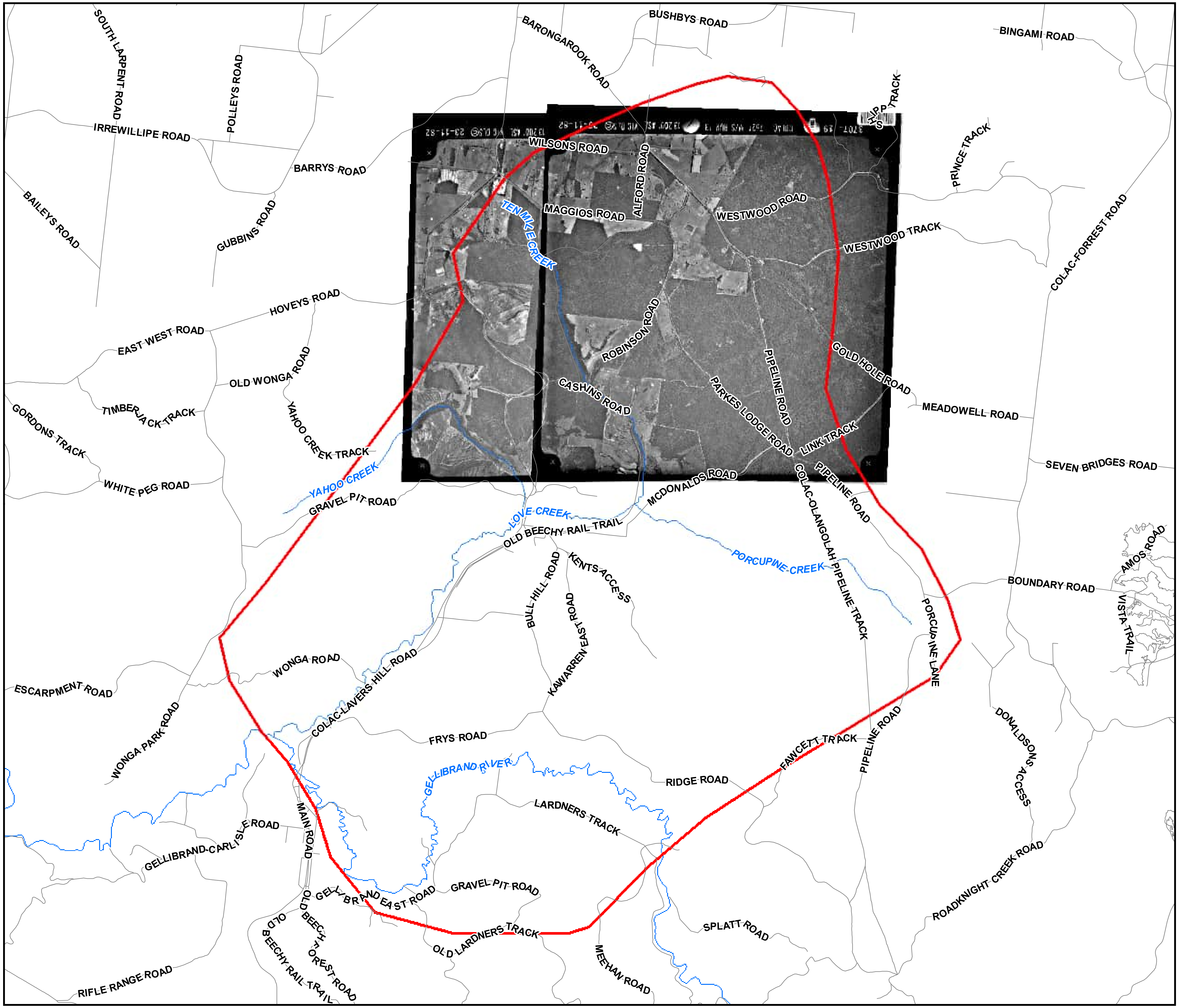
<tr><th>Item</th><th>Details</th></tr>
<tr><td></td><td>Hydrographs for Kawarren/Gellibrand region indicate no response to three relatively wet winters, while there is a recovery in bores in the Barwon Downs area.</td></tr>
<tr><td colspan="2">Otway Water Book 28: The Western Front, Ten Mile and Loves Creek Catchment 2015</td></tr>
<tr><td>Scope</td><td>Draws together various studies to clarify potential impacts of groundwater extraction on the upper reaches of the Gellibrand River Catchment.</td></tr>
<tr><td>Key Findings</td><td>‘Big picture’ should include observation bore info, data, hydrographs and behaviour; observable data of groundwater receptors; rainfall history and patterns; infiltration rates; stream flow gauging station records; land use change.
The groundwater flow path to the west and south west of the Barongarook High (Kawarren sub-basin) has not been studied.
Over several decades locals have noticed dramatic decline in surface water flows in Loves Creek and upper Gellibrand River catchments.
Jacobs (2015) investigated noticeable groundwater extraction taking place in the Kawarren sub-basin. Extremely small pumped from private bore used for stock and domestic purposes. Jacobs recommended further investigation into the causes of drawdown in the region including estimating likely magnitude of groundwater pumping in the area.
Hydrographs indicate decreases of water level of between 4 – 5 m with no noticeable recovery.
Healey rainfall gauge sits within the Barongarook High recharge area. Hopkins rainfall gauge lies to the south.
During periods of drought annual rainfall decreased by more than 200 m. It was thought that this would not have affected the recharge to the aquifer or have a mild impact. Based on precipitation, recharge to the aquifer in the observation bores should ‘reflect a reasonably full aquifer system if it had not been for a significant groundwater extraction.’
Ten Mile Creek Stream Gauge (1985 – 1995, reinstated in 2008 - 2009). Decline in base flows during period of 25,000 ML extraction at Barwon Downs between 1986 and 1990.
Loves Creek Stream Gauge (1979 – at least 2013)
Between 1947 – 1977 there were a number of areas where trees had been cleared. Reduced clearing occurred between 1977 and 2007. Some areas have had pine and blue gum plantations.</td></tr>
<tr><td colspan="2">EAL Consulting Service, 2011, Preliminary Inland Acid Sulfate Soil Assessment Report, Investigation of Wetland Habitats (Barongarook Creek Catchment, Boundary Creek Catchment, Loves Creek Catchment)</td></tr>
<tr><td>Scope</td><td>Identify the presence of potential and/or actual acid sulfate soils within wetlands within the Barongarook, Boundary, Porcupine, Spiny Horn and Yahoo Catchments.
Completion of site specific soil sampling.
YH1 – along Yahoo Creek; PC4 along Porcupine Creek; SH1 along Spiny Horn Creek</td></tr>
<tr><td>Findings</td><td>The area is described as undulating plains with deeply weathered soils (Tertiary clays) and minor outcrops of sands (associated with Yeodene land system). Steep to middle slope consist of yellow gradational sandy loams, while drainage lines and lower lying regions consists of mottled yellow gradational clays.
Peat forests are present within valley infills and low lying drainage lines
The Porcupine Creek sample indicated levels of actual and potential acidity.
The Yahoo Creek sample indicate high levels of actual and very low levels of potential acidity. Soils in the region were considered to be transferral and were not considered indicative of acid sulfate conditions. Although TAA values indicate an acid soil profile not necessarily indicative of sulfidic acidity.</td></tr>
</table>

Item	Details
	• The Spiny Creek sample indicate minute levels of actual and high levels of potential acidity. The site has an extremely high acid neutralising capacity indicating potential to neutralise any sulfur from oxidation. • Excluding Grays land Shorts Road and Yahoo Creek regions all regions in study area show Inland ASS characteristics. • Big Swamp Boundary creek and Parkers old Friend Road regions considered IASS. In regions of depressed groundwater heights and limited recharge, oxidation of soils has resulted in formation of highly acidic conditions. • Areas with sustained groundwater (permanent or semi-permanent) inundation also display IASS characteristics with significant potential for acid generation.
ELA, 2022, Barwon Downs Groundwater Dependent Ecosystems Monitoring Report – November 2020 (V4)	
Scope	• Development of Groundwater Dependent Ecosystems (GDEs) monitoring sites to assess presence of potential GDEs in locations identified by Jacobs as having a high or moderate risk of impact from aquifer drawdown. • Sampling of vegetation from a single 50 m long vegetation transect.
Key Findings	• The identification of GDEs based solely on risk-based modelling was difficult. • Uncertainty whether vegetation that was surveyed was relaying on existing groundwater or using available surface water. Sites were not located close to the Barwon Downs borefield. • Continuation of monitoring the sites for long term effects of pumping will unlikely yield results of value. • Further works required to identify GDEs. Should specifically target where the LTA outcrops.
ELA 2022, Groundwater Dependent Ecosystem Survey of the Barwon Downs Region	
Key Findings	• Investigation areas 6, 7, 8 in the Loves Creek investigation area. • Water tables varied between 5 and 20 m in investigation areas 6 and 7 depending on topography of water course and adjacent banks. • Mapping of water courses indicating probability of groundwater interaction. Major watercourses in investigation 8 had a high probability while in investigation areas 6 and 7 there was a moderate probability. • Vegetation in Investigation areas 6 – 8 was considered to be of high quality remnant vegetation. Classified as herb-rich foothill forest.
Preliminary Draft Regional Landcare Action Plan for the Corangamite Region, 1993	
Scope	• Develop a Corangamite Regional Landcare Action Plan, defining where the Landcare Group was at the time, where they want to get to and how to get there.
Key Findings	• Major issues identified in the plan included salinity of groundwater in the Barwon Downs area. • Minor issues included landslips

Appendix C

Aerial Photographs (1982 – 2019)



PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

N

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 1982

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
A1

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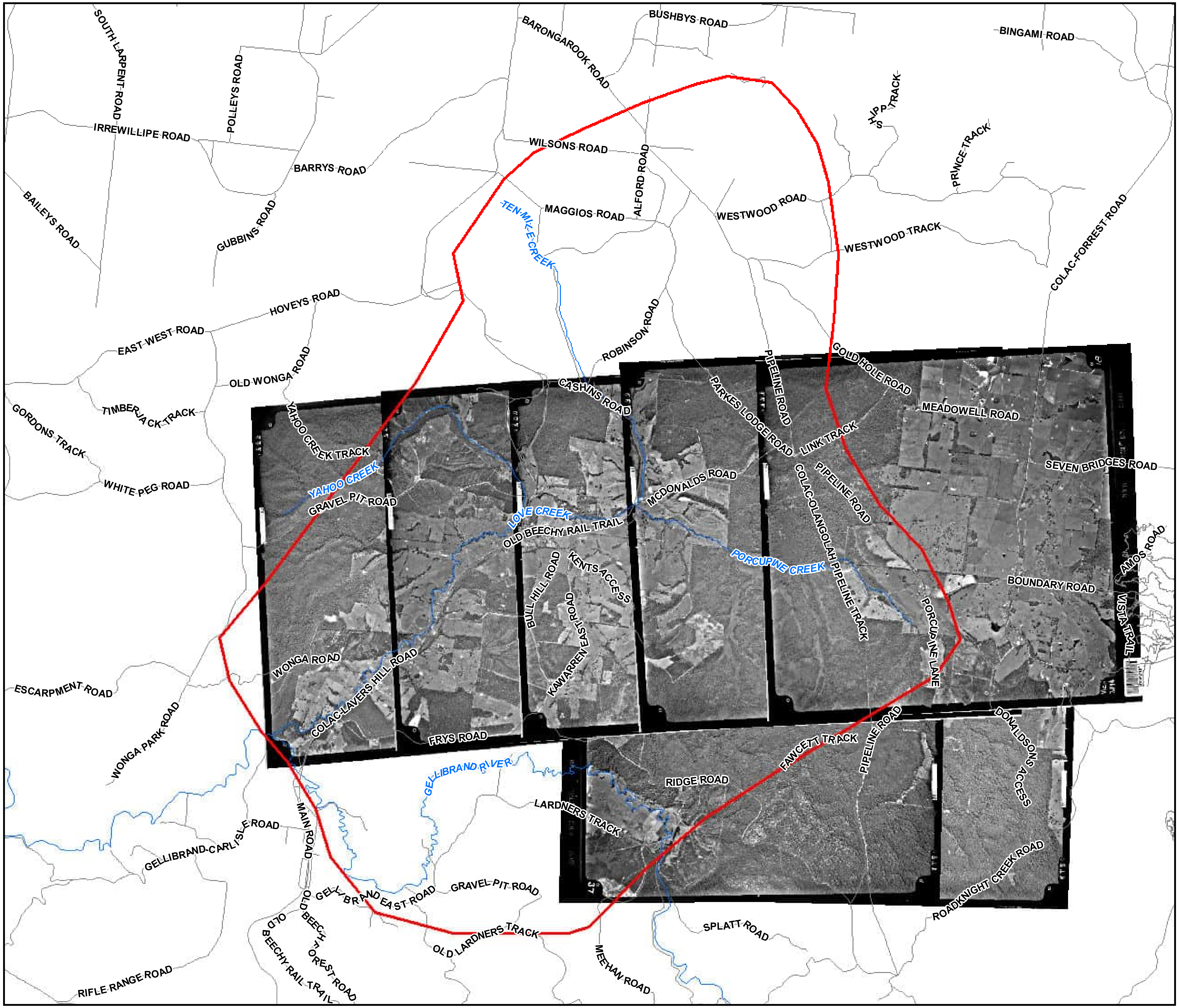

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

N

0 0.6 1.2 1.8 2.4 3

Kilometres

1:60,000 when printed at A3

GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 1983

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin

Barwon Water

Figure

A2

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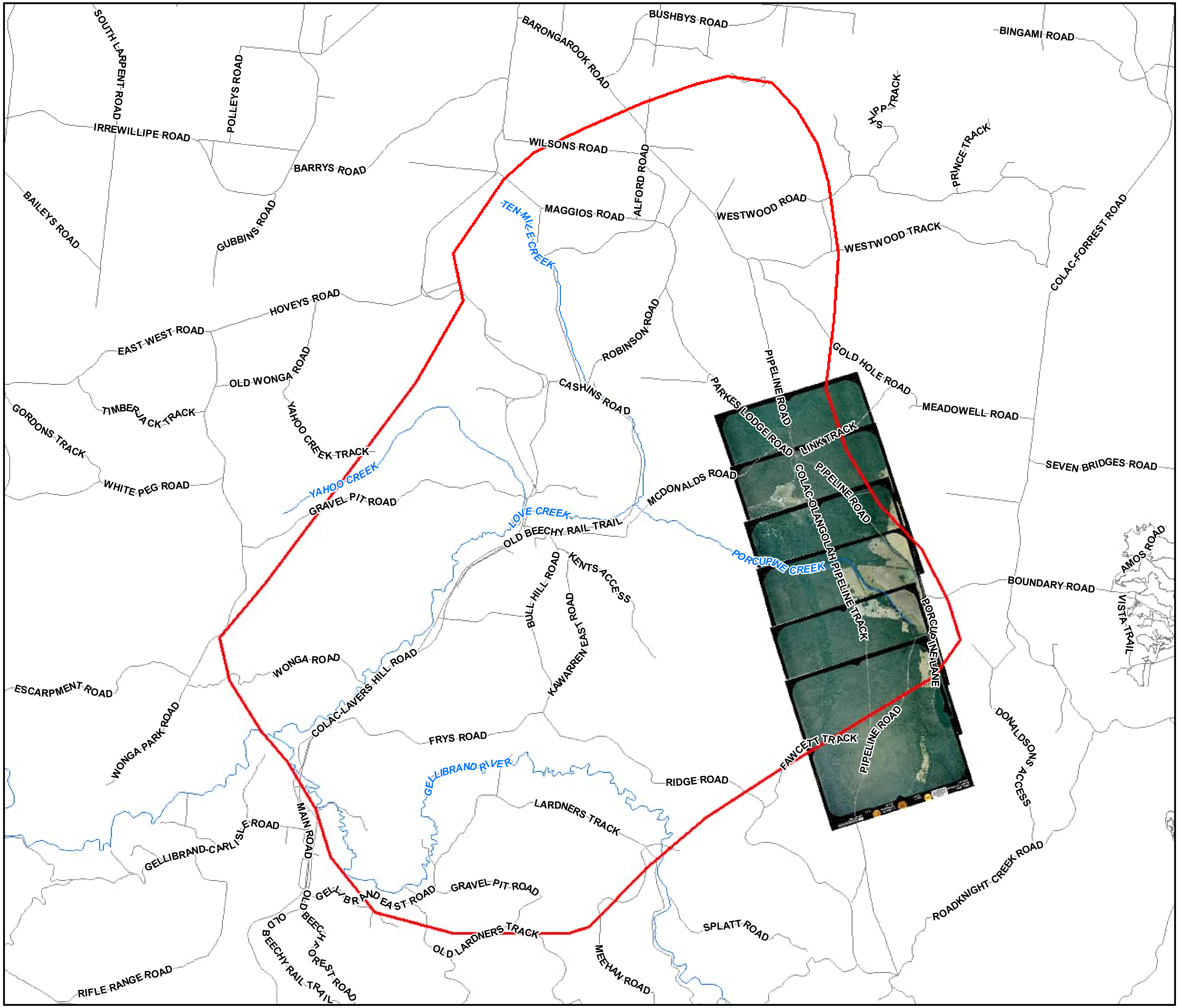

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

N

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 1998

Hydrogeological Assessment - Kawarren Sub-basin

Figure **A3**

Kawarren Sub-basin
Barwon Water

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_App03_Aerials_1998.mxd.mxd

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Kawarren Sub-basin Investigation Area (approx. extent)

Watercourse

N

0 0.6 1.2 1.8 2.4 3

Kilometres

1:60,000 when printed at A3

GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 2000

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
A4

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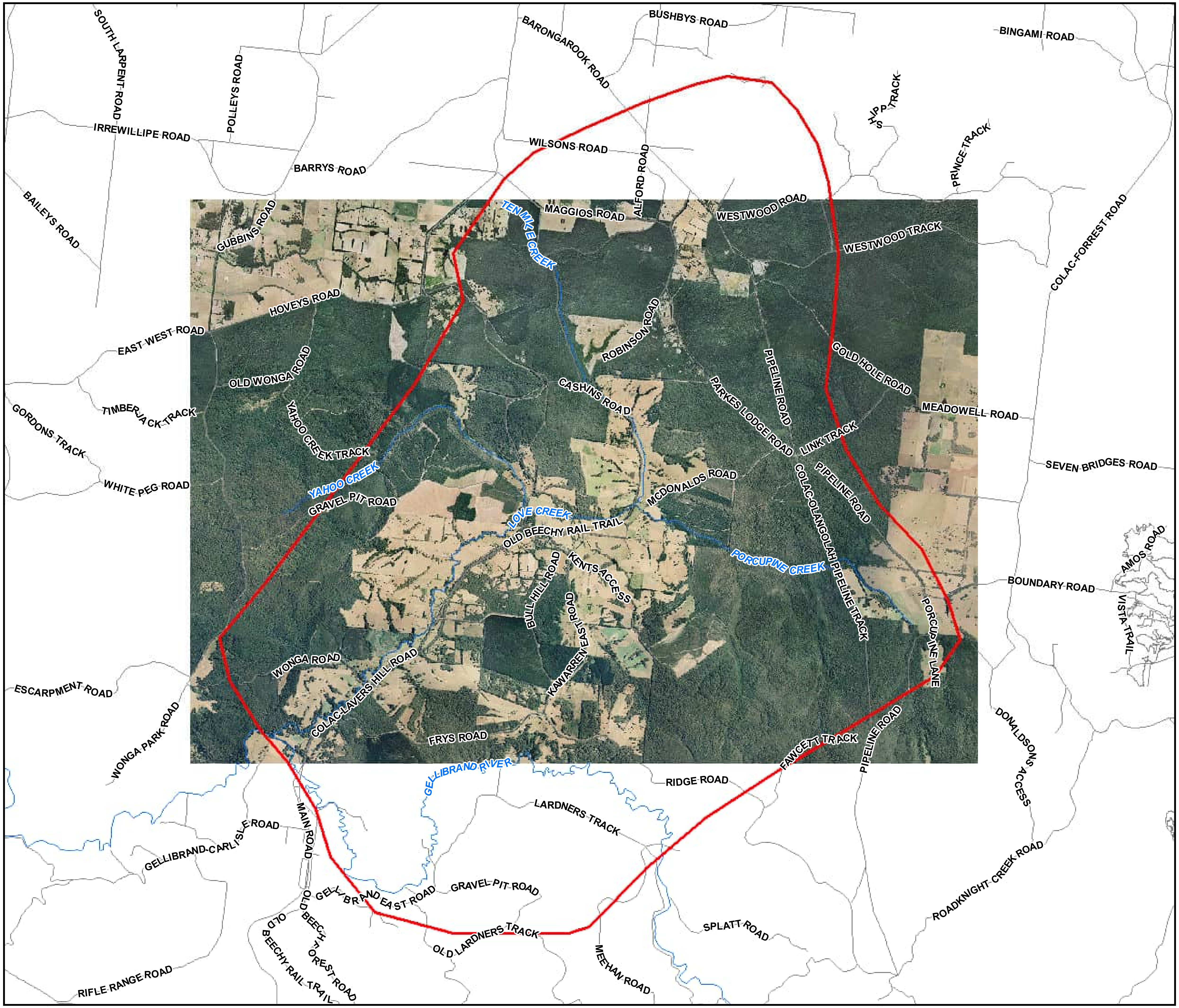

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Kawarren Sub-basin Investigation Area (approx. extent)

Watercourse

N

0 0.6 1.2 1.8 2.4 3
Kilometres

1:60,000 when printed at A3
GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 2007

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
A5

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_App05_Aerials_2007.mxd.mxd

PROJECT ID 31155.01
DATE 27/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Kawarren Sub-basin Investigation Area (approx. extent)
- Watercourse

N

0 0.6 1.2 1.8 2.4 3
Kilometres
1:60,000 when printed at A3
GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 2019

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
A6

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_01_App06_Aerials_2019.mxd.mxd

Appendix D

Site Inspection and Interview Summaries

Knowledgeable Landholder Site Inspection Observations 23-24 November 2022

Landholder and Location	Observations / Comments
M & K Gardiner 1805 Colac-Lavers Hill Road, Kawarren	Pompa Bill Creek runs through property and runs all year round. At least two springs are located along the creek. Two rock outcrops along creek – in upper reach appears to be Narrawaturk Marl and Yaugher Volcanics and in lower reaches appears to be Dilwyn Formation. The flow of the spring is estimated to be ~1 ML/day. Other observations: Plantations in vicinity of Yahoo Creek have been rotated between gums and pines since ~1970s. A spring (Whiskey Spring) flows all year round in the upper reaches of Ten Mile Creek, Barongarook High area that used to supply the railway line with water. Ten Mile Creek flows into Maggios Swamp that is surrounded by forestry and alternates between pines and blue gums – approximately three rotations. It is understood anecdotally that farmers take water from Loves Creek and that both Porcupine Creek and Loves Creek don't dry up. Following removal of plantations sediment build up washes off into the adjacent waterways.
M & C Maxwell 1840 Colac-Lavers Hill Road, Kawarren	Loves Creek runs through the property. Outcrops of pillow lava were observed along this section of Loves Creek. A pump was observed to be in Loves Creek. Two springs on property in headwaters of Acuna (?) Creek, one at fork of the creek and an additional further up. Surrounding the springs is a swampy area with tea trees and clayey/sandy soils. A landslip area was located at the top of the property that is understood to have been underlain by limestone. The area formed a basin which used to be a spring. M. Maxwell indicated he had dug the basin out to form a dam and dug out the spring. Water is understood to seep out of the clay wall face.
L & V Riches 20 Riches Road, Kawarren	The Riches have been at the property since 1983. One spring on the property which has never been the same since approximately 1986 when it would dry over summer after previously not drying up. Historically was moist/wet in January. Iron flocculation has been observed historically in the spring. Downstream in the lower reaches of the drainage line adjacent to Colac-Lavers Hill Road the land is always wet and boggy. At the time of the inspection the spring was light grey in colour.
D & B Dawes 380 Frys Road, Kawarren	One spring located on southern slope of property towards Gellibrand River. Terraced landscape on way to spring. Spring appears to outcrop on Dilwyn Formation. Dilwyn Formation outcrops also observed along clay track further downslope from spring. D Dawes pers comms: sand hills at base of the track above the river flats.
D & J Jukes 1845 Colac-Lavers Hill Road, Kawarren	~15 springs located across the property. Two in close proximity to the house (the lowest of which appeared at a break in slope). Of the ~15 springs ~30% stay wet all year. Believes there is acid sulfate soil on property in swamp area at lower end of the creek on alluvial flats. Creek on property runs all year round quite well and also during drought. Springs dry out during periods of drought. Soils have approximately 4 inches of topsoil before moving to red clays. Also coffee rock around. The property is susceptible to tunnel erosion, as well as surface erosion. Not aware of rock outcrops on the property.

Landholder and Location	Observations / Comments
	The property was cleared ~50 years ago and since the Jukes have been at the property they have been re planting trees.
R Maxwell 35 Kawarren East Road, Kawarren	~40 springs on property, with some drying up (mid-late 1980s) and some continuing to flow. Between ~1906 to 1956 a quarry and lime kiln operated at the property at the outcrop of Clifton Formation. The Clifton Formation outcrops are apprxoiamtely 20 m high. Springs present along the base of the Clifton Formation and the Quaternary flats along Loves Creek. Historically irrigated in the 1970s and 1980s from Loves Creek – after ~10 minutes of pumping the creek was dry. M. Maxwell also historically irrigated – pumping ~40 gallons ?/minute?
M Calvert Kents Access, Kawarren	Numerous springs on property. One located along Spinyhorn Creek flows all year and during summer. Pockets of Woolly Teatree associated with outcrops of limestone (act as neutraliser for upstream PASS) and swampy areas downstream of the spring. Flow ~9 L/min Springs all along Spinyhorn Creek, generally at break in slope. Anecdotally a spring along Kents Access flows straight out of the ground and has capacity to fill and keep full an ~20 ML dam. A reduction in the flow of springs has been observed. At end of Kents Access on an outcrop of ?LTA or marl is a spring that feeds into Porcupine Creek.
D & J Hopkins	No permanent springs exist on their property. The creek running along their boundary typically runs during the winter, however in 2022 it ran all the way through until November. The creek will typically stop flowing and then soak into the ground. A Pine plantation was planted 40 yrs ago as well as a Blue gum plantation being planted 13 yrs ago. The Pine was harvested last year (2022) and was replanted, the Blue gums are being harvested currently. The property does not have any dams or irrigation licence for water supply. The property below Hopkins was at one point a tobacco plantation and had an irrigation dam built 30 yrs ago but stopped.
Neville & Christine Towers	Have one creek running through their property as well as a spring in the paddock. The creek is permanent and has good year round flow, the farmer previous to them had never seen it stop even in years of drought. They run a pump out of the creek for use as a domestic firefighting mechanism, no permit for this.
Peter & Anette McDonald	Porcupine and Ten Mile creek runs along their property. One major source coming out from their paddock runs into porcupine creek at a consistent level, all others stop running over summer. On the Ten Mile creek side of their property there are only a few springs next to their boundary. They haven't irrigated their property in years, and have said that only a few people with permits actually pump out of Loves Creek.

Landholder and Location	Observations / Comments
	The McDonalds pump out approximately 4 mL/year from porcupine creek and have done this for the past 15 years, creek has gone dry.
Keith & Maxine Armistedd	Have mapped a lot of SW on their home farm. During the 67 drought they were able to bring groundwater to the surface, however the Millennium drought levels have been substantially lower. An extensive spring runs along horn creek, runs across to P McDonalds property. The dam on their property is continually wet, in the 67 drought they could shovel enough water from it all the time. Irrigation at R Maxwells property, behind P McDonald, has occurred since the early 1950s to mid-1970s, withdrawing approximately 40 mL/yr from loves creek.
Other notes	N. Longmore pers comms: Lime kilns used to operate at Kawarren. Jock (?) pers comms: peats located along Yahoo Creek. Additionally prickly tea tree found to be associated with PASS. M. Calvert pers comms: P McDonald pumped from Porcupine Creek in the 1980s which resulted in no flow to Loves Creek from Porcupine Creek.

Appendix E

Acid Sulfate Soil Tables

Location	Sample ID	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
		units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
DMBH01V/DMBH02V	BH18/19_0-1	7.5	6.2	1.3	3	-	-	-	Possible ASS
	BH18/19_1-2	5.3	3.9	1.4	1	-	-	-	
	BH18/19_2-3	4.8	3.9	0.9	1	-	-	-	
BSBH13LTA	BH01_1.0	4.2	1.8	2.4	4	103	69	247	Actual and Potential ASS
	BH01_1.0	4.8	1.6	3.2	4	-	-	-	
	BH01_2.0	3.6	1.3	2.3	4	-	-	-	
	BH01_3.0	3.7	1.4	2.3	4	-	-	-	
	BH01-4.0	4	1.6	2.4	4	-	-	-	
	BH01_6.0	4.3	1.9	2.4	2	-	-	-	
	BH01_7.0	4.4	1.8	2.6	3	-	-	-	
	BH01-8.0	4.2	1.8	2.4	2	-	-	-	
	BH01-11	4.2	1.6	2.6	4	46	625	671	
	BH01-12	4.7	2	2.7	4	-	-	-	
	BH01_15.0	4.5	1.6	2.9	4	23	440	463	
	BH01_16.0	4.9	2.1	2.8	4	-	-	-	
	BH01_17.0	5	1.5	3.5	3	-	-	-	
	BH01-21	6.8	2.5	4.3	2	<2	31	31	
	BH01-23	6.1	1.9	4.2	2	-	-	-	
	BH01-24	6.6	2.2	4.4	2	2	26	28	
WBBH01/WBBH02	BH04_BH05-1.0	6.8	2.6	4.2	3	-	-	-	Potential ASS
	BH04_BH05-2.0	6.7	3.5	3.2	3	7	16	23	
	BH04_BH05-3.0	6.4	4	2.4	4	-	-	-	
GRBH01/GRBH02	BH08_09_1.0	6.8	3.4	3.4	2	-	-	-	Not Identified
	BH08_09_2.0	7.4	5.1	2.3	2	<2	<10	<10	
	BH08_09_3.0	6	3.4	2.6	2	11	<10	14	
BCBH01/BCBH02	BH14_15-1	5.9	4.2	1.7	1	-	-	-	Potential ASS
	BH14_15-2	6	3.7	2.3	1	13	11	24	
	BH14_15-3	5.6	3.8	1.8	1	-	-	-	
	BH14_15-22	5.9	2.4	3.5	4	-	-	-	
NYBH01/NYBH02	BH16_BH17-3.0	5.3	3.6	1.7	1	-	-	-	Not Identified
PCBH01V/PCBH02V	BH20-21-1.0	5.8	3.1	2.7	1	4	<10	11	Not Identified
	BH20-21_2.0	4.9	3.4	1.5	2	-	-	-	
	BH20_21_3.0	4.9	3	1.9	1	-	-	-	
	BH20_21_4.0	5.2	3.5	1.7	2	-	-	-	
McD2	N/A	-	-	-	-	-	-	-	Possible ASS
PC4	N/A	-	-	-	-	-	-	-	Actual and Potential ASS
SB1	* SB1_0.9-1.0	-	-	-	-	80	237	317	Actual and Potential ASS
SB2	* SB2_0.3-0.5	-	-	-	-	128	187	315	Actual and Potential ASS
SB3	* SB3_1.0	-	-	-	-	38	0	38	Actual ASS
SB4	* SB4_0.0-0.1	-	-	-	-	80	87	167	Actual and Potential ASS
SB5	* SB5_0.1-0.2	-	-	-	-	207	2270	2478	Actual and Potential ASS
SB6	* SB6_0.8-1.0	-	-	-	-	255	1628	1883	Actual and Potential ASS
SB7	* SB7_0.2-0.4	-	-	-	-	186	256	442	Actual and Potential ASS
SB8	* SB8_0.1	-	-	-	-	174	6	217	Actual ASS
SB9	* SB9_0.1	-	-	-	-	263	12	291	Actual ASS
SB10	* SB10_0.1	-	-	-	-	698	25	1926	Actual and Potential ASS
SB11	* SB11_0.1	-	-	-	-	543	31	1508	Actual and Potential ASS
SB12	* SB12_0.5	-	-	-	-	1319	443	1770	Actual and Potential ASS
SB13	* SB13_0.1	-	-	-	-	416	6	1159	Actual ASS
SB14	* SB14_0.8	-	-	-	-	1174	9998	11942	Actual and Potential ASS
SB15	* SB15_0.8	-	-	-	-	237	1060	1298	Actual and Potential ASS
SB16	* SB16_0.1	-	-	-	-	499	56	1423	Actual and Potential ASS
SB17	* SB17_0.3	-	-	-	-	51	399	450	Actual and Potential ASS
SH1	N/A	-	-	-	-	-	-	-	Actual ASS
YH1	N/A	-	-	-	-	-	-	-	Not Identified

Prepared by: BS
Checked by: BS

Appendix F

Hydrographs

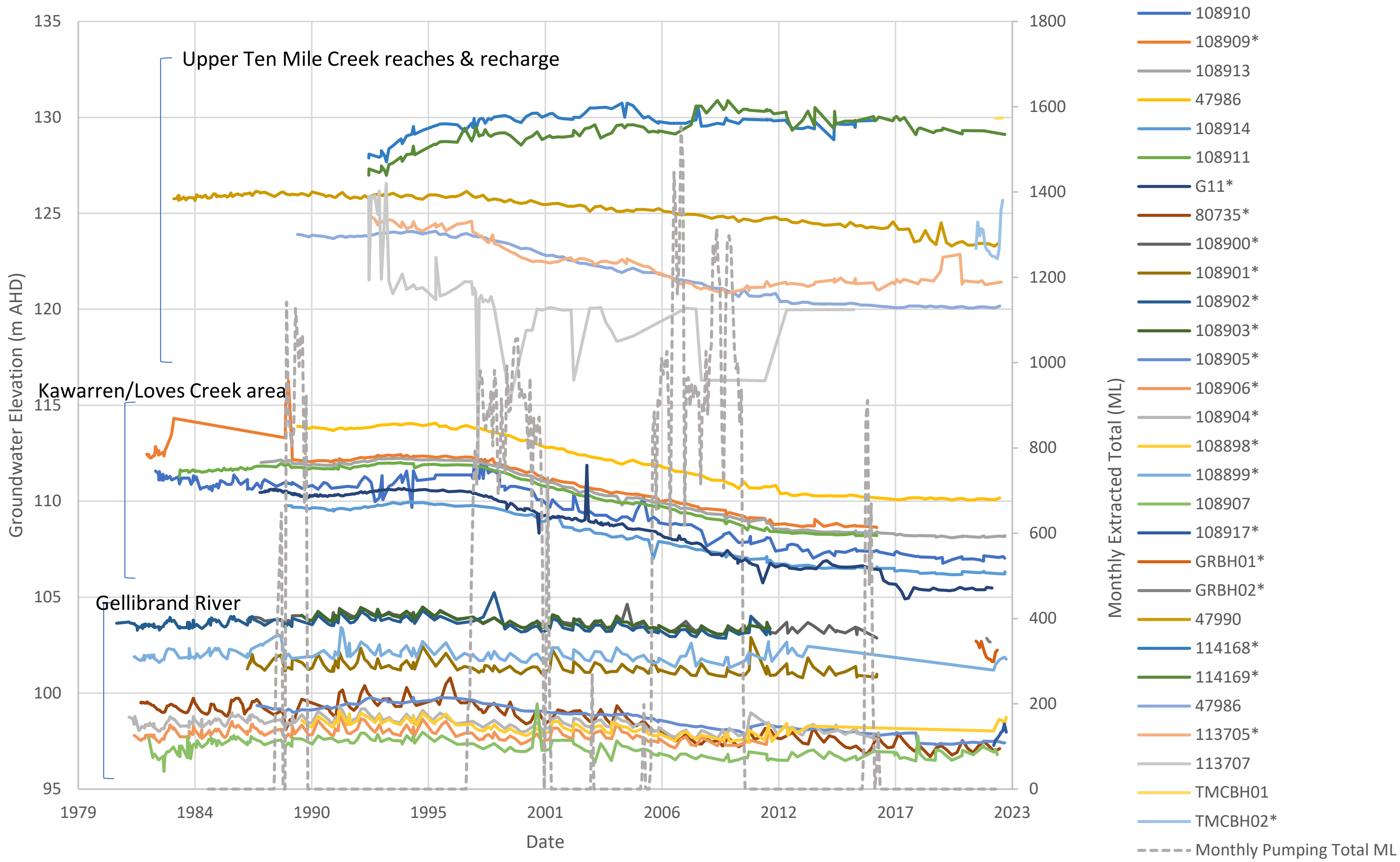

Figure F1 - Groundwater Bore Hydrographs

Hydrogeological Investigation of the Kawarren sub-basin

Surrounding Environment Investigation

Barwon Water

Date: May 23	**Drawn:** BS
Scale: nts	**Chk'd:** RC
Original:	**Rev:** 1
File Reference:	

BlueSphere ENVIRONMENTAL

Appendix B – Hydrogeological Assessment of the Barwon Downs Sub-Basin (BlueSphere, 2023b)

Hydrogeological Assessment of the Barwon Downs Sub-Basin

Surrounding Environment Investigation

Prepared for:

Barwon Water

55-67 Ryrie Street
Geelong VIC 3220

17 July 2023

Hydrogeological Assessment of the Barwon Downs Sub-Basin

Surrounding Environment Investigation

Distribution

Copies	Recipient	Copies	Recipient
1 PDF	Will McCance Environmental Remediation Project Manager Asset Systems & Environment Barwon Water	1 PDF	BlueSphere Project File (31155.02)

Authored and Reviewed by:

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Technical Review	Darren Ellis Senior Principal Hydrogeologist	

Revision History

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Acknowledgments

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In addition, BlueSphere would like to acknowledge local community members who provided rainfall records from both the Barwon Downs region and the Kawarren area.

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List of Abbreviations

Abbreviation	Definition
Act	Environment Protection Act 1970
AHD	Australian Height Datum
AMMR	Accumulative Monthly Residual Rainfall
ANZG	Australian and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS	Australian Standard
AASS	Actual Acid Sulfate Soil
ASS	Acid Sulfate Soils
BDIA	Barwon Downs sub-basin Investigation Area
BGL	Below Ground Level
BGS	Below Ground Surface
BOM	Bureau of Meteorology
CCMA	Corangamite Catchment Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Conceptual Site Model
DELWP	Department of Environment, Land, Water and Planning
EECA	Energy, Environment and Climate Action
EPA	Environmental Protection Authority (Victoria)
ERS	Environmental Reference Standard
GDA	Geocentric Datum of Australia
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information System
GMA	Groundwater Management Authority
GW	Groundwater
HA	Hydrogeological Assessment
KIA	Kawarren sub-basin Investigation Area
km	Kilometre

Abbreviation	Definition
LAWROC	Land and Water Resources Otway Catchment
LMTA	Lower-Mid Tertiary Aquifer
LMTD	Lower-Mid Tertiary Aquifer
LTA	Lower Tertiary Aquifer
NA	Not Applicable
NIWA	National Institute of Water & Atmospheric Research
NR	Not Reported
OGA	Otway Group Aquifer
PASS	Potential Acid Sulfate Soil
PCV	Permissible Consumptive Volume
QSA	Quaternary Sediments Aquifer
REPP	Remediation and Environmental Protection Plan
RL	Reduced Level
SDLs	Sustainable Diversion Limits
SRW	Southern Rural Water
SWL	Standing water level
TAA	Titratable Actual Acidity
TDS	Total Dissolved Solids
VVG	Visualising Victoria's Groundwater
WDE	Water Dependant Ecosystems
WMIS	Water Measurement Information System

Executive Summary

BlueSphere Environmental Pty Ltd (BlueSphere) was engaged by Barwon Region Water Corporation (Barwon Water) to undertake a hydrogeological assessment (HA) of the Barwon Downs area within the greater Barwon Downs Graben. The HA was undertaken to assist Barwon Water with meeting the requirements of the Section 78 Notice issued pursuant to the Water Act 1989 as it relates to the investigation of surrounding areas potentially affected by the historical operation of the Barwon Downs Borefield. This HA specifically relates to the previously identified 'high risk' surrounding areas of Barwon River west branch, Barwon River east Branch, Barwon River (confluence), potential groundwater dependent ecosystems (GDEs) east of Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks) and potential GDEs west of Barwon River (Barongarook Creek). The HA encompasses the investigation area referred to as the Barwon Downs sub-basin Investigation Area (BDIA).

Between 1982/1983 and 2016 Barwon Water operated a borefield within a geological feature known as the Barwon Downs Graben, located approximately 70 km south-west of Geelong. The BDIA lies within the eastern portion of the graben. The borefield was operated in accordance with a licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water (SRW)) and is referred to by SRW as the 'Gerangamete Groundwater Field'. The aquifer from which groundwater was extracted is referred to as the Lower Tertiary Aquifer (LTA).

Over approximately a 30 year period, Barwon Water periodically extracted up to 119,000 ML of groundwater to augment surface water supplies during periods of drought. As a result of the pumping groundwater levels within the LTA were reported to have declined in the order of 60 m in the vicinity of the borefield.

In June 2017 Barwon Water acknowledged that the pumping had led to unintended consequences in the BDIA, including contributing to the drying out and oxidisation of acid sulfate soils in the vicinity of Big Swamp and Boundary Creek. Barwon Water no longer has a licence to extract groundwater from the borefield, and in August 2018 Barwon Water was issued with a Section 78 Notice.

The objectives of the HA of the BDIA were to:

- Develop a robust conceptual site model (CSM) based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if any impacts that may have resulted from historical groundwater pumping activities at the Barwon Downs borefield have occurred in the surrounding investigation areas.

The CSM was developed by desktop review of publicly available information in relation to the BDIA setting including geology, hydrogeology, climate, topography, hydrology, GDEs and ASS. An inspection of the BDIA was also completed. The CSM has been developed with a focus on the LTA in the BDIA and is in large agreeance with previous investigations.

The CSM developed for the BDIA was used to evaluate if impacts have resulted from historical groundwater pumping activities at the Barwon Downs borefield based on the current state of knowledge and best available data. The evaluation identified that the historical groundwater pumping activities have led to a decrease of water levels in the LTA in the order of 60 m in the BDIA. Water levels in the BDIA are showing signs of recovery with up to 80% recovery within the confined areas of the LTA and up to 59% recovery in unconfined areas of the LTA. Based on the CSM the water levels in the LTA in the BDIA should continue to recover, however, may take up to 20 years to recover to 90% of water levels pre-pumping.

Streamflow monitoring records for Boundary Creek and Barwon River indicate declines in low flows (Q90 stream flow) between 1997 and 2013.

In Boundary Creek, where if flows over the LTA between McDonalds Dam and Big Swamp, groundwater extraction is indicated to have compounded pre-existing water demands such as the upstream dam, surface water extraction and climate related influences that would have occurred irrespective of groundwater extraction. There is demonstrable evidence of environmentally significant

impacts within Boundary Creek, with limited down-stream effect within the Barwon River directly downstream of the confluence with Boundary Creek. These impacts are well known and the Remediation and Environmental Protection Plan addresses the remediation of Boundary Creek and Big Swamp to alleviate these impacts.

The CSM and thus the risks indicates that the influence of groundwater extraction on the East Barwon River in particular is likely to have been overestimated in the existing numerical groundwater model (Jacobs 2019) as the model assumes a greater degree of connectivity across the Bambra Fault than evident by geological and hydrogeological data. It is considered that, based on the CSM, the influence of groundwater extraction on the East Barwon River is insignificant. Further, there is no demonstrable evidence of environmentally significant impacts in the East Barwon River. For the West Barwon River the model indicated a minor degree of influence from groundwater pumping which accords with the CSM. A low risk has also been ascribed to potential GDEs west of Barwon River (Barongarook Creek).

There is hydraulic connection between the confined portion of the LTA and the LTA outcrops associated with Pennyroyal, Matthews and Deans Marsh Creeks, located east of the Barwon River. Jacobs (2019) identified downstream areas of the Pennyroyal, Matthews and Deans Marsh Creeks as being impacted from groundwater pumping, however this report has identified that the areas that are potentially susceptible to groundwater pumping related impacts are upstream of the areas identified by Jacobs (2019). However, there is a paucity of suitable historic surface water data that spans both the pre-and post- groundwater extraction phases to appraise the degree of potential hydraulic influence in these areas.

The framework documented in the Ministerial Guidelines for Groundwater Licensing of High Value GDEs was applied retrospectively to provide a point of comparison to aid in future management and to categorise the potential susceptibility in a consistent and transparent manner. The framework identified that the risks to Boundary Creek, Barwon River at its confluence with Boundary Creek by virtue of receiving inflows from Boundary Creek are classified as ‘high’ under the framework. For the up-stream portions of Pennyroyal, Deans Marsh and Matthews Creeks where they flow over LTA up-stream of the Bambra Fault, the risk are also classified as ‘high’ reflecting the need for further information rather than indicating risks are truly high.

The findings from this HA should be used to form the basis for the subsequent management decisions in the catchment. Any change to the existing PCV should consider cumulative effects of any pumping, climate change, land use and existing hydrological stressors to relevant surface water receptors, together with the interconnectivity between the BDIA and surrounding environments, including the KIA to the south-west.

A number of recommendations (see **Section 7.2**) have been made, including the recommendation that monitoring continue to be undertaken to verify that the expected groundwater recovery occurs and the continuation of remediation and rehabilitation activities in Boundary Creek in accordance with the REPP. Data gaps that should be addressed should the PCV be considered to be raised in the future are also highlighted, noting a number of these gaps would be expected to include long-term monitoring so that a suitably robust basis for any change to the PCV is available.

1 Introduction

BlueSphere Environmental Pty Ltd (BlueSphere) was engaged by Barwon Region Water Corporation (Barwon Water) to undertake a Hydrogeological Assessment of the Barwon Downs Sub-basin Investigation Area, herein referred to as the BDIA. The BDIA is located within the Barwon Downs Graben.

The location of the BDIA within the broader Barwon Downs Graben is shown on **Figure F1**, while the Barwon Downs Graben is shown below on **Figure 1**.

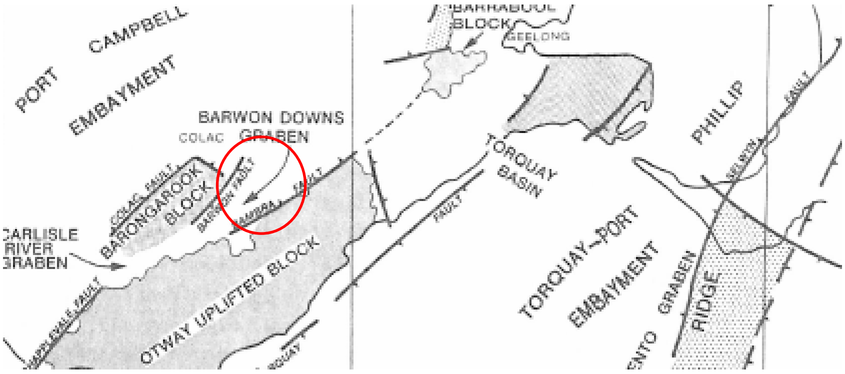

Figure 1 Regional Setting, (after (Department of Minerals and Energy, 1984)) (approximate BDIA location shown in red)

1.1 Background

Between 1982/1983 and 2016 Barwon Water operated a borefield within a geological feature known as the Barwon Downs Graben, located approximately 70 km south-west of Geelong. The borefield was operated in accordance with a licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water (SRW)) and is herein referred to as the Barwon Downs borefield (shown on **Figure F1**). It has historically been referred to as the 'Gerangamete Groundwater Field'.

The Barwon Downs borefield extracted groundwater from the aquifer referred to as the Lower Tertiary Aquifer (LTA). The LTA outcrops on the margins of the groundwater catchment and extends to a depth of approximately 600 m below ground surface within the Barwon Downs Graben (see **Sections 4.8.1.1** and **4.9**).

Over a period of approximately 30 years, Barwon Water periodically extracted a total volume of up to 119,000 ML of groundwater to augment surface water supplies during periods of drought. As a result of the pumping, the pressure head of groundwater within the LTA was reported to have declined in the order of 60 m in the vicinity of the borefield. Investigations to date have identified that this, in concert with other factors, has contributed to unintended consequences on select reaches of Boundary Creek (the location of which is shown on **Figure F1**) including dewatering, oxidisation of acid sulfate soils and increased fire risk in relation to peat deposits.

In June 2017 Barwon Water acknowledged that the pumping had led to unintended consequences. Barwon Water no longer has a licence to extract groundwater from the borefield.

In September 2018 Barwon Water was issued a Section 78 notice (s78) by SRW, acting on behalf of the Minister (see **Section 2.2.1** for further information), that required Barwon Water to:

a) *Continue no extraction, other than for maintenance and emergency response, and*

b) *Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and*

c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.*

In addition to this, the s78 notice also required the development and implementation of the Boundary Creek, Big Swamp and Remediation and Environmental Protection Plan (REPP), this is currently being delivered under two parallel work packages and which was to (among others) include:

- Identification of appropriate hydrogeological, hydrological and geochemical assessments to support the plan;
- Consult with Corangamite Catchment Management Authority (CCMA);
- Consult with SRW appointed expert reviewer; and
- Engage with the local community and seek ideas and feedback.

The REPP had two objectives (which were working in parallel). These were to:

- Boundary Creek & Big Swamp Remediation Plan – address remediation of confirmed impact in Boundary Creek Catchment; and
- Surrounding Environment Investigation – to investigate if other areas within regional groundwater system have been impacted by extraction.

In 2019 an existing numerical groundwater model was updated and used to consider the whole extent of the LTA as the starting point to identify other potentially impacted areas within the broader aquifer system (Jacobs, 2018a). This work identified eight potentially impacted areas where reductions in groundwater levels/pressures could have led to reductions in groundwater discharge from the LTA. The outcomes of this work completed by Jacobs (2018a) were also used to identify what further information and/or monitoring would be required to determine if Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield resulted in any environmentally significant adverse impacts within the broader surrounding environment. This investigation focusses on five of the eight potentially impacted areas as shown on **Figure F2**, and described below:

- Barwon River West Branch;
- Barwon River East Branch;
- Barwon River Confluence;
- Groundwater Dependent Ecosystems (GDEs) east of Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks); and
- GDEs west of Barwon River (Barongarook Creek).

1.1.1 Stakeholders

In May 2018 Barwon Water engaged with the community and other interested parties to establish a working group for the design of the REPP for Big Swamp and Boundary Creek. A summary of the stakeholders and their interest in the REPP and Surrounding Environment Investigation is provided in **Table 1**, below. The working group engaged independent technical experts to provide independent specialist advice and those independent experts are also provided in **Table 1**, below.

Table 1 Stakeholders

Stakeholder Group	Stakeholder	Interest
Barwon Water's Remediation Reference Group	Corangamite Catchment Management Authority (CCMA)	Regional catchment management authority
	Colac Otway Shire Council	Local council
	Land and Water Resources Otway Catchment (LAWROC)	Local community group representing local landholders who may be impacted by the historic pumping activities
	Environment Victoria	Interested environmental group
	Upper Barwon Landcare Group	Interested community group
	Boundary Creek landowners	Potentially affected landholders

Stakeholder Group	Stakeholder	Interest
	Traditional Owners	Interested community group
	Other interested community members	Interested community group
Barwon Water's Remediation Reference Group Independent Technical Experts	Professor Richard Bush, Global Innovation Chair, International Centre for Balanced Land Use Office, Monash University	Independent Technical Expert
	Dr Vanessa Wong, Senior Lecturer, School of Earth Atmosphere and Environment, Monash University	Independent Technical Expert
	Dr Darren Baldwin, independent consultant, visiting adjunct professor, School of Environmental Sciences, Charles Sturt University	Independent Technical Expert
Regulator	Southern Rural Water	Regulator and Issuer of s78 notice
Southern Rural Water's Independent Technical Review Panel (ITRP)		Independent Technical Advice to SRW
Southern Rural Water's Community Leaders Group (CLG)		Community members interested in the REPP and associated works
Department of Energy Environment and Climate Action (DEECA)		Water resource manager for Victoria – will be kept informed of the progress and implementation of the REPP
EPA Victoria		Ensuring appropriate action is being taken to reduce risks and harm to human health and the environment

1.2 Objectives

The objectives of the hydrogeological assessment (HA) of the BDIA are to:

- Develop a robust conceptual site model[1] (CSM) based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield has resulted in any environmentally significant adverse impacts within the broader environment.

The CSM will also form the basis for the subsequent management decisions in the catchment.

[1] "A conceptual (hydrogeological) model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions (Anderson and Woessner 1992). It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes." (Barnett B, 2012).

1.3 Scope of Work and Methodology

In order to achieve the objectives of the project the following scope was completed:

- Review of existing reports and information (refer to **Section 2**, below);
- Desktop review of publicly available information relating to the BDIA setting, geology, hydrogeology, hydrology, rainfall including community gathered and climate, groundwater dependent ecosystems and acid sulfate soils;
- Completion of an inspection of key locations within the BDIA;
- Development of a CSM for the BDIA;
- Identification of susceptible water features;
- Apportionment of likely flow impact from historic groundwater pumping activities as opposed to other factors and identification of confirmed areas of impact;
- Overview of changes and/or improvements since cessation of groundwater pumping activities;
- Consultation with relevant stakeholders including presenting and testing the assumptions in the CSM; and
- Preparation of this report.

The HA was completed in general accordance with Environment Protection Authority (EPA) Victoria Publication 668.1 Hydrogeological Assessment (Groundwater Quality) Guidelines, December 2022.

2 Key Documents and Information Sources

2.1 Introduction

This section summarises the two key documents that provide context to the current investigation and the various information sources that were accessed and reviewed during the preparation of this report.

2.2 Key Documents

2.2.1 Section 78 Notice

Barwon Water was issued with a Ministerial Notice, Issued pursuant to Section 78 of the Water Act 1989, Licence Number: BEE032496 on 11 September 2018 requiring Barwon Water to:

a) *Continue no extraction, other than for maintenance and emergency response, and*

b) *Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and*

c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.*

The notice was issued on the basis of findings from several reports which were:

- *A report (Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts, Jacobs June, 2017) found that the operation of the borefield over 30 years was responsible for 2/3 of the reduction of groundwater base flow into Boundary Creek.*
- *An additional report (2016-2017 Technical Works Program Yeodene Swamp Study, Jacobs, November 2017) indicated the licence condition requiring the release of 2 ML/d of supplementary flow into Boundary Creek had not been effective at offsetting the impacts of the borefield operation on groundwater base flows in Boundary Creek. This resulted in the creek drying out, generation of acid sulfate soils and release of acid water into downstream.*

Southern Rural Water (SRW) (acting on behalf of the Minister) formed the view that the borefield had caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment.

Section 2.2 of the Notice required: *Barwon Water must prepare and implement the 'Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan'*.

Per Section 2.5 of the Notice:

2.5 By 20 December 2019 Barwon Water must submit to SRW the Plan which includes:

a) *A description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment; this will include:*
   - *Hydrogeological conditions (groundwater levels and quality)*
   - *Hydrology (Surface water quality and flow monitoring)*
   - *Ecological assessment*
   - *LIDAR topographic mapping*
   - *Results of soil sampling program (Soil chemistry, peat profile, incubation tests)*
   - *Additional matters arising from the scope contemplated in Item 2.4.*

b) *An outline and risk assessment of the processes/activities on the Property which may impact on Boundary Creek, Big Swamp and the surrounding environment (including, but not limited to hydrogeology, hydrology and soil chemistry);*

c) *A range of controls and actions that could be practicably carried out to protect and improve the condition of Boundary Creek and Big Swamp and the surrounding environment, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;*

d) *A comprehensive risk assessment of proposed controls and actions documented in c);*

e) *The controls and actions to be implemented, including reasonable targets and/or measures of success to be adopted for the purposes of implementation of the plan;*

f) *A monitoring program to check the controls and actions documented in e);*

g) *Contingency measures designed to address any issues identified from monitoring results;*

h) *A schedule of timeframes by which the controls and actions documented in e) will be carried out; and*

i) *A reporting schedule, whereby Barwon Water will provide a minimum of quarterly updates to SRW which report on the progress of the plan, as well as an Annual Report. The Annual Report must be submitted to SRW and made publicly available by 30 September each year.*

The notice remains in effect until Barwon Water can demonstrate to the satisfaction of SRW that the plan has been implemented and measures and outcomes (per Section 2.5 of the Notice) have been achieved. A copy of the Notice is provided in **Appendix A**. In preparing the scope of work for the plan Barwon Water was required to consult with various stakeholders.

2.2.2 Remediation Environmental Protection Plan

A Remediation and Environmental Protection Plan (REPP) was submitted in December 2019 and last amended in December 2022 (interim draft). The implementation of the REPP is a requirement of a Ministerial Notice issued pursuant to Section 78 of the Water Act 1989 by SRW on 11 September 2018. The REPP includes two key work streams:

- The Boundary Creek and Big Swamp Remediation Plan: Remediation of the confirmed areas of impact in the Boundary Creek catchment; and
- The Surrounding Environment Investigation: Investigation of the surrounding environment to identify if any other areas have been impacted by historical management of groundwater extraction from the borefield.

A numerical groundwater model was initially developed in 1994 by Barwon Water which has since evolved and in 2019 the model was used to assess historical impacts of pumping and identify potential high risk areas. The results of the modelling completed by (Jacobs, 2019) identified eight potentially impacted areas (i.e., areas where groundwater extraction had the potential to have led to a hydraulic influence) requiring further investigation:

- Boundary Creek between McDonalds Dam and Big Swamp;
- Barwon River (East branch);
- Barwon River (West branch);
- Barwon River (downstream of the confluence);
- Gellibrand River and associated Groundwater Dependent Ecosystems (GDEs);
- Ten Mile Creek;
- Yahoo Creek;
- GDEs west of the Barwon River (near Yeodene); and
- GDEs east of the Barwon River (between Barwon Downs and Yeodene).

In June 2017, Barwon Water acknowledged that the historic management of the groundwater pumping activities had led to a reduction in groundwater contribution to the LTA into Boundary Creek, a tributary of Barwon River. This reduction, in conjunction with the changes in land use, Millenium Drought, and the complexities associated with management and regulation of a private on-stream dam that controls flows into the lower reaches of Boundary Creek, resulted in the increased frequency and duration of ‘cease to flow’ and ‘acid flush’ events along Boundary Creek and Big Swamp – a wetland that is primarily fed by inflows from Boundary Creek, This was despite meeting the provisions set out in the groundwater extraction licence(s) that were intended to offset the potential impacts from Barwon Water’s groundwater pumping activities on Boundary Creek.

Remedial actions for Boundary Creek and Big Swamp included:

- Cessation of groundwater pumping activities;
- Decommissioning of the Barwon Downs extraction bores;
- Provision of supplementary flows, where required, to minimise the potential for cease to flow events until remediation is successful;
- Prevent the encroachment of dry vegetation classes; and
- Development of risk-based contingency measures.

A number of data gaps were identified in the Surrounding Environment Investigation of which this report looks to address. And associated with those data gaps a Surrounding Investigation monitoring asset installation program was completed involving the installation of site specific monitoring assets including 212 groundwater (GW) bores, 5 stream gauges and 6 new vegetation monitoring sites.

The outcomes of the Surrounding Environment Investigation are to be provided to SRW by 31 July 2023.

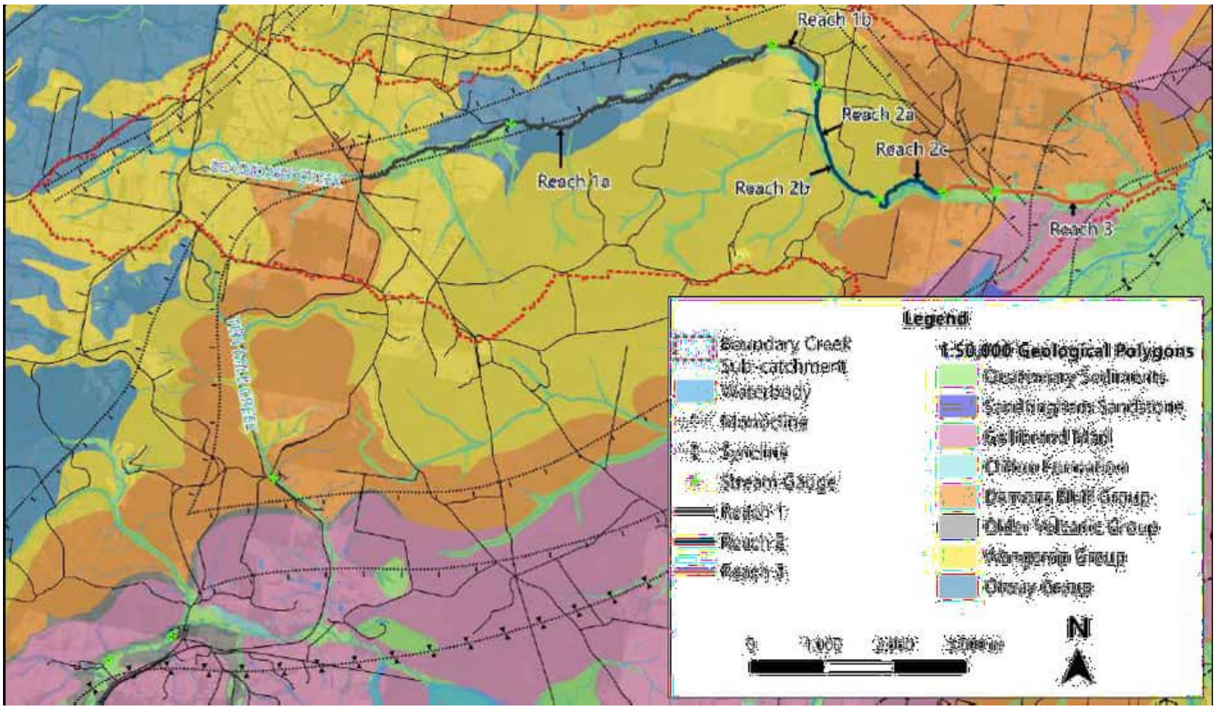

Figure 2 Boundary Creek Reaches (CDM Smith, 2022)

2.3 List of Reports Considered

During the course of the investigation a number of reports as provided by Barwon Water and independently sourced were reviewed. A list of those reports is provided below, and summaries of the reports are provided in **Appendix B**.

- W.J.R. Blake, 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area, Geological Survey of Victoria;
- J. Leonard, R. Lakey, R. Blake, 1983, Hydrogeological investigation and assessment - Barwon Down Graben, Otway Basin, Victoria, Geological Survey of Victoria (unpublished);
- R. Lakey, 1983, Gellibrand Groundwater Investigation – Kawarren Pumping Test Report, Geological Survey of Victoria;
- R. Lakey, J. Leonard, 1983, Gellibrand Groundwater Investigation – Stage II Report, August 1983;

- Geological Survey of Victoria, 1984, Department of Minerals and Energy Submission to Natural Resources and Environment Committee Inquiry into Water Resources Management;
- HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area - Kawarren Groundwater Resource Evaluation;
- P. Dahlhaus, D. Heislers, P. Dyson, 2002, Groundwater flow systems of the Corangamite Catchment Management Authority Region;
- B. Petrides & I. Cartwright, 2006, The hydrogeology and hydrogeochemistry of the Barwon Downs Graben aquifer, southwestern Victoria, Australia;
- SKM, 2012, Newlingrook Groundwater Investigation, Gellibrand River Streambed and Baseflow Assessment, 21 December 2012;
- F. Glover, 2014, Characterisation of acid sulfate soils in south-west Victoria, Australia. PhD Thesis, December 2014;
- Aquade Groundwater Services, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area;
- Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/2016 - Recharge Rate Assessment;
- Aquade Groundwater Services, 2017, Impacts of Barwon Downs extraction on groundwater and surface water in the Kawarren Area;
- Jacobs, 2018, Barwon Downs Technical Works Program - Potential impacts and risks from future operation of the Barwon Downs Borefield;
- Aquade Groundwater Services, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment;
- Jacobs, 2019, Technical support for Section 78 Scope of Works - Historical Pumping Risk Assessment Method and Results;
- M. Gardiner, 2013, Otway Water Book 21: An aquifer divide shift and Study of the EVF aquifers in the Gerangamete and Gellibrand Groundwater Management Areas, 2013;
- M. Gardiner, 2015, Otway Water Book 28: The Western Front, Ten Mile and Loves Creek Catchment, 2015;
- Preliminary Draft Regional Landcare Action Plan for the Corangamite Region, 1993;
- Stanley 1991, Preliminary Groundwater Resource Evaluation of the Kawarren Sub-region of the Barwon Downs Graben;
- Jacobs 2022, Surrounding Environment Bore Completion Report, Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan (REPP), 25 October 2022;
- Austral Research and Consulting 2022, Upper Barwon River Macroinvertebrate Sampling Report 2019-2022;
- EAL 2011, Preliminary Inland Acid Sulfate Soil Assessment Report, prepared for LAWROC;
- Eco Logical Australia 2022, Barwon Downs Vegetation Monitoring Report, - November 2020, prepared for Barwon Water, 28 June 2022;
- Eco Logical Australia 2022, Groundwater Dependent Ecosystem Survey of the Barwon Downs region, prepared for Barwon Water, 19 August 2022;
- Jacobs 2015, Barwon Downs Vegetation Monitoring Report;
- Jacobs 2017, Barwon Downs Vegetation Monitoring Report;
- Muir and Carr 1994, Barwon Downs aquifer flora;
- Jacobs 2022, Otway Ranges surrounding areas hydrogeological investigation, October 2022;

- Witebsky, Chandrika, Shugg 1995, Groundwater development options and environmental impacts, Barwon Downs Graben South-Western Victoria, Department of Natural Resources and Environment;
- Jacobs 2017, Barwon Downs Technical Works Program, Integration Report, 22 March 2017;
- Jacobs 2018, Barwon Downs Hydrogeological Studies 2016-2017, Numerical Model Calibration an Historical Impacts, 22 August 2018;
- Aquade 2019, Impacts of Barwon Downs Extraction on Groundwater and Surface water in the Kawarren Area, Part B (Update), 15 November 2019;
- GHD 2021, Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design, Technical Modelling Report. Prepared for Barwon Water, April 2021;
- CDM Smith 2022, PRB Assessment. Prepared for Barwon Water, 13 September 2022; and
- Nation Partners 2023 (draft), Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River. Prepared for Barwon Water, June 2023.

2.4 Information Sources

During the preparation of this report various sources of information were reviewed including:

- Public Databases:
  - Water Measurement Information System (WMIS);
  - Visualising Victoria’s Groundwater (VVG);
  - GeoVic – Earth Resources;
  - Bureau of Meteorology – Climate and Past Weather;
  - Bureau of Meteorology – Groundwater Dependent Ecosystem Atlas;
  - Australian Stratigraphic Units Database;
- Publicly available information relating to geology, hydrogeology, topography, surface water;
- Previous reports provided by Barwon Water;
- Spatial data provided by Barwon Water;
- Excel databases provided by Barwon Water;
- Community recorded rainfall;
- Site inspection; and
- Stakeholder informal and formal feedback.

3 Barwon Downs Sub-Basin Investigation Area (BDIA) Overview

3.1 Introduction

The following sections detail the location of the BDIA, a brief history and a brief overview of previous investigations.

3.2 BDIA Definition

The BDIA sits within the wider region identified as the Barwon Downs Graben (see **Figure 1**), which lies approximately 63 km south west of Geelong. The Barwon Downs Graben covers an area of approximately 480 km^2, extending from the Gellibrand area at its southern most extent and north east towards Birregurra (**Figure F1**). The Barwon Downs Graben is divided into two sub-basins as shown on **Figure F1**, which are referred to as:

- The Barwon Downs Sub-basin Investigation Area, i.e., BDIA, which is the subject of this report; and
- The Kawarren Sub-Basin Investigation Area (herein referred to as KIA).

The BDIA is bound to the north west by the Barongarook High, which further east reduces in elevation but continues along the northern boundary to approximately Birregurra, and Otway Ranges to the south. The topography is shown on **Figure F3** and further discussed in **Section 4.3**.

The BDIA sits within the Corangamite Catchment Management Authority (CMA) management area. The Barwon River is the main surface water catchment within the BDIA, with Barwon River East and West branches, Boundary Creek, Pennyroyal Creek, Deans Marsh Creek, Matthews Creek, Dewing Creek, Barongarook Creek, Yan Yan Gurt Creek and Wurdiboluc Channel all draining into the Barwon River (**Figure F4**).

3.3 BDIA History

Pre-European settlement, the BDIA would have been vegetated more than it currently is with native vegetation. Clearing of native vegetation for farmland generally occurring during early European settlement circa. 1930s (Mary Sheehan & Assoc. , 2003). Townships were progressively developed from the 1860s (Mary Sheehan & Assoc. , 2003). Rail was developed within the BDIA in the 1880s which assisted the vegetable and livestock industry (Mary Sheehan & Assoc. , 2003).

Within the Boundary Creek catchment land clearing occurred pre the 1940s. Boundary Creek and Big Swamp were partially drained in ~1946 for agricultural purposes. These included deep trench like drainage lines which are still present today. In 1979 a dam was constructed along Boundary Creek, up-stream of Big Swamp, with a storage capacity of 160 ML. The dam is herein referred to as McDonalds Dam. Between 1998 and 2010 a sub-surface fire smouldered in the swamp while the swamp was dry. A fire trench was dug in March/April 2010 along the southern and eastern sides of the swamp to contain the smouldering.

Vegetable crops were grown in the early 1900s on the Barwon River flats along with hops, which were also grown in the upper reaches of the Barwon River (Mary Sheehan & Assoc. , 2003). Timber mills began in the area including Forrest and Barongarook in the early 1900s and continued before being rationalised in the 1980s. Six large mills now remain including in Forrest and Barongarook (Mary Sheehan & Assoc. , 2003).

The BDIA and KIA were first investigated as a potential water supply option to augment Geelong's drinking water during periods of drought in the 1960s (Blake, 1974). The borefield was developed in the 1970s and Geelong Waterworks and Sewerage Trust (now Barwon Water) was granted an extraction licence in 1975, however, extraction did not occur until 1982 (Barwon Water, 2019). Further information regarding the borefield and extraction volumes and periods is provided in **Section 4.10.2,** below.

3.4 Previous Investigations

The BDIA and KIA have been the subject of numerous historical investigations since ~1960s, when the Barwon Downs area was first mentioned as a potential option for a borefield to augment Geelong's water supply during periods of drought. The BDIA was the first option considered for groundwater supply and planning and investigations occurred c. 1970s before the installation of three production bores in the current borefield area (further detail on the production bores is provided in **Section 4.10.2**, below). A relatively large monitoring network of bores including State owned and Barwon Water owned bores exists across the BDIA and wider Barwon Downs area and these are shown on **Figure F19**.

The first phases of investigations were completed on behalf of Geelong Waterworks and Sewerage Trust (now Barwon Water) (Blake, 1974) and identified the main recharge areas of groundwater to the LTA were along the flanks of the Barongarook High, while groundwater flowed from the Barongarook High south west towards Gellibrand River and east north east towards the BDIA and the thickest portions of the Barwon Downs graben. Studies completed in the 1980s (Leonard et al., 1983) estimated a recharge of ~14,800 ML/year from Barongarook High to the primary aquifer of interest (LTA), noting that these recharge estimates have varied over time and are further discussed in **Section 4.9.5.6.**

Leonard et al., (1983) noted that pumping of the Barwon Downs borefield was scheduled to commence in February 1983 with a total of three production bores and a combined daily extraction allowance of 35 ML. It was noted that if recharge calculations were correct then the annual extraction allowance of 12,400 ML would exceed recharge (estimated to be 6,300 ML) from one of the main recharge avenues (Yeodene recharge avenue). Additional sources of recharge were identified once the Barwon Downs borefield had been developed including: enhanced natural recharge as a result of lowered water levels, induced stream bed infiltration as levels fell below stream level, leakage from overlying marl members, leakage from clay and silt layers within the LTA, leakage from the Otway Group underlying and flanking the graben, and natural recharge from along the Bambra Fault (Leonard et al., 1983). A second borefield was proposed and was under consideration pending further pumping test results, however, was not constructed.

An investigation into the recharge area of the Barongarook High by HydroTechnology (1994) identified an area of approximately 12 km^2 of outcropping aquifer material which was considered to act as the principal recharge area to the KIA, from a total outcrop area of 28 km^2. An area was not determined for recharge to the BDIA. A groundwater divide was found to separate groundwater flow from the Barongarook High into either the BDIA or the KIA. Groundwater discharge was considered to occur to streams draining the Barongarook High including Ten Mile Creek and Boundary Creek. HydroTechnology (1994) concluded the sustained pumping (from either or both the Barwon Downs borefield and proposed Kawarren borefield) would reduce water levels on the Barongarook High and thus the groundwater divide would shift resulting in reduction of rejected recharge to the surface water systems, streams and springs. However, the degree and magnitude of the groundwater divide shift would be dependent on the scale of extraction.

Between 2018 and 2022 a number of investigations have been completed on the BDIA assessing the potential impacts from the pumping including Jacobs (2018), Jacobs (2019), Austral Research and Consulting (2022) and EAL (2022). A summary of the key findings from these reports is provided below:

- The estimated aquifer volume of the LTA is 3,000,000 ML with an average recharge over the past 30 years of 5,900 ML/year, occurring predominantly where the aquifer outcrops.
- A number of surface water bodies and areas were identified as having a medium to high risk of experiencing potential environmental impacts as a result of water levels reducing due to pumping including Boundary Creek and Big Swamp, Barwon River East Branch, Barwon River West Branch, Barwon River (main branch), Barongarook Creek and Deans Marsh area, based on the groundwater model prepared by Jacobs.
- Potential groundwater dependent ecosystems (GDEs) were identified at Deans Marsh and Barwon River East Branch based on EAL (2022) using groundwater level and groundwater salinity modelling.

4 Conceptual Site Model

4.1 Introduction

The Conceptual Site Model (CSM) for the BDIA, including consideration of climate, topography and drainage, vegetation, land use, hydrology, acid sulfate soils (ASS), geology and hydrogeology is presented in the following sections.

4.2 Climate

4.2.1 Regional Conditions

The BDIA sits within the Otway Ranges, which has one of the highest annual rainfall totals (over a 30 year period) in Victoria (see **Figure 3**, below). As can be seen below, the annual rainfall for the region ranges between 1,000 mm/year and 1,500 mm/year. Average annual rainfall between 1960 and 1991 indicated averages of between 900 and 1,200 mm/year (Barwon Water, 2022) indicating an overall increase in average annual rainfall during the most recent 30 year period. Regions inland from the Otway Ranges record average annual rainfall totals of <1,000 mm/year. Regionally, the average annual pan evaporation ranges between 1,200 and 1,400 mm/year.

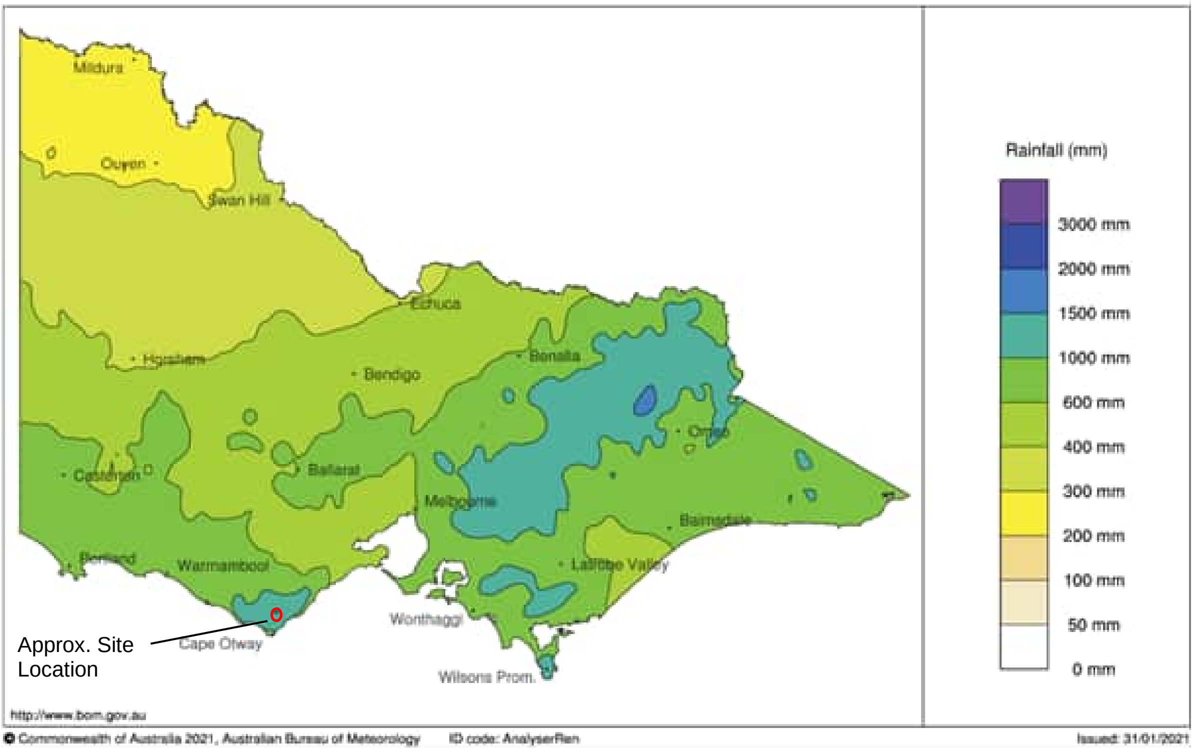

Figure 3 Spatial Trend of Average Annual Rainfall in Victoria (1991 – 2020, 30 year period) (BoM, 2020)

4.2.2 Recognised Drought Periods

A review of Bureau of Meteorology (BoM) data shows approximately seven periods of recognised drought in Australia, since Federation summarised as follows:

- 1895 – 1902 “Federation Drought”;
- 1914 – 1915;
- 1937 – 1945 “World War II Drought”;
- 1965 – 1968;
- 1982 – 1983 considered one of the most severe in Australia;
- 1997 – 2009 “Millennium Drought”; and

· 2017 – 2019.

The droughts identified during 1982-83 and 1997-2009 indicate rainfall in the BDIA was 'very much below average' and 'lowest on record', respectively as defined by the BoM (see **Figure 4** below).

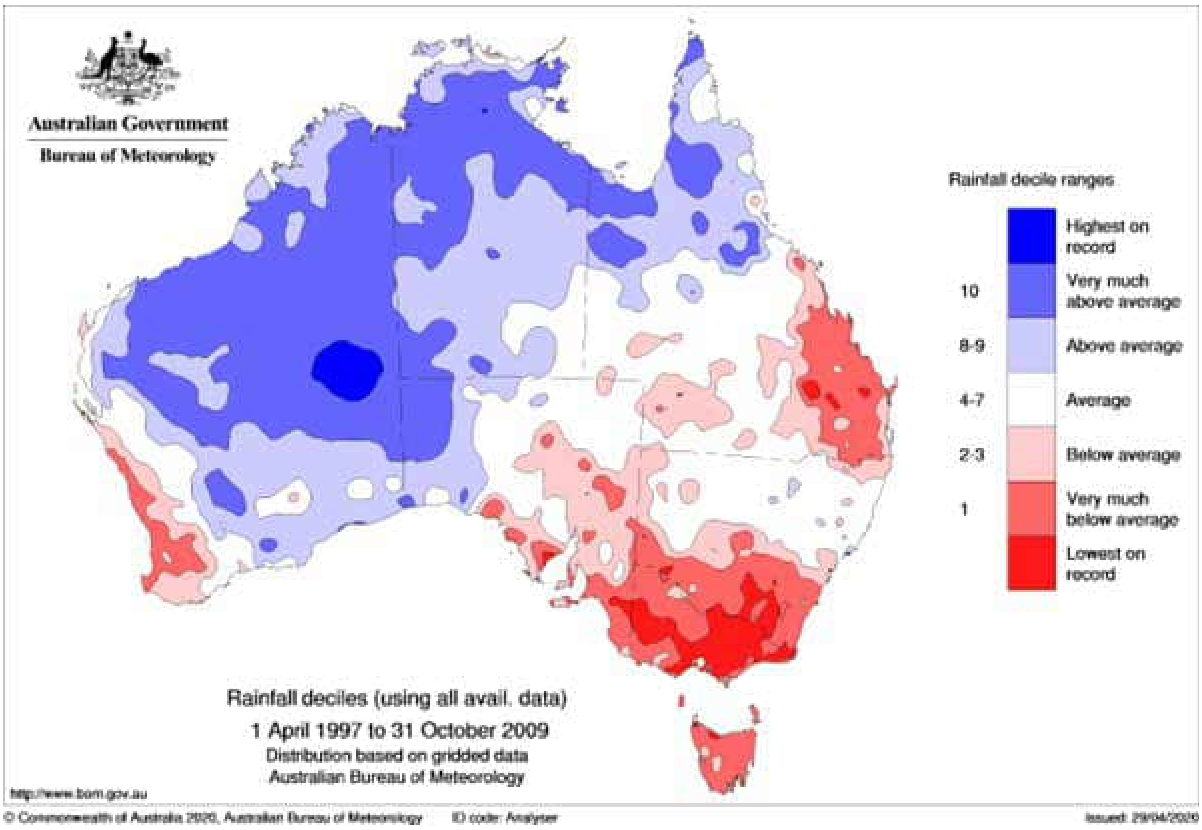

Figure 4 Rainfall Deciles for the Millennium Drought (1997 – 2009) (BoM, 2020)

4.2.3 Local Rainfall Conditions

4.2.3.1 Available Data

Rainfall data within the BDIA and surrounding areas has been collected by both community members and BoM from nine stations across the Barwon Downs Region. The records start from as far back as 1900 for several of the stations. The locations of the rainfall collection stations are shown **Figure F4** and their name and station number are provided in **Table 2**, below.

The rainfall records collected and identified as Barwon Downs (station #90004) and Forrest State Forrest (Station #90040) have been adopted specifically for this HA based on their long durations which are of specific value to appraising long-term groundwater influence, and Agroforestry (#233250) for its location within the BDIA. Additionally, the rainfall records for Barongarook Rainfall (J. Healey) have been used as this station sits within the main recharge area.

Table 2 Rainfall Stations

Station	Type	Source	Within BDIA	Period of Collection
Kawarren Rainfall (M.Calvert)	Community Gathered	M.Calvert, Kawarren	No	1900 – 2022
Gellibrand River Forestry #90134	BoM	BoM	No	1956 – 2015

Station	Type	Source	Within BDIA	Period of Collection
Wanawong Rainfall (D. Hopkins)	Community Gathered	D. Hopkins, Barongarook West	No	1976 – 2022
Kawarren Rainfall (M. Gardiner)	Community Gathered	M. Gardiner, Kawarren	No	1999 – 2004
Gellibrand Rainfall (B.Dawes)	Community Gathered	B. Dawes, Kawarren East	No	2009 – 2022
Forrest State Forrest #90040	BoM	BoM	Yes South western portion	1900 – 2017
Barwon Downs #90004	BoM	BoM	Yes Adjacent to borefield	1900 – 2022
Barongarook Rainfall (J. Healey)	Community Gathered	J. Healey, Barongarook	No However, closest to the headwaters of Boundary Creek and recharge area of the LTA	1978 – 2022
Agroforestry Site #233250	WMIS	WMIS	Yes	1994 – 2022

4.2.3.2 Average Annual Rainfall

Average annual rainfall is presented for each station in **Table 3**. The peak annual rainfall totals are evident in the south western portion of the BDIA (up to 1009 mm/year at Forrest State Forest), with lower totals in the Barwon Downs area (611 mm/year and 760 mm/year around the Barwon Downs borefield). To the west of the BDIA, within the Kawarren Area, rainfall totals are generally >900 mm/year.

Average annual rainfall and a five year moving average, from all rainfall stations over time is shown on **Figure 5**. Periods of below average rainfall (generally coinciding with acknowledged drought periods) are evident throughout the dataset period. The five year moving average smooths the dataset over time. Long term-trends are further described in **Section 4.2.3.3**.

Table 3 Average Annual Rainfall by Station

Station	Average Annual Rainfall (mm/year)	Period of Collection
Kawarren Rainfall (M.Calvert)	981	1900 – 2022
Gellibrand River Forestry #90134	961	1956 – 2015
Wanawong Rainfall (D. Hopkins)	970	1976 – 2022
Kawarren Rainfall (M. Gardiner)	909	1999 – 2004
Gellibrand Rainfall (B.Dawes)	1006	2009 – 2022
Forrest State Forest #90040	**1009**	**1900 – 2017**
Barwon Downs #90004	**760**	**1900 – 2022**

Station	Average Annual Rainfall (mm/year)	Period of Collection
Barongarook Rainfall (J. Healey)	**897**	**1978 – 2022**
Agroforestry Site #233250	**611**	**1994 – 2022**

Notes: **Bold text** indicates station is within the BDIA boundary. Barongarook Rainfall (J. Healey) has also been included due to its proximity to the headwaters of Boundary Creek and the recharge area of the LTA.

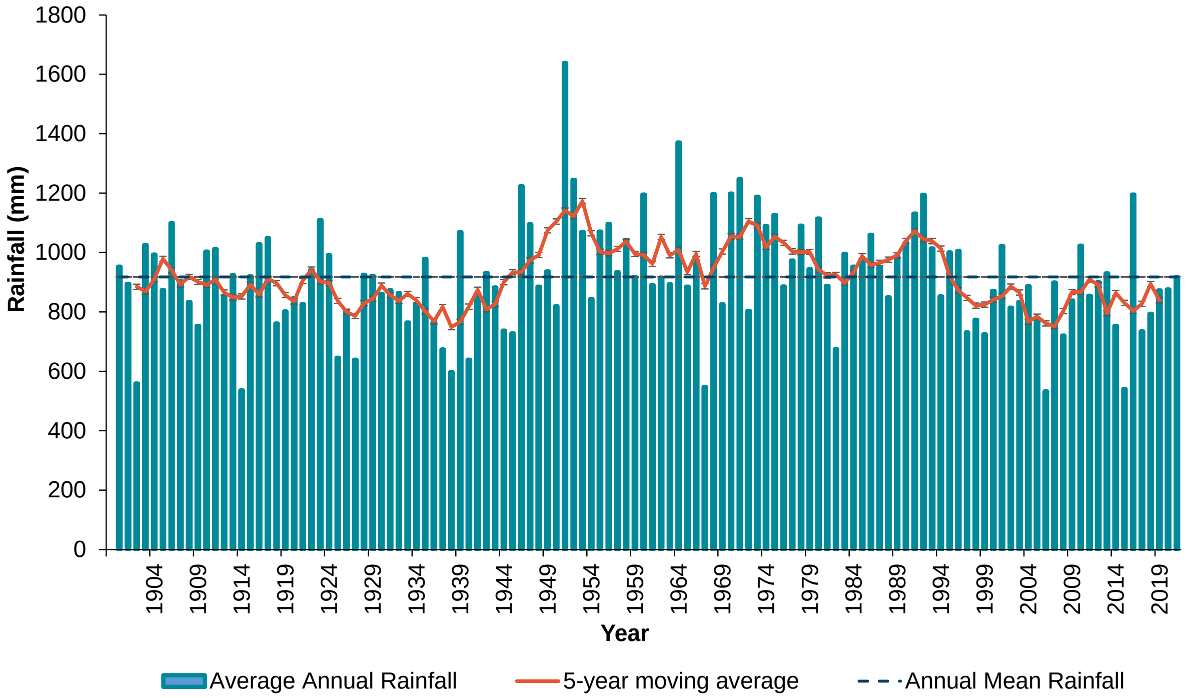

Figure 5 Average Annual Rainfall from nine rainfall station sites

4.2.3.3 Long-Term Rainfall Trends

To provide a further indication of long-term rainfall trends, rainfall data collected has been plotted as accumulative monthly residual rainfall (AMMR) for the nine stations (see **Figure 6** below). AMRR provides the cumulative deviation of rainfall totals from the average monthly total. A negative deviation indicates a declining rainfall trend (i.e., potential period of drought) and a positive deviation indicates an increasing rainfall trend (i.e., above average rainfall).

The following observations are noted:

- The rainfall data follow a largely consistent pattern with some deviations at several stations, most notable during the late 1990s when data from J.Healey (Barongarook recharge area), Wanawong (D.Hopkins) and Agroforestry #233250 trends up while the remaining data tends to trend down. The trend down corresponds with the Millennium Drought period.
- Rainfall data from J.Healey (Barongarook recharge area) continues to trend down until the last record available (August 2022). This is also the case for data collected from Gellibrand Station #90134, however, the data collected ceases in June 2015, so it is not clear if there is an increase in rainfall.
- From approximately 2017, rainfall appears to stabilise at M. Calvert (Kawarren Area), Agroforestry #233250, Wanawong (D.Hopkins) and D.Dawes (Gellibrand River area) and appear to stabilise close to average monthly totals.

- Conversely from approximately 2017, rainfall continues to decline at J. Healey (Barongarook recharge area), Gellibrand Station #90134, Forrest #90040 and Barwon Downs #90004, remaining well below average monthly totals.

Overall, the long-term patterns are relatively consistent particularly since the 1950s. A period of overall increasing rainfall was evident between the 1950s and approximately 1997, after which a period of decreasing rainfall has prevailed.

The cumulative change in monthly rainfall during the period 1997 to 2009 (i.e., the millennium drought) is provided in **Table 4**. This shows that the cumulative reduction in rainfall from the mean during the Millennium Drought was a deficit of between 426 mm and 1,921 mm over the 13 year period. This equates to average annual deficits of between 33 mm/year (in the BDIA) and 148 mm/year at Kawarren (M.Calvert). The peak average rainfall deficit in the BDIA was 88 mm/year at Forrest State Forest.

It is noted that each monitoring location in the BDIA shows variable deficits and percentage changes in rainfall. The discrepancies appear to represent local variation, with the greatest deficits occurring in the elevated areas on the margins of the BDIA. The percentage change is greatest at Barwon Downs #90004 presumably as this station has the lowest average annual rainfall, which makes the relative contribution proportionally greater.

Table 4 Cumulative Change in Rainfall (1997 to 2009) by Station

Station	Average Annual Rainfall (mm/year)	Total Cumulative Change in Rainfall (1997-2009)	Average Cumulative Change in Rainfall (mm/year)	Percentage Change from Mean Annual Rainfall (%/year)
Kawarren Rainfall (M.Calvert)	981	-1921	-148	15%
Gellibrand River Forestry #90134	961	-1528	-118	12%
Wanawong Rainfall (D. Hopkins)	970	-859	-66	7%
Kawarren Rainfall (M. Gardiner)	909	Incomplete record during applicable time period	Incomplete record during applicable time period	-
Gellibrand Rainfall (B.Dawes)	1006	Incomplete record during applicable time period	Incomplete record during applicable time period	-
Forrest State Forest #90040	**1009**	**-1145**	**-88**	**9%**
Barwon Downs #90004	**760**	**-426**	**-33**	**4%**
Barongarook Rainfall (J. Healey)	**897**	**-797**	**-61**	**7%**
Agroforestry Site #233250	**611**	**-599**	**-46**	**7%**

Notes: **Bold text** indicates station is within BDIA boundary. Barongarook Rainfall (J. Healey) has also been included due to its proximity to the headwaters of Boundary Creek and the recharge area of the LTA.

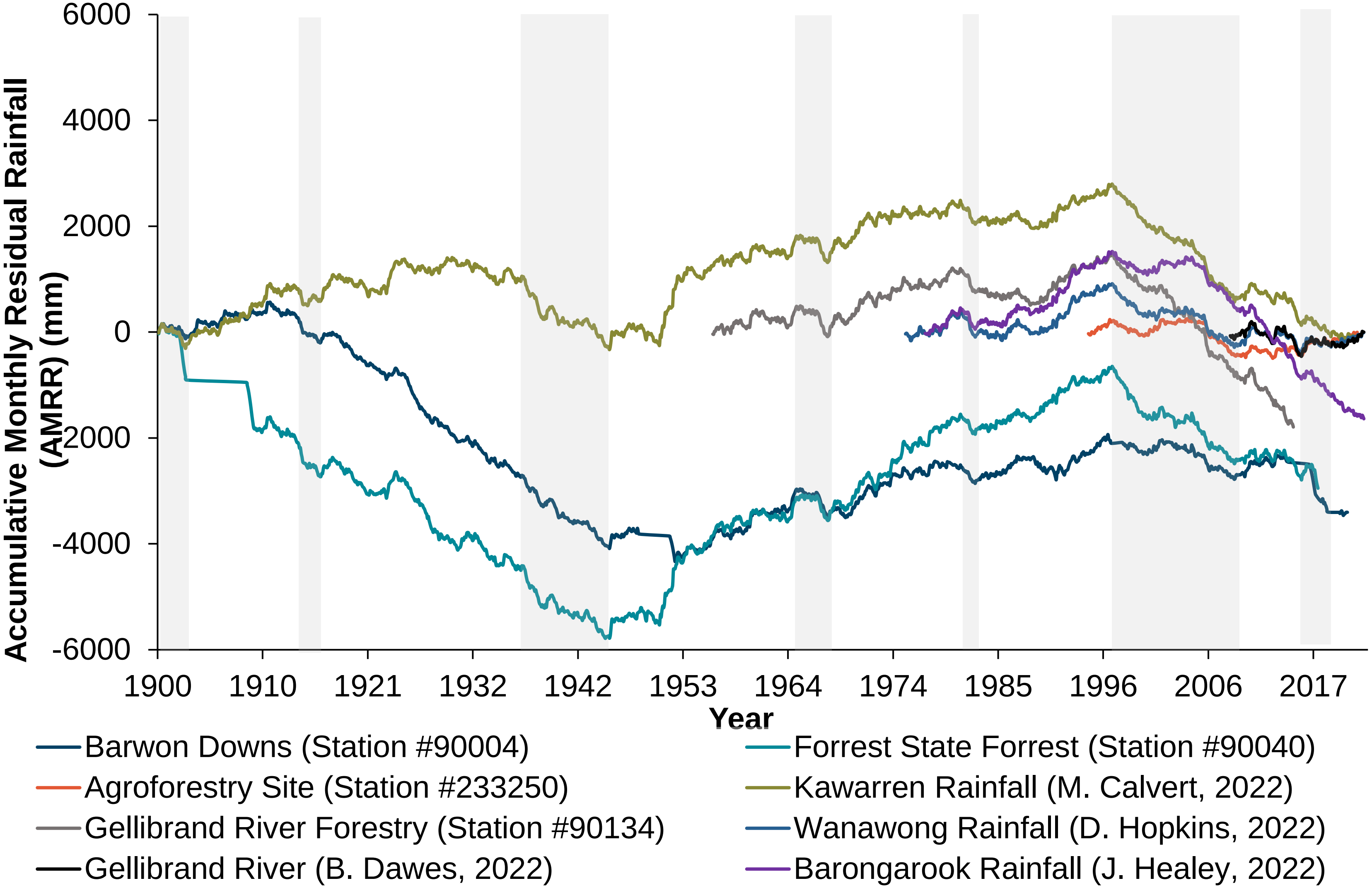

Figure 6 Accumulative Monthly Residual Rainfall (grey shading indicates periods of droughts)

4.2.4 Evaporation

The annual pan evaporation for the Barwon Downs region since 1985 has ranged between approximately 1,400 mm/year and almost 1,800 mm/year, which is generally higher than the Victorian average annual pan evaporation (see **Figure 7**, below).

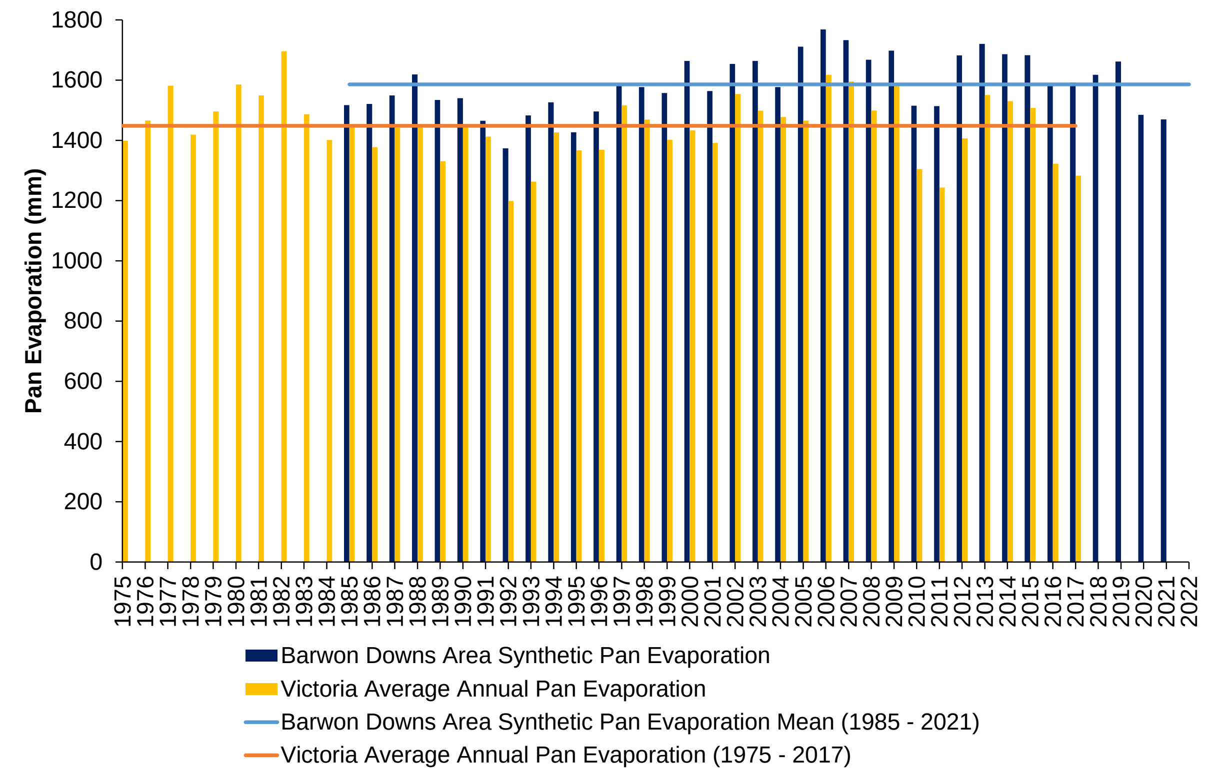

Figure 7 Pan Evaporation Barwon Downs Area

4.2.5 Climate Change

In 2019 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) published a report titled Barwon Climate Projections 2019 (Clarke *et al.*, 2019). This report details the projected change in climate within the Barwon region as a result of global warming from anthropogenic influences. Predicted outcomes are based off two plausible scenarios of future greenhouse gas emissions: medium emissions and high emissions. Additionally, BoM and CSIRO published a 'State of the Climate 2022' report in 2022 (Commonwealth of Australia, 2022).

It is estimated that over the coming decades there will be a decline in total annual rainfall as well as an increase in the natural variability of rainfall. Projected future rainfall values were modelled and compared against the mean annual rainfall from 1986 – 2005. It is projected that under a high emission scenario, there will be a median of 24% decrease in annual rainfall totals with the greatest change (34%) noted in spring. This is largely supported by the Commonwealth of Australia (2022) report which reports that rainfall in south eastern Australia has decreased by around 10% in April to October since the late 1990s, with 19 of the 22 years from 2000-21 being below the 1961-90 average. The April-October period is important as it is generally when peak stream flow occurs in catchments in the south eastern region of Australia. The reduction is due to a *"...combination of natural variability on decadal timescales and changes in large-scale circulation caused by an increase in greenhouse gas emissions."* (Commonwealth of Australia, 2022). The report notes that the Millennium Drought was a major influence in the declining rainfall however, cool season rainfall totals are 7% below the 1900-99 average post 2010 (Commonwealth of Australia, 2022).

A decrease in streamflow is projected to be greater than the predicted decrease in mean annual rainfall with the greatest impacts noted to be present in Victoria's south-west (DEWLP *et al.,* 2020). It is projected that there may be an average streamflow reduction by up to 50% in some catchments by 2065 (BOM *et al.,* 2020). As a result, catchment runoff generation is expected to decline in the coming decades with the reduction in streamflow. A declining trend in streamflow is seen in more than 60% of

Australia's hydrologic reference stations, with more than 20% showing a statistically significant declining trend (Commonwealth of Australia, 2022).

4.3 Topography

The topography for the BDIA and surrounding area is shown on **Figure F3**. The BDIA is bound to the south east by the Otway Ranges peaking at approximately 600 m Australian Height Datum (m AHD). The Otway Ranges form a ridge and slope toward both north west, i.e. towards the BDIA and south east, i.e. away from the BDIA. On the north western side, the ranges form ridges and valleys with the ridges decreasing relatively steeply into the valleys decreasing from approximately 450 m AHD to approximately 150 m AHD, respectively. The topography of the BDIA is relatively low comparatively to the Otway Ranges generally sitting at approximately 100 m AHD, with low points largely following drainage lines.

The north western portion of the BDIA is a topographical high associated with the Barongarook High which peaks at approximately 250 m AHD.

The elevation of the BDIA flattens through the northern and north eastern portions, generally flattening to between 150 and 100 m AHD.

4.4 Drainage

The BDIA sits within the Otway Coast Basin which extends from east of Torquay to just west of Port Campbell. The BDIA is located within the Otway Coast catchment, with the Gellibrand River catchment sitting to the west of the BDIA. The predominant surface water body in the Otway Coast catchment is the Barwon River (see **Figure F4**), which originates from the foothills of the Otway Ranges via the east and west branches, before joining and becoming Barwon River main branch in the central western portion of the BDIA.

The Barwon River catchment is fed by a number of surface water bodies including Boundary Creek, Pennyroyal Creek, Deans Marsh Creek, Wurdiboluc Channel, Matthews Creek, Dewing Creek, Barongarook Creek, Yan Yan Gurt Creek and Dividing Creek (see **Figure F4**). Surface water is discussed further in **Section 4.13**.

4.5 Vegetation

Regionally, outside of the BDIA, the vegetation is predominantly Lowland Forest and Shrubby Wet Forest, with non-native vegetation as can be seen on **Figure F6**. The Lowland Forest appears to be predominantly located on elevated areas, i.e., Barongarook High, while the Shrubby West Forest appears to be associated with the Otway Ranges.

The majority of the BDIA is unclassified. Locally, in the western portion of the BDIA, the dominant vegetation apparent in the BDIA is Lowland Forest and Heathy Woodland, both located in the western portion of the BDIA. Small pockets of Grassy Woodland are located along tributaries of the Barwon River West Branch.

In 1983 the Ash Wednesday bushfires occurred in the Otway Ranges burning large areas of bushland, some of which included the lower foothills of the Otway Ranges around the Deans Marsh area.

Vegetation studies completed in the 1980s indicated vegetation was not well understood in the area Jacobs (2019). Principal types of trees were Peppermints, Messmate Stringybark and Manna Gum (Farmer-Bowers, 1986). In open forest areas Swamp Gum was widespread and was found in areas that were waterlogged and sometimes associated with acidic soils.

Vegetation surveys completed in the early stages of the Millennium Drought, at 24 quadrats surveyed in 1994 (Carr and Muir 1994), identified the health of vegetation had declined at several swamp sites, the locations of which are unknown. The re-surveyed quadrats *"…targeted swampy areas with Manna Gum Riparian Forest, Swamp Gum Forest, Scented Paperbark-Woolly Tea-tree Forest or Scrub, Swamp Gum Grassy Wetland, Pith Saw-sedge Sedgeland and Fine Twig-sedge Sedgeland."* (Jacobs, 2019). It was concluded (Jacobs, 2019) that the decline in vegetation health was likely due to a combination of below average rainfall and declining groundwater levels from pumping. Numerous tea-tree swamps that potentially contain acid sulfate soils (ASS) occur in areas with sustained waterlogging across the Otway Ranges, particularly to the north of the foothills (Glover, 2014).

As observed during the site inspection (see **Section 4.6**, below), there are several large pockets of plantations (either blue gum or pines) which are identified as non native tree areas on **Figure F6**. The non native tree areas align with the plantation areas observed during the site inspection (see **Section 4.6**). The largest plantation was observed adjacent to the Barwon River confluence.

Vegetation areas identified as potential high risk due to groundwater drawdown included west of the Barwon River to the north of Yeodene, east of the Barwon River extending from the area around Barwon Downs to Deans Marsh and south of the BDIA along Gellibrand River (Jacobs, 2019).

4.6 Site Inspection

On the 27 April 2023 representatives from BlueSphere and Barwon Water completed an inspection of key locations within the BDIA including Boundary Creek, Big Swamp, Barwon River confluence, Barwon River east and west branch headwaters and the Murroon area. The inspection was competed to gain a firsthand appreciation of the BDIA.

As discussed in the sections above, there was a distinct change in vegetation between the elevated areas and the lower lying areas. In the areas of Boundary Creek and Big Swamp and the headwaters of the Barwon River east and west branches the vegetation was dense with mature trees and a dense understorey, while in the lower lying areas the vegetation was predominantly grass land/pasture for agricultural use.

The lower reaches of Boundary Creek were observed to be heavily modified, with trenches evident draining Big Swamp into Boundary Creek. Further downstream at the Boundary Creek Barwon River confluence, the landscape was heavily modified with predominantly agricultural pastures on the low lands and pine plantations on the elevated ridge to the north.

Across the wider Barwon Downs area, the predominant land use on the low lands was observed to be agricultural pastures. The areas along the foothills of the Otway Ranges, on the south eastern portion of the BDIA, there was generally little agricultural use and large amounts of vegetated bush land. Various pine plantations were observed in this area also.

4.7 Land Use Review

Regionally land use generally corresponds with the changes in topography with the elevated areas generally corresponding with forested areas (and in some instances national parks) and the lower areas generally corresponding with farming.

Within the BDIA, the land use appears to be a mix of forested areas, plantations and farming. As is the case regionally, farming is generally constrained to the lower elevations of the BDIA while the forested areas are predominantly in the higher elevations. As discussed in **Section 4.6**, above, plantations of pine and gum were observed in the BDIA with the largest observed adjacent to the Barwon River confluence.

A review of recent Google Earth imagery indicates that in 2002 plantations (pine) to the south west of Barwon Downs township were partially cleared, and by 2003 had been completely cleared. During 2011 the large plantation at the Barwon River confluence had been cleared, and by 2013 it had all been removed. This was also the case for plantations at the foothills of the Otway Ranges to the east of Barwon Downs township. All of these plantations were progressively replanted and are still present today. In 2019 plantations along the eastern boundary of the BDIA were progressively harvested.

Hydrological changes are also evident in the BDIA. Glover (2014) notes that Pennyroyal Creek and Bambra Wetlands are tributaries of Upper Barwon Catchment and many swamps and wetlands along tributaries have been drained by artificial deepening of channels and land use change. Boundary Creek and Big Swamp have also been historically subject to drainage modifications from 1946 (**Section 3.3**)

4.8 Geology

4.8.1 Structural Geology

The BDIA sits within the Otway Basin which is an east-west aligned trough containing a thick sequence of Tertiary aged sediments and volcanics. The Otway Basin is divided into a number of intra-basinal structural embayments, troughs and highs Holdgate & Gallagher (2003) of which the Port Campbell Embayment is one.

The BDIA is located in the north-eastern corner of the Port Campbell Embayment (see **Figure 8**). The BDIA is dominated by faulting along northeast / southwest alignments with the Loves Creek-Barwon Fault and Bambra Fault bounding the Barwon Downs Graben to the northwest and southeast, respectively (see **Figure F1**). It should be noted that the Loves Creek-Barwon Fault was reclassified to a monocline by Tickell *et al.,* (1991). The graben is truncated by the east / west aligned Birregurra Monocline and Colac Fault in the north and the converging uplifted blocks in the south in the vicinity of Gellibrand township (see **Figure 9**, below) Blake (1974).

During the Late Cretaceous period, the Otway Group was block faulted with the Otway Ranges and the Barongarook High undergoing an initial uplift Lakey & Leonard (1983); Tickell *et al.,* (1991) (see **Figure F7**). The two uplifted blocks, the Otway Ranges and Barongarook High, experienced erosion during the Late Cretaceous period with a later depositional environmental causing an unconformity between the Otway Group and later Tertiary Sediments Stanley (1991).

During the mid-Tertiary period, the north eastern portion of the Port Campbell Embayment underwent another major tectonic event during which the area was block faulted by a series of northeast-southwest trending faults known as the Boundary Creek and Loves Creek-Barwon Faults Tickell *et al.,* (1991) (see **Figure 9**, below). Tertiary sediments were later draped in either anticlinal or synclinal folds (Stanley (1991) over the top of the Otway basement fault structures concealing the surface feature of the faults, forming monoclines.

4.8.1.1 Grabens

The Barwon Downs Graben and Carlisle River Graben are the two main structural low features in the north-eastern portion of the Port Campbell Embayment and separate the structural highs of the Otway Ranges to the south east and the Barongarook High to the west (see **Figure 8**, below). The Barongarook High is dominated by several north easterly trending anticlines and north westerly trending monoclines, which have further divided the Barongarook High into several minor structural elements over which the Otway Group are generally encountered at shallow depths, or even outcrop in valley sides (Lakey & Leonard, 1983).

The Barwon Downs Graben is bordered by the Loves Creek / Barwon Monocline to the north west, separating the graben from the Barongarook High (**Figure 8**). The Bambra Fault Zone to the south east separates the graben from the elevated Otway Ranges.

The Barwon Downs Graben is separated into two distinct sub-basins, the Kawarren sub-basin (also previously referred to as the Gellibrand Depression) and the Barwon Downs sub-basin (i.e., the BDIA). The Barwon Downs syncline, which is orientated in a south-west to north-east orientation, runs through the centre of the Barwon Downs Graben.

The Barwon Downs Graben is at its widest in the north eastern portions of the graben and narrows to the south west near Gellibrand where the Loves Creek Monocline and Bambra Fault converge (**Figure F1**). The narrowing of the graben is coincidental with a shallow basement structural high referred to as the Gellibrand Saddle (see **Figure 9**, below).

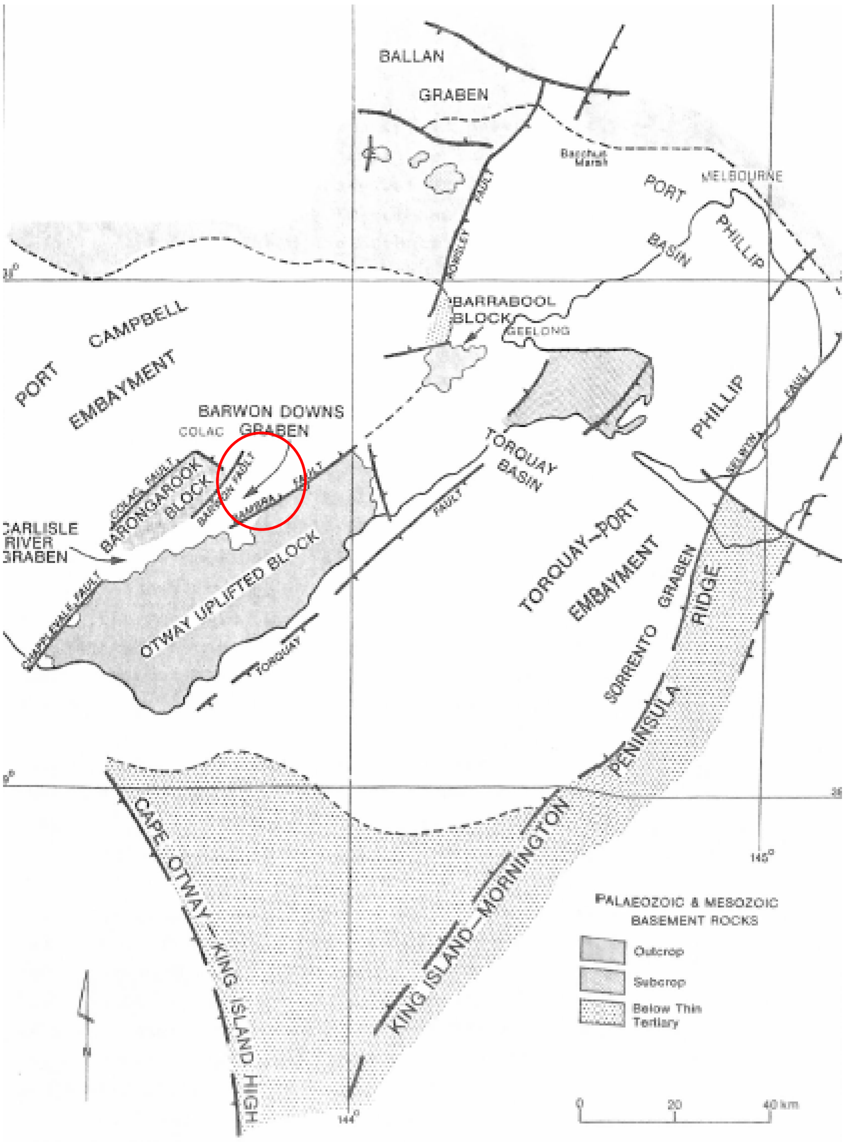

Figure 8 Regional Tectonic Setting, Eastern Otway Basin (after deformation (Department of Minerals and Energy, 1984)) (approximate BDIA location shown in red)

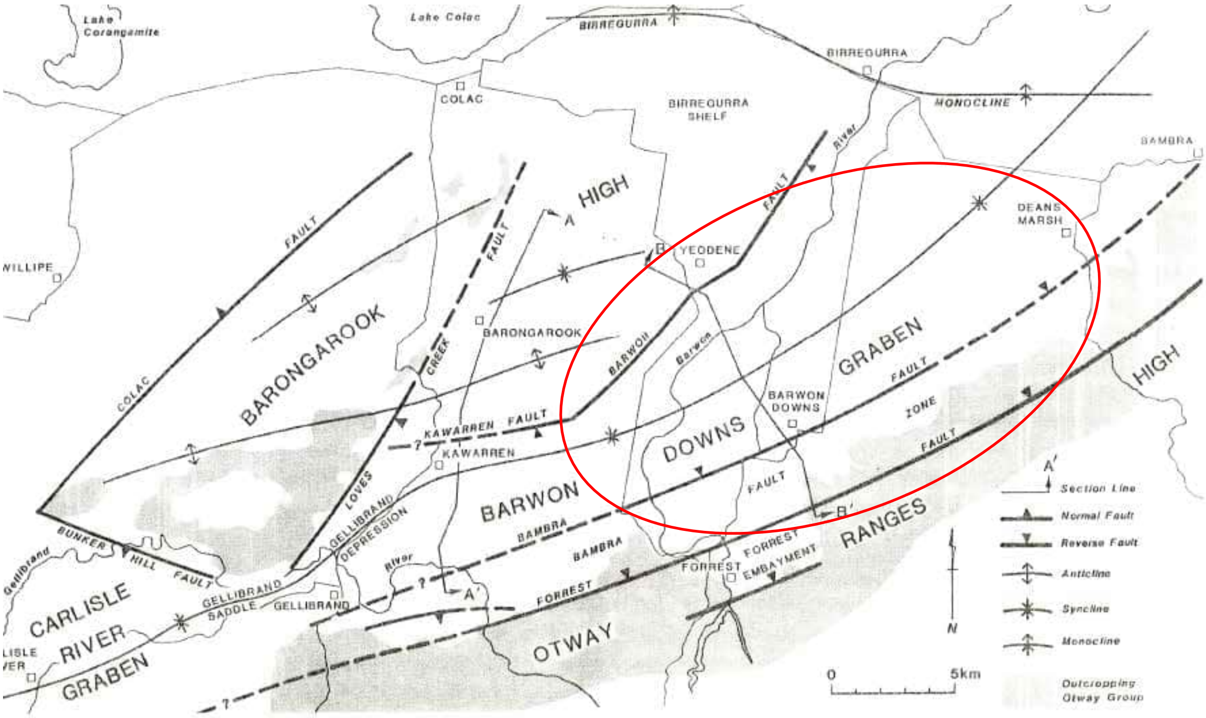

Figure 9 Regional Structural Setting (Leonard *et. al.,* 1983) (red indicates approximate BDIA boundary)

4.8.1.2 Barongarook High

A portion of uplifted Otway group sediments is located in the north western portion of the BDIA and is referred to as the Barongarook High (see **Figure F1** and **Figure 9**, above). This uplifted block is bound by the Loves Creek-Barwon Monocline to the southeast and the Colac Fault to the northwest (Lakey & Leonard, 1983) and features northeast trending anticlinal folds within the overlying Tertiary sediments relating to deeper basement faults (Witebsky et al., 1995).

Sediment deposition during the Tertiary period occurred concurrently with fault movement causing the formation of monoclines along the flanks of the Barongarook High. The Tertiary sediments are found to be thickest within the Barwon Downs graben and thinner over the Barongarook High with connection across the highs and lows (Leonard et al., 1983). Dilwyn formation outcrops in a large area over the Barongarook High (Blake, 1974), however it has experienced post-deposition erosion and inferred to only be between 30 – 80 m in thickness across this area (HydroTechnology, 1994).

4.8.1.3 Basement Topography

Figure F7 presents contours of the top of the basement (Otway Group) in m AHD. The top of basement contours indicate that there is a basement low following the approximate alignment of the Barwon Downs Syncline. The top of basement is at depths of up to -442 m AHD in the central portion of the BDIA. The basement shallows up towards the north east and south west creating a bowl like structure. The basement in the north-eastern portion of the BDIA is pinched between the Bambra Fault to the southeast and the Birregurra Monocline to the north resulting in a basement high which outcrops up to 169 m AHD just beyond the BDIA Witebsky *et al.* (1995) (also see **Figure F7**). Similarly, the basement gradually shallows to approximately -293.5 m AHD in the south west, in the vicinity of Gerangamete (**Figure F7**).

The Kawarren sub-basin to the south of the BDIA is partially separated from the BDIA by a basement high (part of the Barongarook High) that is bordered by the Boundary Creek and Barwon Monoclines to the north and south respectively (**Figure F7**). The basement in this area shallows and outcrops at approximately 151 m AHD. The Barongarook High basement high is overlain by a relatively thin veneer of overlying Dilwyn Formation sediments with some Otway outcropping around Boundary Creek (HydroTechnology, 1994).

4.8.2 Regional Geology

The regional surface geology is presented on **Figure 10** below and a representative cross section is shown on **Figure 11**. To the south of the Bambra Fault are Cretaceous aged sediments of the Otway Group (shown in bright green) (**Figure 10**). These dominate the elevated areas to the south of the BDIA and also the Barongarook High in the northwest.

Between the elevated Otway Group is a sequence of Tertiary age sediments which were deposited during major regressive and transgressive cycles (Lakey & Leonard (1983). These dominate the BDIA lithology. The Tertiary age sediments including those grouped in the Wangerrip Group (refer **Section 4.8.3**) outcrop on the Barongarook High, on the margins of the Otway Ranges in the south, in the far eastern portion of the BDIA and in the south west of the KIA in the vicinity of the Gellibrand River.

Beyond the Barongarook High to the northwest of the BDIA is another area where there is a deep sequence of Tertiary sediments. To the north, the Tertiary sediments are overlain by basalts of the Newer Volcanics; these form a flat plain with volcanic eruption points forming localised elevated areas. The basalt of the Newer Volcanics are not present within the BDIA. To the west of the BDIA, more recent Tertiary sediments outcrop forming a series of paleo ridge lines representing the former coastal extent with only small areas of the Hanson Sands (Sandringham Sandstone) capping some hills present in the north eastern portion of the BDIA.

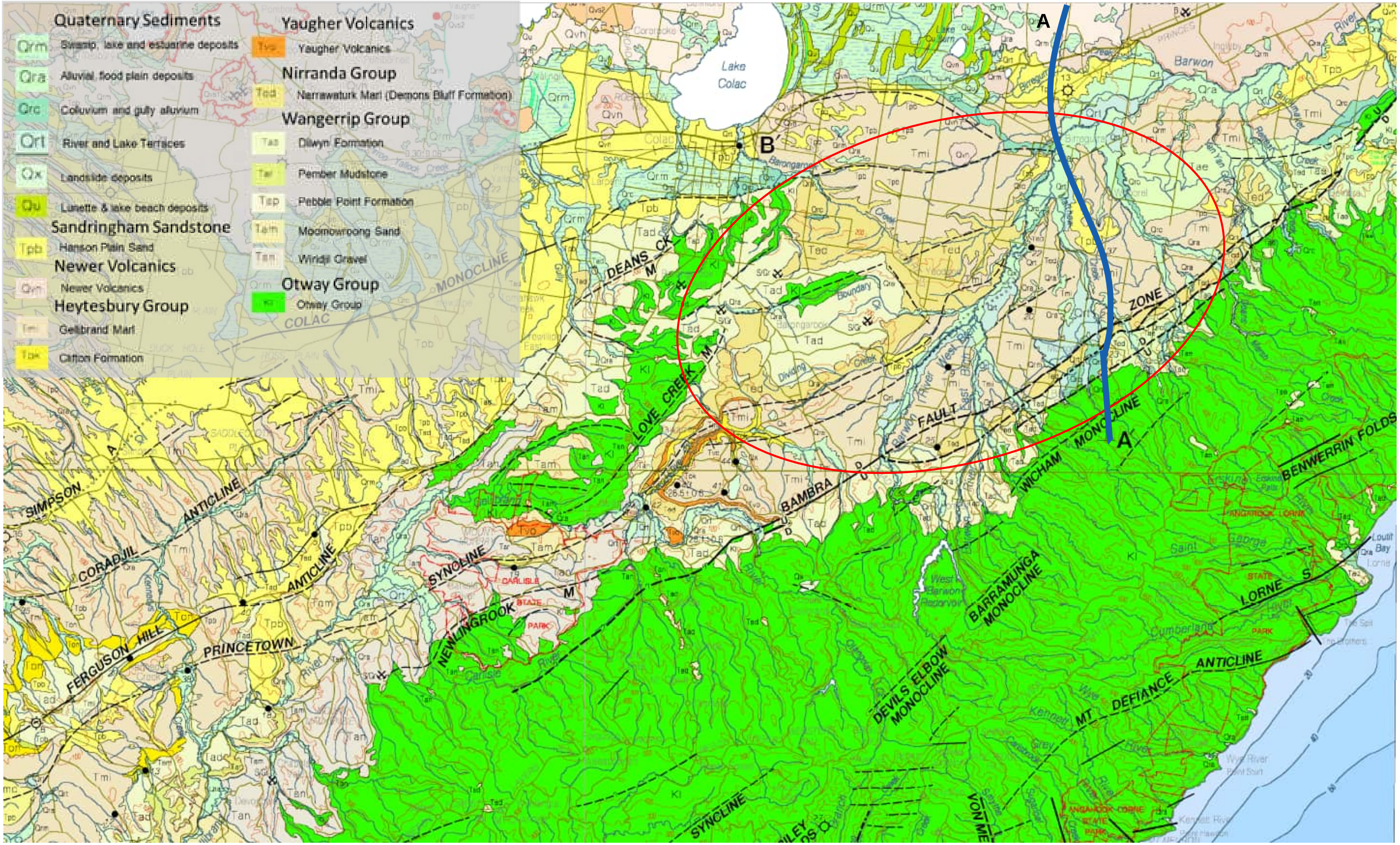

Figure 10 Regional Surficial Geology (Colac 1:250,000 Geological Map Series) (approx. BDIA area shown in red, blue line indicates cross section alignment A-A')

Figure 11 Regional Geological Cross Sections (Colac 1: 50,000 Geological Map Series)

4.8.3 Geology of the BDIA

A map showing the surficial geology in the BDIA is presented on **Figure F8**. Thickness contours have been prepared for selected Tertiary units including the Clifton Formation, Narrawaturk Marl and LTA and are presented on **Figure F9** - **Figure F11**, respectively. These are discussed further in **Table 5**, below. Four geological cross sections have been modified after Witebsky *et al.,* (1995) (**Figure F12** - **Figure F15**), presenting the sub-surface geology along the following alignments:

- A-A': south west to north east extending through the BDIA along the alignment of the Barwon Syncline. This section shows the LTA shallowing in the far south west in the KIA before deepening and daylighting in the far north east of the BDIA. The LTA can be seen thinning in the area referred to as the Pipeline Restriction. In the Barwon Downs borefield area a thick sequence of Tertiary sediments, including Gellibrand Marl, Clifton Formation and Narrawaturk Marl, overly the LTA (up to 400 m thick);
- B-B': north west to south east extending across the Barongarook High and south western portion of the BDIA. This section shows the outcropping of the LTA on the Barongarook High, either side of a basement high where the Otway Group outcrops. The LTA progressively thickens to the south east where it is overlain by a thick (~300 m) sequence of sediments. Along the Bambra Fault the LTA appears partially disconnected between the Barwon Downs area and the area south east of the fault, where the LTA outcrops;
- C-C': north to south extending across the central portion of the BDIA to present the bowling of the Barwon Downs sub-basin. The alignment indicates a thickening of the LTA in the north east of the BDIA before progressively thinning to the south. While displacement is evident along both the Birregurra Fault (north east) and the Bambra Fault zone (south east) there appears to be connection of the LTA across the faults. The LTA outcrops in the south east in the Bambra Fault zone; and
- D-D': north to south extending through the far eastern portion of the BDIA to present the thinning of the basin and Tertiary sediments with the Birregurra Fault. The alignment shows substantial thinning of the LTA to the north of the Birregurra Fault and displacement of the LTA either side of the Birregurra Fault. In this section of the BDIA the LTA is overlain by a relatively thin (~100 m) layer of Gellibrand Marl. Between the Birregurra and Bambra Faults Narrawaturk Marl, Sandringham Sandstone and LTA outcrop.

It is noted that the cross section of Witebsky *et al.,* (1995) were modified based on stratigraphic logs available in GeoVic and from new bores installed since the time of Witebsky's investigation (e.g., (Jacobs, 2022).

A summary of each of the geological formations, depositional environment, lithological description, approximate thickness and distribution and outcropping areas within the BDIA is provided below in **Table 5**. In summary (youngest to oldest):

- Quaternary sediments.
- Between the Loves Creek-Barwon monocline in the northwest and Bambra Fault to the southeast the basement is overlain by a thick sequence of Tertiary sediments comprising (from top to bottom):
  - Hanson Plain Sand (Sandringham Sandstone).
  - The Heytesbury Group including the Clifton Formation and Gellibrand Marl.
  - The Nirranda Group is comprised of the Mepunga Sands Formation, and the Narrawaturk Marl (Demons Bluff Formation) both of which underlie the BDIA. However, as mentioned in the point below, the Mepunga Sands Formation is included in the Wangerrip Group for consistency purposes with previous investigations.
  - Wangerrip Group: Pebble Point Formation and the Dilwyn Formation, of which the Pember Mudstone forms the base. For the purposes of this report, and for consistency with previous investigations the Mepunga Sands Formation is also included within the Wangerrip Group, as is the Eastern View Formation.
- The Otway Group is the oldest rock that outcrops in the BDIA and forms basement.

The Yaugher Volcanics are present in the KIA located to the west of the BDIA. The geological information indicates that these are absent from the BDIA.

Table 5 Detailed Stratigraphy (Top to Bottom of Sequence)

Unit	Depositional Environment	Age	Lithology Description	Distribution	Thickness	Outcrop
Quaternary Sediments						
Quaternary Sediments	River, swamp, alluvial deposits	Quaternary	Mixed sediment composition – mostly moderately to poorly sorted and poorly to unconsolidated Silts and clays dominate in swamp environments (e.g. Big Swamp and Bambra Wetlands)	Largely limited to creek and river alignments.	Quaternary sediments are interpreted to be localised along creeks, rivers and wetland areas. Sediments are on average 5 – 7 m thick and up to 14 m in Big Swamp along Boundary Creek in the north west.	Largely limited to creek and river alignments
Sandringham Sandstone						
Hanson Plain Sand	Fluvial and minor shallow marine deposits	Pliocene	Quartz sand, clayey sand, gravel, minor calcareous clay and limonite pisolites; surface may be lateralised	Overlies the Gellibrand Marl in a non-continuous layer.	Expected to be in the order of 5-10 m in the BDIA.	Most of the Hanson Plain Sands within the BDIA has been eroded with only small areas of outcrop remaining as hill caps near Dividing Creek, in the central east portion and in the far eastern portion of the BDIA (**Figure F8**).
Heytesbury Group						
Gellibrand Marl	Deep to shallow marine	Late Oligocene – Middle Miocene	Predominantly calcareous clayey silt, less commonly calcareous fine sand, calcareous silty clay and marl. Commonly glauconitic. Shelly in parts. Bluish grey in colour Outcropping of the Gellibrand Marl causes oxidation and it is difficult to distinguish from the Narrawaturk Marl (Tickell *et al.*,1991)	Present across the Site	The marl is thickest (up to 250 m) in the central portion of the BDIA and thins out along the edges of the BDIA and Barwon Sub-basin.	The Gellibrand Marl outcrops across the majority of the BDIA (**Figure F8**).
Clifton Formation	Shallow marine / littoral, minor beach deposits	Late Oligocene – Early Miocene	Cream-white bryozoal limestone, limonitic calcareous quartz sand or sandstone. Occasionally glauconitic. The base of the unit can be conglomerate with basalt boulders. In the upper sections it can be interfingered with Gellibrand Marl. Blake (1974) reported the unit becoming siltier in the centre of the KIA, west of the BDIA.	Predominantly in the centre of the Barwon sub-basin area and pinches out towards the Barongarook High and the Bambra Fault.	Up to 47 m thick in the south western portion of the BDIA (**Figure F9)**. The Clifton Formation thins out along the northern, western, and eastern edges of the graben and pinches out before outcropping at the surface.	A small outcrop of Clifton Formation can be seen to the southwest in the vicinity of Loves Creek and Yahoo Creek, west of the BDIA (**Figure F8**). No outcrops have been noted within the BDIA.
Nirranda Group						
Narrawaturk Marl[2]	Deep marine	Late Eocene – Late Oligocene	Olive grey to brownish grey marl, silty marl, calcareous mudstone and muddy limestone. Thin beds of calcareous sandstone are also present. Commonly glauconitic and limonitic (Douglas & Ferguson, 1988). Tickell *et al.,* (1991) describe the Demons Bluff Formation as 'calcareous silt which is locally sandy and clayey and contains abundant shelly fragments. High amounts of very fine carbonaceous material gives the marl a dark brown colour. High amounts of very fine carbonaceous material gives the marl a dark brown colour.	Underlies the BDIA and is thickest within the central portion of the BDIA (**Figure F10**).	Thickest (~180 m) in the central region of the BDIA and thins out to between ~30 and ~95 m along the edges of the basin where the marl outcrops.	The Narrawaturk Marl outcrops around the Barongarook High and extends east and north of the Barongarook High and along the Bambra Fault. Small outcrops are present along part of Matthew Creek.
Wangerrip Group						

[2] The Narrawaturk Marl is often referred to as the Demons Bluff Formation. The most recent geological mapping (Tickell et al., 1991) has differentiated these units given that the differing depositional setting of these two units. As they were deposited contemporaneously with each other they do transition into one another which makes differentiation challenging. To maintain consistency with previous descriptions in the BDIA BlueSphere has adopted the term, Narrawaturk Marl in this HA when referring to either of these units or their transitional equivalents.

Unit	Depositional Environment	Age	Lithology Description	Distribution	Thickness	Outcrop
Mepunga Formation[3]	Tickell *et al.,* (1991): fluviatile environment, with some minor marine influence	Late Eocene	Well sorted reddish-brown limonitic quartz sand, calcareous limonitic sand and limonitic sandy limestone Lakey (1983). The sand is considered to be very mature with grains characteristically very well rounded Lakey (1984).	Across the Barwon Downs Graben.	Thinnest in the central portion of the BDIA at ~15 m and thickest (~ 45 m) in the north eastern portion. On average around 30 m thick.	The surficial geology map (**Figure F8**) has not differentiated between the three formations in the north eastern portion of the BDIA. The 'Eastern View Formation' (grouped within the LTA as being laterally equivalent) is shown to outcrop in the north eastern portion of the BDIA. The Mepunga Formation is not known to outcrop. The Dilwyn Formation outcrops are present along the north western and south eastern edges of the BDIA and across the Barongarook High. The Pember Mudstone is not known to outcrop. The Pebble Point Formation is not known to outcrop.
Dilwyn Formation[4]		Late Eocene – Early Palaeocene	Fine to medium grained sand bedded into units 2 – 10 m thick, which are separated by layers of clay and silt that are generally <2 m thick (Tickell *et al.,* 1991). Clean quartz sand interspersed with thinner beds of yellow to light brown clayey sands, with gamma ray logs indicating it is characterised by sandstone layers alternating with thinner mudstone units Lakey (1983).	Across the Barwon Downs Graben.	Thickest in the north western portion of the BDIA (up to 144 m thick) near Birregurra.	
Pember Mudstone	Holdgate & Gallagher (2003) describe it as originating from a transgressive – regressive repetitions of sandstone-siltstone-claystone	Late Eocene – Early Palaeocene	Tan to grey siltstone, mudstone and shale, usually pyritic, carbonaceous and micaceous, and locally glauconitic Holdgate & Gallagher (2003). Fine grained clastic consisting of grey to dark brown and black mud, clay and silt, which was commonly micaceous and carbonaceous, and also contains glauconitic and limonitic clays and pyrite Lakey (1983).	Across the Barwon Downs Graben	Generally 10 – 15 m thick across the BDIA. Thickest in the north west around Yeodene (~30 – 35 m thick)	
Pebble Point Formation[5]	Primarily in a transgressive shallow marine environment	Late Eocene – Early Palaeocene	Predominantly quartzose sand and gravel (poorly to well sorted) usually with significant quantities of grey lithic pebbles (mainly of Palaeozoic aged fragments of siltstone, sandstone, chert and hornfels). In places it is represented by compacted silty and gravelly sand with a ferruginous cement Lakey (1984). Holdgate & Gallagher (2003 describe the formation as ferruginous (mainly quartz) sandstone, grit and conglomerate, with less common fossiliferous beds	Across the Barwon Downs Graben	The Pebble Point Formation is ~15 m thick across the BDIA and thins to approximately 5 m near the Bambra fault. Is thickest (~35-40 m) in the north west near Birregurra.	
Otway Group						
Eumeralla Formation	Interbedded volcanogenic sandstone and mudstone of a fluvio-lacustrine deposition	Early Cretaceous	Sandstone is the dominant rock type of the Otway Group and is generally fine to medium grained, moderately to well sorted and may be cross bedded. Both the sandstone and mudstone are characterised by high proportions of lithic and feldspathic grains and these give the sandstone a characteristic 'pepper and salt' appearance. The colour of the mudstone can vary in colour from light grey to dark grey and greenish grey in fresh rock Tickell *et al.*, (1991). The volcanogenic rock fragments are generally fine grained, highly altered volcanics with lesser amounts of quartzite, mica-schist and micro-granite.	Widespread across the Port Campbell Embayment.	In central part of Barwon Downs Graben the Otway Group is up to 800 m thick	The Otway Group outcrops along the margins of the BDIA in the northwest (Barongarook High) and southeast (Otway Ranges) (**Figure F8**). Depths to the top of the Otway Group decrease substantially to the south west of the BDIA, in the area identified as the Gellibrand Saddle (shallow basement structural high) along with to the north east (**Figure F7**). The Otway Group becomes increasingly shallower before outcropping along the edge of the Barongarook High in the western portion of the BDIA (see **Figure F8**).

[3] Also referred to as the Upper Eastern View. The Mepunga Formation is included in the Nirranda Group (Holdgate & Gallagher, 2003) but for the purposes of this HA is considered as part of the Wangerrip Group
[4] Also referred to as the Middle Eastern View. Note the Pember Mudstone has been regarded as the lower member of the Dilwyn Formation but has separated out for the purpose of this HA.
[5] Also referred to as the Lower Eastern View. The Pebble Point Formation is equivalent to the Moomowroong Sand and Wiridjil Gravel units encountered elsewhere.

4.8.4 Geology of Big Swamp

The geology of Big Swamp has been studied in detail given that this area has realised environmentally significant impacts that have been linked to groundwater extraction from the Barwon Downs Borefield. The location of Big Swamp which is shown on **Figure F8**.

Big Swamp is a peat swamp located along Boundary Creek comprising channel-filled Quaternary Sediments (GHD, 2021) and are described as black-brown silty clays with some organic matter (Jacobs, 2022). It is noted that recent investigations (Ecological Risk Assessment completed by Nation Partners, 2023, draft) have highlighted that whilst Big Swamp has historically been referred to as a peat swamp it does not meet the definition of a peat swamp, rather it falls within the definition of a wetland. This report does not intend to define Big Swamp as either a peat swamp or a wetland. Drilling completed by GHD observed the Quaternary Sediments beneath the swamp to be at least 6 m in thickness. Nearby boreholes with available inferred lithologies, report Quaternary Sediments varying in thickness of 8 m in the upstream portion of Big Swamp and 14 m downstream. The sediments are noted to be thickest in the centre of the creek channel and thin out to the north and south where the Narrawaturk Marl and LTA outcrop. Previous investigations undertaken at Big Swamp have determined that the Quaternary Sediments contain pyritic materials and are acid sulfate soils. Further acid sulfate soil detail is provided in **Section 4.15**.

It was previously understood that the Quaternary Sediments within the Big Swamp were underlain by Narrawaturk Marl in the east and Mepunga Formation (LTA) in the west with the boundary between the two located approximately in the middle of the swamp and oriented roughly north-south. Recent drilling conducted by Jacobs (2022) noted that the Quaternary sediments at drilling location BSBH13LTA located in the western portion of Big Swamp, were underlain by approximately 6 m of Narrawaturk Marl. These findings have led to changes in the understanding of the swamp and confirmed that the swamp is not in direct hydraulic connection with the LTA and the Narrawaturk Marl is acting as a confining layer (as shown on **Figure 12**, below).

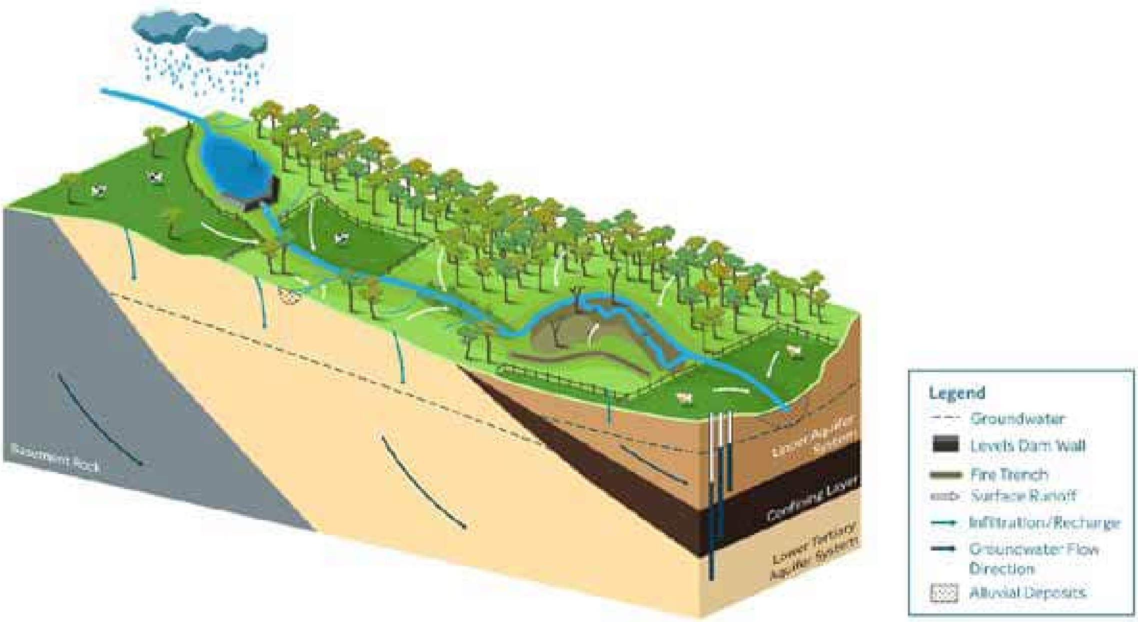

Figure 12 3D Cross Section of Big Swamp (Barwon Water supplied image)

4.9 Hydrogeology

4.9.1 Hydrostratigraphy

There are a number of hydrostratigraphic units within the BDIA. These comprise either individual geological units, or a combination of geological units that share comparable hydrogeological properties. Each hydrostratigraphic unit has been classified as either an aquifer or aquitard. These are defined as follows:

- Aquifer: A geological formation which contains and yields water; and
- Aquitard: A geological formation which cannot transmit significant quantities of water but can transmit small quantities (i.e., not totally impermeable).

It is important to note that these are adopted as relative terms and have also been adopted based on best available information. Where there is uncertainty or variability with regard to the hydrogeological properties of a geological formation this has been highlighted.

The predominant aquifers and aquitards identified within the BDIA have been summarised below (from youngest to oldest) and are largely consistent with the previous HA completed for the KIA (BlueSphere, 2023):

- Quaternary Aquifer (QA) – Quaternary Sediments;
- Upper Mid Tertiary Aquifer (UMTA) - Sandringham Sandstone;
- Upper-Mid Tertiary Aquitard (UMTD) – Gellibrand Marl;
- Lower-Mid Tertiary Aquifer (LMTA) – Clifton Formation;
- Lower-Mid Tertiary Aquitard (LMTD) – Comprising the Narrawaturk Marl;
- Lower Tertiary Aquifer (LTA) – Comprising the Pebble Point, Dilwyn and Mepunga Sands Formations; and
- Otway Group Aquifer (OGA) – Comprising the Eumerella Formation of the Otway Group.

A summary of the aquifers and aquitards including description, occurrence and nature are described further in **Table 6** below. Further detail is provided in **Sections 4.9.2** to **4.9.5** below.

Table 6 Summary of Regional Aquifers / Aquitards (Top to Bottom of sequence)

Geological Group	Geological Formation	Hydrostratigraphic Unit	Lithological description	Occurrence	Type and Form	Comment
Quaternary Sediments	River, swamp, alluvial deposits	Quaternary Aquifer (QA)	Alluvial deposits, clays, sands	Localised aquifers associated with prominent drainage lines including the Barwon River, including west and east branches in the upper catchment and tributaries including Boundary, Matthews, Pennyroyal, Deans Marsh and Retreat Creeks. Some laterally extensive deposits exist along the Barwon River and other parts of the lower catchment.	Unconfined	Local groundwater flow systems exist which are likely to be in hydraulic connection with surrounding hydrostratigraphic units.
Heytesbury Group	Sandringham Sandstone Gellibrand Marl Clifton Formation	Upper Mid Tertiary Aquifer (UMTA) Upper-Mid Tertiary Aquitard (UMTD) Lower-Mid Tertiary Aquifer (LMTA)	Undifferentiated marl, sand, gravel	Sandringham Sandstone (formerly Brighton Group) is reported in isolated outcrops in the eastern portion of the BDIA, where it is expected to directly overlie the Gellibrand Marl. Gellibrand Marl outcrops extensively in the central, eastern and south western portions of the BDIA. The Clifton Formation occurs at depth in the Barwon Down Sub-Area. There are small outcrops of Clifton formation in the Loves Creek catchment to the west, but none are documented in the BDIA.	Unconfined	Due to a paucity of information these have been grouped together. The Clifton Formation is likely to form its own aquifer, and is typically confined beneath the Gellibrand Marl. Minor aquifers likely to exist within the Gellibrand Marl (particularly more sandy upper zones).
Nirranda Group	Narrawaturk Marl	Lower Mid Tertiary Aquitard (LMTD)	Silty marl	Extensive outcrop at Yeodene and at the periphery of the Barongarook High, where it directly overlies and confines the LTA. Present at depth across much of the balance of the BDIA, where it attains thicknesses of almost 200 m (**Figure F10**). Is	Aquitard	Considered to act as a confining unit to the underlying LTA based on hydraulic properties and thickness (**Figure F10**).

Geological Group	Geological Formation	Hydrostratigraphic Unit	Lithological description	Occurrence	Type and Form	Comment
				not present where LTA outcrops at the Barongarook High and in the far eastern portion of the BDIA.		
Wangerrip Group	Mepunga Formation Dilwyn Formation Eastern View Formation Pember Mudstone Pebble Point Formation	Lower Tertiary Aquifer (LTA)	Quartz sands, gravels, clay and silts	Outcrops across the Barongarook High and occurs sub-surface across the majority of the BDIA, reaching thicknesses up to 200 m south of Birregurra. Interpreted to be a lateral facies change to the north east into the Eastern View Formation, which outcrops at the eastern end of the BDIA, between Whoorel and Bambra.	Confined in central BDIA. Unconfined at areas of outcrop including Barongarook High.	Forms the principal aquifer in the BDIA. Was the source aquifer of the Barwon Downs Borefield. The LTA is disconnected across parts of the Bambra Fault, predominantly in the far south west and up to approximately the Barwon Downs region (see **Figure F8**, and **Figure F13**) before it appears to be largely connected across the fault, all the way up to approximately the Deans Marsh area. The LTA is also disconnected between the BDIA and the Birregurra Fault in the north eastern portion of the BDIA, as shown on **Figure F15**. Although some lithological variability is evident, the individual units appear to be in strong hydraulic connection and form a single aquifer, the thickness of which is shown on **Figure F11**.
Otway Group	Eumerella Formation	Otway Group Aquifer (OGA)	Sandstone / Siltstone fractured rock	Present beneath the entire BDIA at depths of up to 500 – 600 m below ground level. Minor outcrop on the northern margin of the Barongarook High, in the north west of the BDIA.	Confined Unconfined in areas of outcrop	Not considered to form a significant aquifer in comparison to the overlying LTA.

4.9.2 Quaternary Aquifer (QA)

There is little information available regarding the hydraulic properties of the QA, apart from in the vicinity of Big Swamp. Tickell *et al*. (1991) considered that the thin deposits of Quaternary Sediments within the BDIA would have a low potential of forming substantial aquifers in their own right. Rather, these deposits are likely to form local groundwater flow systems which are likely to be in hydraulic connection with surrounding hydrostratigraphic units. Within the BDIA the QA is considered to form predominately around the Barwon River, including the East and West Branches, and tributaries including Boundary, Matthews, Pennyroyal, Deans Marsh and Retreat Creeks, where they comprise river terraces and alluvial deposits (Tickell *et al*., 1991).

The QA is most extensive in the vicinity of Boundary Creek and Barwon River, where in the order of 5 m sediments has been reported overlying Narrawaturk Marl, respectively (Jacobs, 2022).

Jacobs (2018) report that the QA is variably in direct hydraulic connection with the LTA and LMTA, with upward hydraulic gradients to the QA existing under 'normal conditions'. Boundary Creek (Reach 2) and the upper portions of the Barwon East and Barwon West River branches were identified as flowing directly over LTA outcrop areas, with the potential for periodic downward vertical flow from the QA to the LTA and LMTA during periods of higher river flow or pumping induced drawdown within the LTA (Jacobs, 2018). Further to the northeast it can also be inferred from the geological mapping (**Figure F8**), that the QA is likely to be directly hydraulically connected with the LTA in isolated upper portions of Pennyroyal and Deans Marsh Creeks and in parts of the lower Deans Marsh Creek near Whoorel, the Wurdiboluc Inlet Channel and portions of Yan Yan Gurt Creek.

Slug testing of the QA reported hydraulic conductivity values ranging between 0.005 and 4.7 m/day with an average of 0.63 m/day (Jacobs, 2018). Analysis of slug tests at the Big Swamp completed by GHD (2021), reported similar results of 0.02 to 1.4 m/day with a geometric mean of 0.2 m/day. Gamma logging completed by Jacobs (2018) suggested an absence of substantial clay layers within the aquifer, indicating that the QA can have a reasonably high hydraulic conductivity in some areas. However, GHD (2021) characterise the QA in the vicinity of Big Swamp as being predominantly comprised of clay, with minor silts and discrete lenses of sand, which result in highly variable hydraulic conductivities.

4.9.3 Upper Mid and Lower-Mid Tertiary Aquifers

The Sandringham Sandstone, Gellibrand Marl and Clifton Formation form individual hydrostratigraphic units (UMTA, UMTD and LMTA) respectively. Given the paucity of information in the BDIA these have been grouped together for the purpose of the following discussion. A summary of information as presented in (Tickell *et al*., 1991) is provided in the following sections.

The Clifton Formation is considered to constitute an aquifer, while the Gellibrand Marl is generally considered to be an aquitard, confining the underlying Clifton Formation. Tickell *et al.* (1991) notes that the more sandy facies of the Gellibrand Marl (generally towards the top of this unit) is a minor aquifer. The Gellibrand Marl is expected to be in direct hydraulic connection with the QA over large portions of the BDIA. There is very little information on the hydraulic properties of the isolated occurrences of Sandringham Sandstone, which are known to be laterally discontinuous. Based on the properties of this formation elsewhere in Victoria, it would be expected to behave as a minor aquifer, with localised flow patterns consistent with its limited extent. It is noted that Jacobs (2018) broadly refers to all units above the LTA as aquitards however, our review indicates that this is not accurate.

As documented in Tickell *et al*., (1991) bore yields up to 10 L/s have been reported for the Clifton Formation and the Gellibrand Marl is a locally utilised source of groundwater for stock and domestic purposes with bore yields of between 0.1 to 0.5 L/s.

Recharge to the Sandringham Sandstone and Gellibrand Marl is likely to be via direct infiltration of rainfall, with groundwater discharge likely occurring via leakage from the Sandringham Sandstone to the Gellibrand Marl, where it is subjacent (Daulhaus *et al*., 2002) and from both units via springs and other discharges to localised surface water systems and/or overlying and adjacent Quaternary alluvium. Groundwater flow systems in the Sandringham Sandstone and Gellibrand Marl are considered to follow the local topography with flow paths classified as local in extent (Daulhaus *et al*., 2002). Under ambient conditions (i.e. non-pumping conditions in the Barwon Downs borefield), downward leakage from the Gellibrand Marl to underlying Tertiary aquifers (i.e. Clifton Formation) is precluded by the upwards hydraulic gradient; however, such leakage could be induced during periods of extensive drawdown at the borefield. However, as discussed in **Section 4.9.4** below, downward leakage from the Gellibrand Marl to underlying Tertiary aquifers such as the LTA is unlikely to be significant given the low transmissivity of the Narrawaturk Marl.

The Clifton Formation does not outcrop within the BDIA and therefore receives recharge from surrounding units. Some recharge may also occur from small outcrops of Clifton Formation in the Kawarren area. Recharge to the Clifton Formation within the BDIA is understood to be dominated by upward leakage transmitted through the Narrawaturk Marl from the LTA (Jacobs, 2017), however, as discussed in **Section 4.9.4** below this would be considered to be low to unlikely given the transmissivity of the Narrawaturk Marl. Discharge from the Clifton Formation is likely accounted for via upward leakage to the Gellibrand Marl and aquifer throughflow towards the north east. Leakage from the Gellibrand Marl may contribute to recharge of the Clifton Formation during periods of pumping induced depressurisation of the underlying LTA.

4.9.4 Lower Mid Tertiary Aquitard (LMTD)

The Narrawaturk Marl forms the Lower Mid Tertiary Aquitard (LMTD) within the BDIA. The LMTD confines the LTA within the Bambra and Birregurra faults, apart from the areas of LTA outcrop where the LTA directly overlies the OGA, such as Barongarook High. The LMTD is approximately 150 m thick in the central region of the BDIA as shown on **Figure F10**, Lakey (1983), however, thins towards the Bambra and Birregurra faults (**Figure F10**) (~100 m) and towards the eastern end of the graben (<50 m; Witebsky *et. al.,* 1995). The LMTD was previously considered to overlie the Yeo Dome in the far north west of the BDIA, however, more recent investigations indicate the LTA directly overlies the OGA in this area.

Hydraulic conductivities for the Mid Tertiary Aquitard (which includes the LMTA (Gellibrand Marl) and LMTD (Narrawaturk Marl)) as reported in (Jacobs, 2018) appeared to show a correlation with screen depth whereby bores screened at <25 m below ground level reported a hydraulic conductivity range of between 0.026 to 0.3 m/day, while bores screened >35 m reported hydraulic conductivities between 1.8x10-5 to 5.8x10-4 m/day. These are substantially below the range of K values reported in the LTA (between 4 m/day and 22.1 m/day, **Table 7**).

Based on the thickness of the LMTD (~100 m), a horizontal K of 1.8x10-5 to 5.8x10-4 m/day (it is noted that horizontal K is likely to be greater than vertical K), i of 0.07 (**Section 4.9.5.4**) and effective porosity (n_e) of 5%, it would take in the order of 300 to 10,000 years for water to transmit vertically through the aquifer. This highlights that whilst the groundwater movement is possible between the LTA and LMTA through the LMTD, it is very slow to occur and consequently the flux may be a minor contributor to the water balances in surrounding units separated from the LTA by the LMTD. Groundwater pumping from the LTA would increase this rate by increasing the vertical hydraulic gradient.

The limited transmissivity of the Narrawaturk Marl is supported by measured water levels of bore 64242 screened in the LMTD, which showed little if any response when compared to water levels in 64230 screened in the LTA, which showed a decrease in water levels during peak LTA pumping periods (**Figure 13**; Jacobs, 2018). This is also seen to a lesser degree in nested bores in Big Swamp (TB1b (LMTD) and TB1c (LTA)), albeit post pumping.

Three bores located in the BDIA (G19, G18 and M22) are screened within the Clifton Formation which is separated from the LTA by the Narrawaturk Marl by approximately 95 m, 145 m and 200 m, respectively. As can be seen by the hydrograph of these three bores (see

Figure 14, below) there has been a minor response in water level reductions at G18 and G19 (~1 m decrease). It is noted that this also corresponds with a decline in rainfall over the same period, which may account for some of the observed decrease. At bore M22 there has been up to 7 m decrease. It is noted that bore M22 underwent refurbishment in 2014/15 and since then water levels have stabilised substantially with the previous seasonality supressed. This suggests that the 7 m decline observed is likely to be an artefact of bore construction and not reflective of the permeability of the Narrawaturk Marl.

On balance the CSM indicates that there is very minor flux between the LTA and the Narrawaturk Marl with an approximately 1 m decrease in water level over a 12 year period at G19 where the Narrawaturk Marl is approximately 95 m thick. This is largely consistent with the calculations presented above.

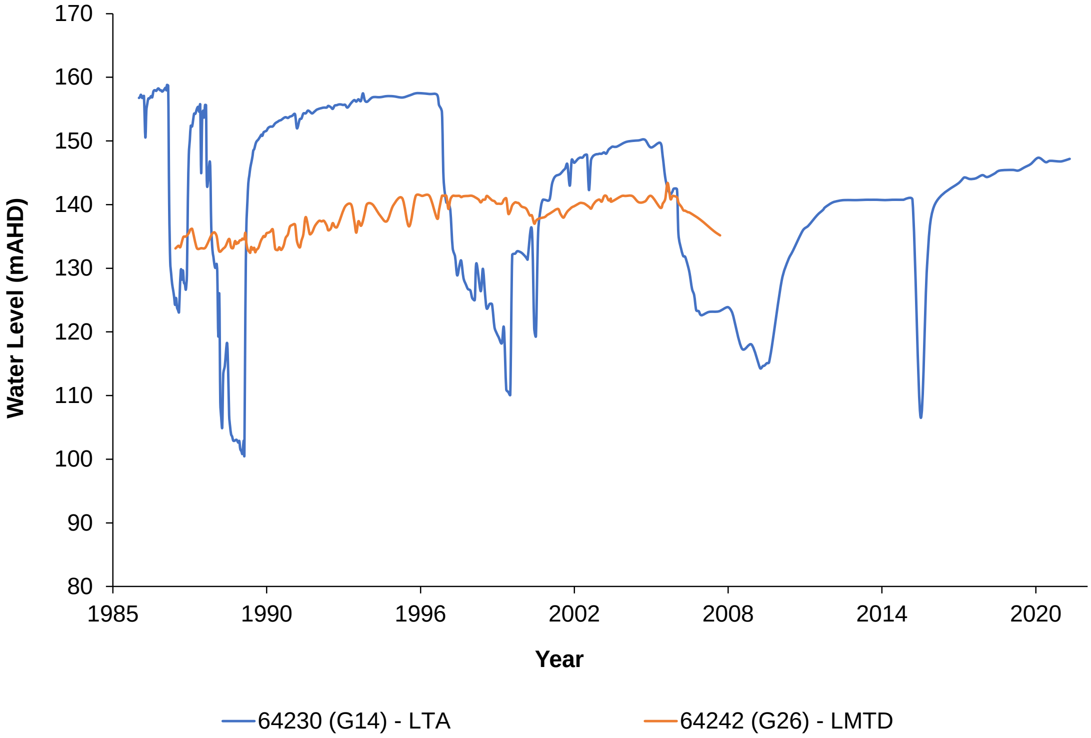

Figure 13 Bore hydrographs in LTA and LMTD

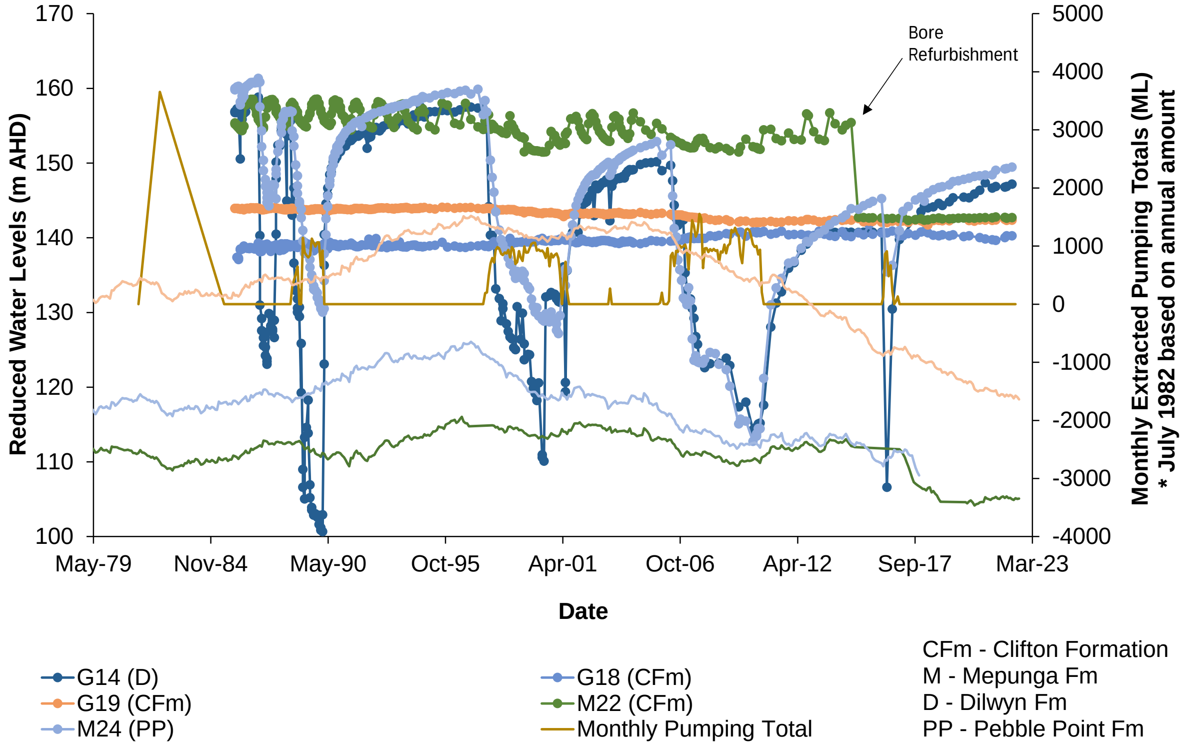

Figure 14 Bore Hydrographs in LTA and Clifton Formation (uncertainty regarding M22 water levels pre refurbishment)

4.9.5 Lower Tertiary Aquifer (LTA)

4.9.5.1 Aquifer Distribution

The LTA extends across a large area incorporating the Barwon Downs Graben, as far north as Birregurra, and south in the Carlisle River Graben (Department of Minerals and Energy, 1984). The LTA is thickest along the Barwon Downs Syncline between the Bambra Fault (along the south eastern margin) and the Birregurra Fault (along the northern margin) in the BDIA with thicknesses in excess of 300 m (Leonard, 1983) to 400 m (Lakey, 1983), but more typically 100 – 200 m (**Figure F11**). The LTA is interpreted to thin across a basement high referred to as the Yeo Dome, located, between the Barwon Downs and Kawarren sub-basins, but remain in limited hydraulic connection through this area (Aquade, 2015). To the west of the Gellibrand Saddle the LTA attains thicknesses of up to 150 m in the Carlisle River Graben (Department of Minerals and Energy, 1984).

The LTA outcrops on the margins of the BDIA, principally to the north west at the Barongarook High (**Figure F8**). Outcrop also occurs along the south-eastern side of the Bambra Fault and associated sub-faults. The aquifer is unconfined in these areas but is at least partly disconnected from the balance of the LTA by the fault zone. North of the Bambra Fault the LTA is present at depths of between 300 – 400 m (below ground surface) and abuts Otway Group sediments to the south, which are interpreted to substantially impede groundwater flow in this direction. The outcrops of LTA south of the fault are relatively thin (between ~25 m and 100 m) (Lakey, 1983).

Jacobs (2016) conducted targeted drawdown analysis of paired bores located either side of the Bambra Fault and concluded that the Bambra Fault zone is likely to result in an average LTA transmissivity reduction of 95%; however, there were portions of the fault zone (e.g. the central portion near Murroon (Bore 82845/M29)) which had a substantially higher degree of connection, presumably due to lower levels of LTA displacement. Jacobs (2016) also indicated that the equivalent transmissivity reduction across the Colac Fault at the northern edge of the Graben was of the order of 99%, with evidence suggesting that leakage across the Colac Fault was substantially less than that which could occur across the Bambra Fault.

The majority of the LTA in the BDIA is confined, and this corresponds with the thickest sequence of the aquifer. While the density of deep drilling locations in the central portions of the Graben is relatively low, previous investigations characterise the LTA as occupying a single deep basin coincident with the Barwon Down Syncline with the thickest and deepest portions in the vicinity of Yeodene and Murroon, midway between Birregurra and Barwon Downs (e.g. Leonard, 1983; Lakey, 1983).

Leonard *et al.,* (1983) previously considered that the LTA sediments did not continue over the area referred to as the Yeo Dome. However, on the basis of re-interpretation of boreholes and further drilling by HydroTechnology (1994) it has been established that LTA sediments directly overly Otway Group sediments in this area. That is, there is a direct hydraulic connection across the Yeo Dome between the BDIA and KIA (Blue Sphere, 2023).

Investigations by Witebsky *et al.,* (1995) and subsequently Petrides & Cartwright (2006) described the existence of a groundwater barrier separating the BDIA with the KIA based on responses in observation bores to the borefield production. Whilst no structural feature was identified in this area, Witebsky *et al.* (1995) were of the opinion that the LTA thinned with the aquifer thinning from over 150 m in the borefield area to 20 m at the inferred barrier. Aquade (2019) considered that the barrier was not a complete barrier, rather a restriction through which the aquifer could maintain reduced hydraulic connectivity. Aquade (2017) referred to this area as the Pipeline Restriction. BlueSphere 2023 agreed with the findings of HydroTechnology (1994) and Aquade (2015, 2017 & 2019) based upon a review of the geological information, the hydraulic response to pumping events at the Barwon Downs borefield and potentiometric trends across the BDIA and KIA.

4.9.5.2 Groundwater Flow Systems

Potentiometric surface plans of the LTA have been reproduced (after Leonard *et. al.,* 1983) for 1983 and prepared for 2010 and 2022, and are presented on **Figure F16**, **Figure F17** and **Figure F18**, respectively. These 1983 potentiometric surface contours are considered to represent the baseline, pre-pumping conditions.

The 1983 potentiometric surface plan supports previous interpretations that recharge to the LTA in the BDIA occurs via rainfall infiltration to the outcrops of LTA on the Barongarook High. Recharge in the Barongarook High flows in a north-easterly direction within an area of locally deeper LTA sediments referred to as the 'Yeodene Recharge Avenue' (see **Figure 15**, below), which is considered to be the primary flow path in the BDIA. A cross section showing this flow path, perpendicular to flow, is provided on **Figure 16**. Groundwater thereon has two predominant flow paths, the majority continues in a north-easterly direction through the LTA where the gradient is relatively flat, whilst a portion of flow wraps around the previously identified Yeo Dome bedrock high and flows along a narrow valley across the Pipeline Restriction from the BDIA and into the KIA.

Groundwater flowing to the north-east may partially discharge to LTA equivalent sediments across the Birregurra Fault as the LTA is only partially disconnected, (**Figure F15**), could wrap around and head to the south-west, or transmit to other units by way of fault zones. These specific discharge mechanism in this area is unresolved. Groundwater along the Pipeline Restriction flow path discharges in the Gellibrand River in the reach east of Clancys Hill which is a regional groundwater discharge zone.

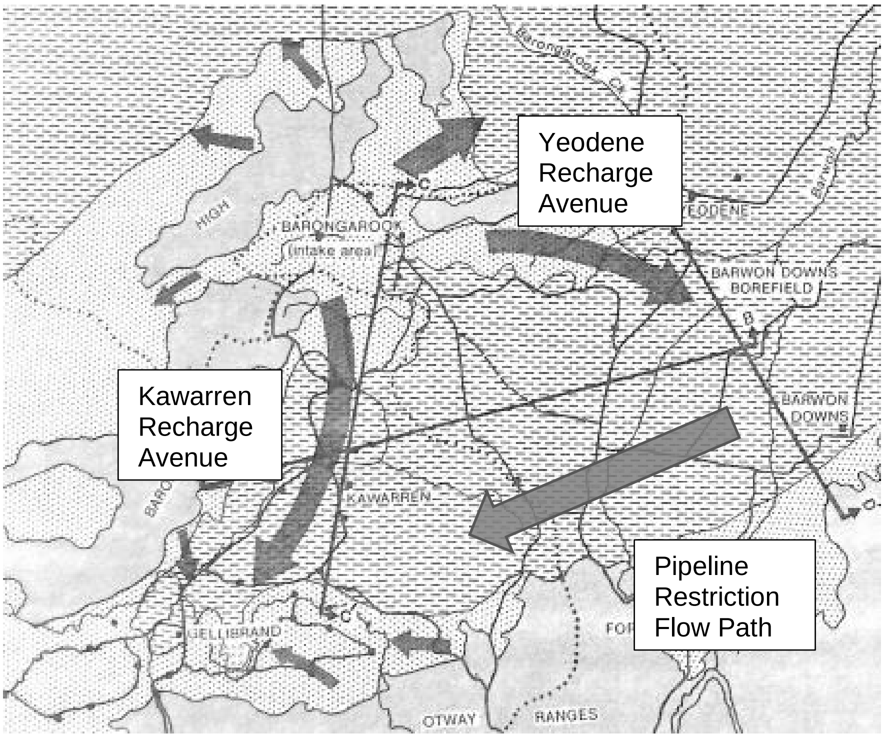

Figure 15 Dominant Flow Pathways in the LTA from the Barongarook High Recharge Area (Modified from (Department of Minerals and Energy, 1984))

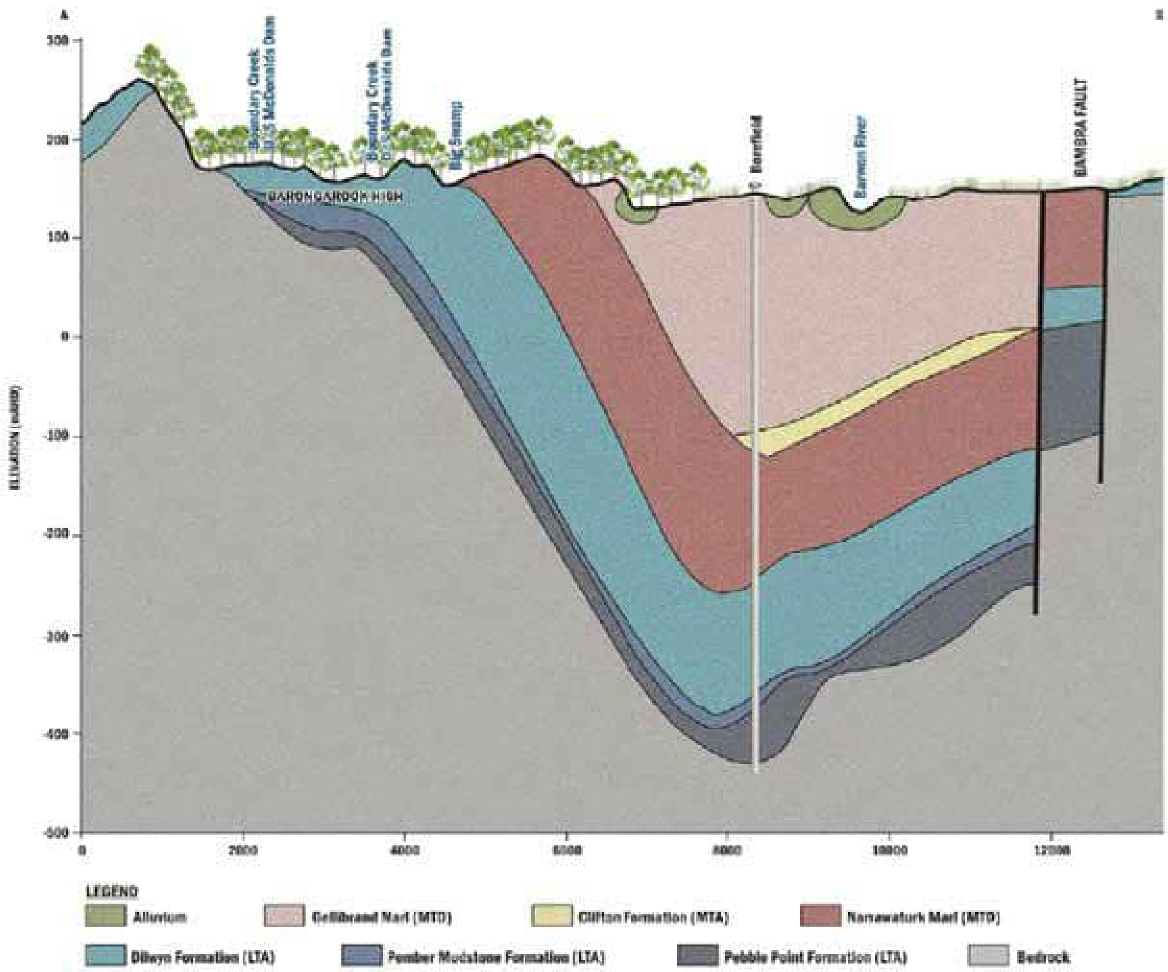

Figure 16 North – South Cross Section through the Barwon Downs Graben (Jacobs, 2018)

It is noted that the potentiometric contours of Leonard *et al.,* (1983) do not extend across the Yeo Dome on the understanding at the time that it was a marl covered basement high. However, as documented in Stanley (1991) following reinterpretations it was established that the Yeo Dome was not marl covered but rather covered in LTA. As such the more recent groundwater flow interpretations (i.e., those shown on **Figure F17** and **Figure F18**) show connection and continuation of the LTA across this region.

At the end of the Millennium Drought the potentiometric surface of the LTA shows a cone of depression around the Barwon Downs borefield (**Figure F17**), with the Pipeline Restriction flow path having been reversed and now flowing into the BDIA rather than south west towards Gellibrand River. By 2022 (**Figure F18**) groundwater flow via the Pipeline Restriction has returned. The amount of groundwater flow to the north east, from the Yeodene Recharge avenue, is unclear with the potentiometric surface flattening substantially.

The potentiometric surface of the LTA at the end of the Millennium Drought period (2010) and more recently (2022) are further described in **Section 5.1**, along with associated trends.

4.9.5.3 LTA Hydraulic Parameters

A number of previous investigations have reported on and collated pumping test information on the LTA. This has been summarised in (Department of Minerals and Energy, 1984) and presented in **Table 7** below.

Lakey & Leonard (1983) have also documented transmissivity values of the LTA specifically within the KIA, while the information presented in **Table 7** is based on pumping tests predominantly completed in the BDIA. As such the Department of Minerals and Energy (1984) data are considered more representative of the LTA within the BDIA.

The pumping tests completed within the BDIA indicated transmissivity ranged between 366 and 650 m^2/day, with corresponding hydraulic conductivities of 6.8 and 8.3 m/day (Department of Minerals and Energy, 1984) (**Table 7**).

Table 7 LTA Hydraulic Properties Summary

Test Site	Pumping Bore	No of Observation Bores	Aquifer(s) tested	Total length screened interval (m)	Pumping Rate (m3/day)	Test Duration (days)	Drawdown in Production Bore at Test End (m)	Transmissivity of Aquifer Interval test (m2/day)	Hydraulic Conductivity of aquifer tested (m/day)	Storage Coefficient
Barwon Downs	GW1	4	Mepunga; Dilwyn	40	7179.12	1.6	50.6	366	9.2	3.0×10^{-4}
Gerangamete (Barwon Downs Borefield)	GW2	6	Dilwyn; Pebble Point	75	5564.16	5.0	25.75	512	6.8	3.2×10^{-4}
	GW2A	-	Mepunga; Dilwyn; Pebble Point	78	7732.8	0.08	21.45	650	8.3	2.8×10^{-4}
	GW4	-	Mepunga; Dilwyn; Pebble Point	82	7776.0	0.02	37.25	-	-	-
	GW5	-	Mepunga; Dilwyn; Pebble Point	79	7776.0	0.04	21.55	-	-	-
Wire Lane	Muroon 23	1	Pebble Point	13	984.96	0.83	9.50	64	4.9	1.8×10^{-5}
Deans Marsh	Whoorel 6	1	Dilwyn	14	1330.56	0.54	-	-	-	-
Forrest Lodge	Yaugher 8014	4	Dilwyn; Pebble Point	42	1114.56	3.06	24.60	320	7.6	2.4×10^{-3}

Test Site	Pumping Bore	No of Observation Bores	Aquifer(s) tested	Total length screened interval (m)	Pumping Rate (m3/day)	Test Duration (days)	Drawdown in Production Bore at Test End (m)	Transmissivity of Aquifer Interval test (m2/day)	Hydraulic Conductivity of aquifer tested (m/day)	Storage Coefficient
Gellibrand	Yaugher 27	3	Dilwyn	15	2743.80	10.0	24.88	220	14.7	5×10^{-4}
McDonalds Lane	Yaugher 31	1	Dilwyn	10	497.68	2.08	43.40	40	4.0	1.5×10^{-2}
Carlisle River	Newlingrook	1	Dilwyn	50	1870.68	2.00	1.76	1100	22.1	2.2×10^{-3}
Kawarren	Yaugher 37	4+	Dilwyn; Mepunga	72	5413	6.5	-	970	13.5	3.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 50		-	-	-	-	968	-	3.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 35 (108910)		-	-	-	-	1056	-	1.0×10^{-4}
Kawarren	Yaugher 51	Yaugher 34 (108909)	-	-	-	-	-	728	-	1.1×10^{-3}
Kawarren	Yaugher 51	Barongarook 54 (47986)	-	-	-	-	-	4408	-	4.8×10^{-3}

4.9.5.4 Hydraulic Gradients

The horizontal gradients of the LTA in the BDIA have been estimated based on a number of previous investigations. The horizontal hydraulic gradients have ranged between 0.003 and 0.026 in the LTA through the Yeodene recharge avenue. Numerous previous investigations have noted that horizontal hydraulic gradients flatten substantially in the eastern portions of the BDIA, and this is corroborated by the interpretations presented in **Figure F16** - **Figure F18**. Flat gradients in this portion of the LTA may indicate a relative lowering of lateral groundwater migration rates, and/or an increasing role of vertical hydraulic gradients and vertical flow in the groundwater flow regime, given the decreasing thickness of the overlying Narrawaturk Marl and eventual outcrop of LTA in this area.

Upward vertical hydraulic gradients have been reported at nearby bores within the LTA in the BDIA, with values of 0.0076 and 0.025; however, the upward leakage may reverse during periods of pumping (Witebsky *et al.*, 1995). However, this reversal could only occur where the hydraulic head in the LTA was drawn down to below the hydraulic head in the overlying LMTD. Witebsky also noted that the vertical hydraulic gradients were typically greater than the horizontal gradients, with the vertical hydraulic gradients being over 60 times the horizontal gradient in the Murroon area near the Bambra Fault.

Previous investigations including Jacobs (2018) have identified upward vertical leakage of groundwater from the LTA to the LMTD as a potential discharge process for the LTA under ambient potentiometric conditions. While the permeability of the overlying Narrawaturk Marl indicates upward leakage would be significantly impeded, it may be occurring at low rates, but over a relatively large areal extent.

Previous interpretation by GHD (2020) was that the QA was in direct hydraulic connection with the LTA within portions of Big Swamp and in the remaining areas the QA and LTA were generally disconnected by the LMTD. However, subsequent drilling completed by Jacobs (2022) in the Big Swamp area reported thicknesses of intercalated Demon's Bluff/Narrawaturk Marl much further upstream, separating the QA from the LTA throughout Big Swamp.

Whilst there are upward hydraulic gradients from the LTA, that is not to say that groundwater is likely to actually be migrating upward through these sequences and dominating spring discharge to any significant degree. That is, the Narrawaturk Marl (LMTD) appears to be acting as a competent confining layer where it overlies the LTA (refer to **Section 4.9.4**).

4.9.5.5 Flow Rates and Residence Times

The average linear velocity of groundwater within the LTA via the likely predominant flow paths, the Yeodene Recharge Avenue and south west via the Pipeline Restriction, have been calculated using a derivation of Darcy's Law:

$$V = Ki \div ne$$

The average linear velocity represents the actual rate that groundwater is moving within the aquifer. These are summarised in **Table 8**. Based on the length of each key flow path, expected residence times have also been calculated.

Table 8 Average Linear Velocity of Key Flow Paths in the BDIA

Parameter	Yeodene Recharge Avenue	Pipeline Restriction	Comment
K (m/day)	6.8	1	Lower end of the range of values reported in **Section 4.9.5.3.** This has been adopted as bores are typically screened in high productivity zones, which biases the K values to higher numbers.
i	0.003	0.008	Average gradient across both flow paths based on

Parameter	Yeodene Recharge Avenue	Pipeline Restriction	Comment
			2022 potentiometric surface.
n_e	0.1	0.1	Consistent with porosity value adopted by Atkinson *et.al* (2014)
V	0.204 m/day	0.08 m/day	Calculated
Average flow path length (km)	25	20	Flow paths as per (Leonard *et. al.,*1983) (i.e. pre-pumping). Corroborated with 2022 potentiometric surface.
Years to travel flow path	~350	~700	Calculated

Radiocarbon dating conducted by Petrides and Cartwright (2006), suggest older corrected radiocarbon ages between 5,000 and 18,000 years, noting the interaction with carbonate cements or other non-radioactive carbon sources in the aquifer would bias results older, with estimates based on Darcy's Law suggesting substantially younger ages in the order of 100s to 1,000s of years, broadly similar to those estimated in **Table 8**.

Petrides and Cartwright (2006) used a porosity of 0.15 and a conductivity of 1 – 10 m/day in their Darcy's Law-based estimates, a similar range to that adopted in **Table 8**.

Estimates based on Darcy's Law rely on the key aquifer parameters, of which hydraulic conductivity is often the most variable and least well constrained, particularly at a regional or basin scale. It is considered that the estimates arrived at in **Table 8** (and those determined by Petrides and Cartwright, 2006) are possibly biased high by the hydraulic conductivity values adopted, which are determined from aquifer testing utilising wells. This is considered likely to result in hydraulic conductivities that are representative of the more permeable horizons within the LTA, which bores would typically be constructed to intersect. Average hydraulic conductivities across the full breadth and depth of the LTA may be considerably lower. Petrides and Cartwright (2006) also considered this to be a contributing factor to the difference between residence time estimates and radiocarbon ages.

There is the possibility that the older groundwater ages are a function of the groundwater flow paths being longer than that adopted in **Table 8**. For example, there is uncertainty regarding the discharge mechanism from the north-eastern portion of the LTA in the BDIA (refer to discussion below in **Section 4.9.5.6**. One possible mechanism is that the north-easterly component of groundwater flow also ultimately flows toward the Pipeline Restriction, which would correspond to a flow paths double that assumed in **Table 8**.

4.9.5.6 Aquifer Recharge and Discharge Estimates

The main recharge mechanism for the LTA is via rainfall infiltration directly to the aquifer where it outcrops across the Barongarook High. While only a portion of the Barongarook High (approximately 25 km^2; **Figure F8**) falls within the BDIA, based on potentiometry presented by Leonard (1983), HydroTechnology (1994) and others including interpretations presented on **Figure F16** - **Figure F18**, the intake area relevant to the BDIA (including via the Yeodene Recharge Avenue) is likely to be substantially larger. The intake area of the Barongarook High contributing to flows into the BDIA is estimated to be approximately 40 km^2.

Connectivity between outcropping LTA to the south of the Bambra Fault and the LTA at depth, within the graben itself is understood to be limited (by up to 95% transmissivity reduction on average; Jacobs, 2016); however, there are some areas (i.e. in the vicinity of Murroon) which have been shown to have a higher degree of interconnectivity due to relatively smaller displacement by the fault zone (**Figure F14**). In these areas, it is considered likely that recharge to the graben would occur via these outcrops in the foothills of the Otway Ranges. The LTA outcrops that occur in the vicinity of the East and West Barwon Rivers are considered to have limited connectivity and therefore these areas are not considered significant areas of groundwater recharge to the confined portions of the LTA.

A range of recharge estimates to the LTA have been made. These are summarised **Table 9**, below.

Table 9 Previous LTA Recharge and Discharge Estimates (as quoted)

Recharge (ML/year)	Discharge (ML/year)	Recharge/ Discharge Zone	Assumptions / Comments	Source
5,361	-	Barangarook to Yeodone (North-Easterly Component)	· Recharge was estimated based on a 5% effective infiltration	Blake, 1974
3,200	-	Barangarook to Yeodone (North-Easterly Component)	· Intake area for Barwon downs Graben is ~54 km^2 · Effective infiltration of 27.4 cm/year or 30% annual precipitation (using 900 mm as mean annual precipitation)	Lakey & Leonard, 1983
1,800	-	Barangarook to Yeodone (North-Easterly Component)	· Intake area for Barwon downs Graben is ~28 km^2, 10km^2 of which is considered to flow to BDIA · Effective infiltration of 14% annual precipitation (using 1,000 mm as mean annual precipitation)	Lakey & Leonard, 1984
18,000	-	Barangarook to Yeodone (North-Easterly Component) and infiltration across BDIA area	· Recharge estimates based on numerical modelling	SKM, 2001
9,000 – 14,000	-	Barangarook to Yeodone (North-Easterly Component) and infiltration across BDIA area	· Variation based on climate change model adopted · Recharge estimates based on numerical modelling	SKM, 2011
5,835 (current) 4,145 – 6,336 depending on climate change scenario adopted	-	Barangarook to Yeodone (North-Easterly Component) and infiltration across BDIA area	· Variation based on climate change model adopted · Recharge estimates based on numerical modelling	Jacobs, 2018
5,340	-	Barangarook High, Bambra Fault Area and Eastern Area	· Estimated by Blake (1974) based on effective recharge rate of 5% of annual rainfall of 890 mm and a larger area of potential aquifer outcrop of 120 km^2	Witebsky *et al.*, 1995

Recharge (ML/year)	Discharge (ML/year)	Recharge/ Discharge Zone	Assumptions / Comments	Source
-	383[6]	Discharge to Boundary Creek	· Based on vertical hydraulic gradient of 0.07, vertical conductivity of 0.5 m/day and discharge area of 3,000 m x 10 m.	Witebsky *et al.,* 1995

Other possible intake areas include the outcrops of the LTA immediately adjacent and to the south of the Bambra Fault, although these are understood to have variable degrees of connection to the LTA within the graben based on the hydrograph responses to pumping, and possibly LTA outcrop areas between Whoorel and Bambra in the far east of the BDIA. However, these latter areas appear to be hydraulically downgradient of the LTA in the central portion of the graben.

Overall the hydraulic gradient in the LTA in the eastern half of the BDIA is very flat (e.g. 0.0005; based on head differences between M24 and YYG221) and discharge pathways from the aquifer in this area remain unclear. Two primary pathways have been postulated (e.g. Blake, 1974; Leonard, 1983 and Petrides and Cartwright, 2005, among others):

1) South westerly flow to the Gellibrand River (via the Pipeline Restriction); and
2) North easterly flow and discharge via leakage along the Bambra Fault.

The north-eastern flow path is the least well defined and considerable uncertainty remains as the veracity and magnitude of this pathway, partly due to a lower density of water level data in this region.

Other possible discharge mechanisms that are considered plausible include upward leakage into the overlying aquitard/s (under ambient conditions), a higher volume of discharge (from a greater areal extent of the LTA) via the Karwarren Recharge avenue and discharge to the north towards Birregurra, all of which can be inferred from the available hydraulic data. It is noted that, based on analysis by Witebsky *et. al.,* (1995), the Birregurra Fault only partially truncates the LTA, with some contiguous layers interpreted to extend across the fault in the central northern portions of the graben.

Given the uncertainty regarding discharge mechanisms from the LTA within the BDIA, estimates of discharge volumes are therefore unlikely to be meaningful. It can be said that during ambient (non-pumping) conditions within the aquifer, where change in storage is minimal, that discharge from the LTA would be broadly equal to the recharge entering the system via the pathways described above. During periods of extended pumping, changes in storage would likely be attributable to groundwater extraction; however, may also be influenced by the net effects of reduced discharge from other pathways, due a reduction or reversal in hydraulic gradients, and enhanced recharge due to induced leakage from adjacent formations or increased available storage in intake areas.

BlueSphere's analysis of likely recharge for the LTA within the BDIA suggests at least two probable intake areas being the Barongarook High and outcropping areas of LTA south the Bambra Fault in the vicinity of Pennyroyal Creek. As previously noted, the intake area for the BDIA on the Barongarook high is considered to be larger than the area that lies within the BDIA, with potentiometry indicating groundwater inflows from further upgradient (**Figure F19**). The BDIA portion of the intake area on the Barongarook High is considered to cover an area of approximately 40 km^2, with a further 12 km^2 attributable to possible intake areas south of the Bambra Fault. While literature values vary widely, in large part due to widely variable inputs and assumptions, there is a general consensus that recharge rates based on Darcy's Law and related hydraulic approaches tend to be higher than those determined by other methods including radiocarbon dating, chloride mass balance and numerical modelling. This is likely to due in part to inherent bias towards higher hydraulic conductivities from wells being constructed in relatively transmissive portions of the aquifer, but also due to present day climatic conditions not being representative of conditions in the recent geological past (i.e. the end of the last glacial period), where rainfall volumes would have been substantially lower. Land clearing

[6] Witebsky reports a discharge rate of 1,000 ML/year, however, this appears to be incorrect on the basis that the vertical hydraulic conductivity was reported in units of m/day, not m/year. Based on the parameters reported by Witebsky, the volume of discharge should be 383 ML/year (0.5 m/day x 30,000 m^2 x 0.07).

since European settlement is also considered to have altered recharge dynamics by reducing the amount of rainfall taken up by vegetation.

The most robust account of recharge processes, determined through comparison of multiple estimation methodologies is considered to be that presented in Jacobs (2016), which can be summarised broadly as present day recharges rates are likely to be of the order of 10% of annual average rainfall in the vicinity of the recharge areas, as supported by short lived radio isotope and other methods, with long term average recharges rates, which account for historic climatic and land use scenarios being closer to 5% of present day rainfall rates based on chloride mass balance and numerical model calibration approaches.

Table 10 below summarises the estimated apportionment of annual recharge to the BDIA, discretised broadly into the key flow paths as determined by the ambient potentiometry.

Table 10 Recharge Estimates for LTA Recharge Areas in the BDIA

Intake Area Name	Dominant Flow Path	Estimated Intake Area (km^2)	Incident Annual Rainfall (mm)	% Modern Day Recharge Rate	Annual Recharge Volume (ML)
Barongarook High	Yeodene (North-Easterly Component)	21	897	10%	1,884
	South West via Pipeline Restriction	18.6	897	10%	1,668
Bambra Fault – Pennyroyal Area	?	12.3	760	10%	935

This analysis suggests present day recharge volumes via the Barongarook High intake area to the BDIA of the order of 3,500 ML, with total annual recharge via all contiguous LTA outcrop areas to the BDIA of the order of 4,500 ML. These estimates accord reasonably well with previous estimates, particularly those of Witebsky *et al.,* (1995) and Lakey and Leonard (1983).

4.9.6 Otway Group Aquifer

There is little information available regarding the properties of the OGA. Tickell *et. al,*. (1991) consider the OGA to be a poor aquifer producing little water and generally having a low permeability. Where a fracture and/or joint is encountered then the aquifer may be considered a minor aquifer. As documented in Tickel *et. al,*. (1991) there are several records which indicate bore yields in the range of 0.1 – 1.26 L/s.

The OGA outcrops along the Otway Ranges to the south of the graben and in parts of the Barongarook High. In this area the OGA is unconfined with recharge occurring via direct infiltration of rainfall. Discharge is expected to occur via either evapotranspiration or via direct discharge into local streams (Tickell *et. al.,* 1991) where the OGA outcrop. Tickell *et. al.,* (1991) also note that discharge of groundwater from the OGA contributes the base flow of the overlying streams during dry periods. Where the OGA is overlain by the LTA, groundwater is expected to either discharge from the OGA into the LTA, or vice versa depending on the hydraulic potentials (which are not well characterised in the BDIA).

Groundwater flow within the OGA is expected to broadly follow topography and flow in a north/north westerly direction from the most elevated parts of the Otway Ranges to the south, consistent with regional topography and surface water drainage.

4.10 Groundwater Resource Utilisation

4.10.1 Registered Extractive Use Bores

A search of the Water Measure Information Systems (WMIS) database identified a number of registered groundwater users within the BDIA (**Figure F19**). Within the BDIA 41 groundwater bores were registered for domestic/stock use while one was non groundwater. One non-groundwater bore located immediately outside of the BDIA boundary as shown on **Figure F19** is used for irrigation purposes (WRK056121). This bore is 44 m deep and based on the information publicly available for this bore it is screened within sand (inferred to be LTA) between 30 and 36 m bgl. It was installed in 2010.

4.10.2 Barwon Downs Borefield

The history of the borefield has been documented in (Jacobs, 2018a) and is briefly summarised below:

- The drought of 1967-68 resulted in reduced water supply levels for Geelong, prompting investigations of a groundwater resource to augment supplies for the Geelong region by the Geelong Waterworks and Sewerage Trust (now Barwon Water).
- The Barwon Downs Graben was identified as a significant groundwater resource following investigations and a trial production bore was constructed in 1969, followed by an additional bore in 1977 at Gerangamete.
- Stage I of the borefield involved the construction of three production bores (see **Table 11**, below), while Stage II was to construct an additional three bores (Lakey & Leonard, 1983).
- An additional two production bores were installed in 2001.

Table 11 Production Bore Summary (after Barwon Water)

Production Bore ID	Date Installed	Bore Depth (m)	Screen Interval (m)	LTA[1] Units
GW2A	20 May 1982 Relined in 1998 and refurbishment works in 2016	543	383 – 542	Mepunga, Dilwyn, Pebble Point
GW3	1983 Relined in 1997 and refurbishment works in 2016	538.8	361 – 538.8	Mepunga, Dilwyn, Pebble Point
GW4	15 February 1982 Relined in 1997 and refurbishment works in 2016	645	452.5 – 645	Mepunga, Dilwyn, Pebble Point
GW5	29 November 1981 Re-sleeved in 1987 and refurbishment works in 2016	506	350 – 506	Mepunga, Dilwyn, Pebble Point
GW6	12 January 2001 Refurbishment works in 2016	552	328.5 – 488.2	Mepunga, Dilwyn, Pebble Point
GW8	31 January 2001 Refurbishment works in 2016	561	339 – 547	Mepunga, Dilwyn, Pebble Point

Notes: 1. LTA – Lower Tertiary Aquifer – refer to **Sections 4.8** and **4.9** for further detail.

4.10.2.1 Licence

Barwon Water was issued with a licence by the State Rivers and Water Supply Commission (now Southern Rural Water) in 1975. It is, however, noted that the borefield did not commence operation until the 1982-83 drought. The licence allowed the operation of four production bores. The licence was renewed several times between the period of 1975 and 2019 and allowances are summarised below in **Table 12**. In 2019 Barwon Water let the licence expire.

Table 12 Licence Conditions

Licence Period	Maximum Daily Extraction	Maximum Annual Extraction	Maximum 10 year Extraction
1975 – 1990 Renewed two times for 5 year periods up to 2000	42.5 ML	12,600 ML	80,000 ML
2000 - 2004 From 2000 temporarily extended 3 times for a total of four years	42.5 ML	12,600 ML	80,000 ML
2004 – 2019 Extra conditions included Long term (100 year period average extraction rate of 4,000 ML/year)	55 ML	20,000 ML	80,000 ML

4.10.2.2 Operational History

The operational history of the borefield has been documented in (Jacobs, 2018a) and is summarised in the table below and is also presented graphically in **Figure 17**. However, based on correspondence from Barwon Water the documented extraction volumes have potentially been reported differently over the years, e.g. if the reporting has been completed over a calendar year or a financial year. There has also been some uncertainty regarding extraction in the 1980s and if the volumes related to Barwon Water needing the water to supplement water supply or it was during a pump test.

Between the granting of the licence in 1975 and the end of the licence 2019 (44 year period) extraction occurred five times.

Based on correspondence from Barwon Water it is understood that bores GW6 and GW8 were used the most during the extraction periods, followed by GW5, GW4 (due to being deeper and less affected by draw down), GW2A. Production bore GW3 was typically used last as it had approached trigger levels earlier than the other bores.

Table 13 Pumping Summary

Pumping Period	Extracted Volume	Comment
1983	3,652 ML	Corresponded to the 1982-83 drought
1988 – 1990	19,074 ML	Corresponded with a pumping test, no recorded drought
1997 – 2001	36,820 ML	Corresponded with the first half of the Millennium drought – 1997 – 2001
2003	271	Correspond with drought period
2005 – 2010	52,683 ML	Corresponded with the second half of the Millennium drought – 2005 – 2010

Pumping Period	Extracted Volume	Comment
2015 – 2016	3,449.1 ML	Corresponded with a ‘record dry summer’ (Jacobs, 2018a)
Total Volume Extracted	115,949.1 ML	Up to 119,000 ML

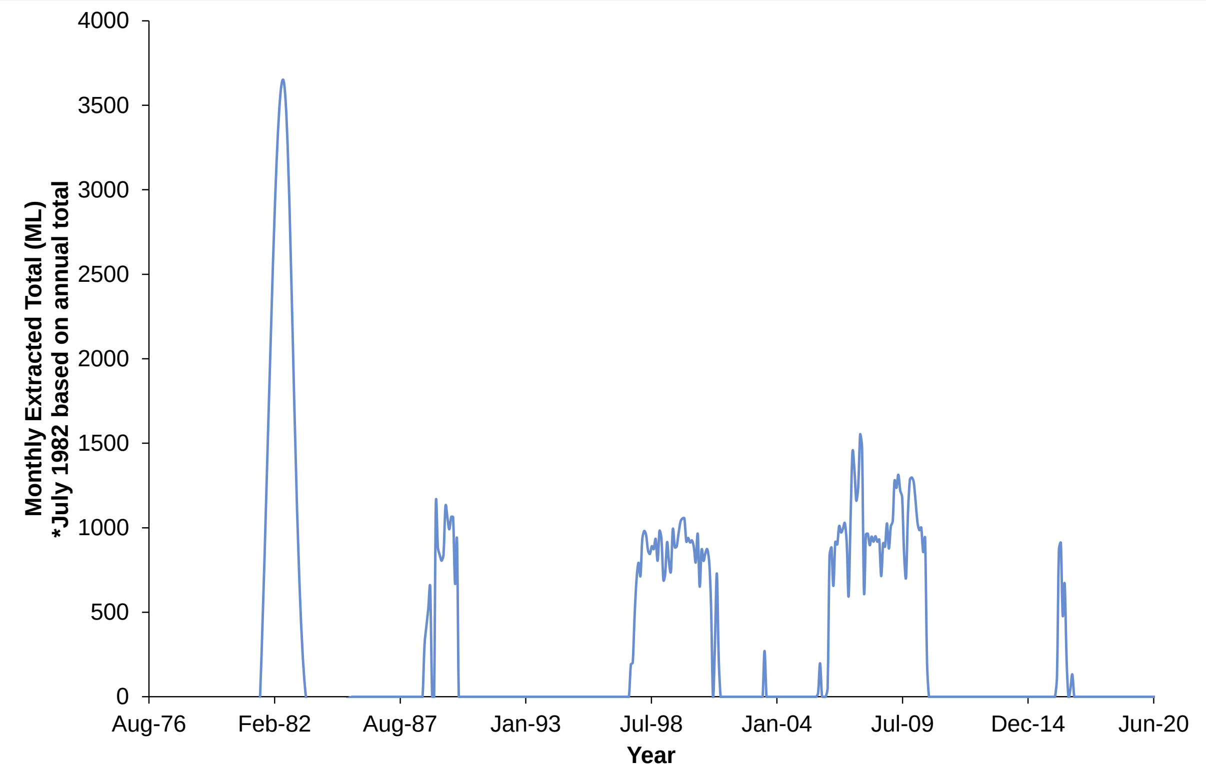

Figure 17 Monthly Extracted Total

4.11 PCV Amendment Rationale

On 26 June 2019 an order was made under Section 22A of the Water Act 1989 in relation to the permissible consumptive volume (PCV) for the Gellibrand and Gerangamete Groundwater Management Areas (GMAs). The PCV for the Gerangamete GMA was previously set as 20,000 ML/year with no more than 80,000 ML in consecutive period of ten years[7]. This was equivalent to the Barwon Water licence current at the time.

The PCV was reduced to 239 ML/year with no more than 30 ML/year under a licence for the purpose of pump tests. A PCV for the Gellibrand GMA of 0 ML was established.

The 2019 PCV of 239 ML/year for Gerangamete was set at a level lower than the inferred recharge rate at the time so as to allow the aquifer to recover following cessation of extraction from the Barwon Downs Borefield whilst honouring the balance of existing licences in the Gerangamete GMA, of which there are three individual licences[8]. The Gerangamete Local Management Plan was last updated in April 2023 and is to be reviewed on an as needs basis [9].

[7] Victorian Government Gazette, Permissible Consumptive Volume Groundwater Order 2011, No. G28, Thursday 14 July 2011

[8] Hopkins-Corangamite Groundwater Catchment Statement, Southern Rural Water, 18 September 2019

[9] Gerangamete Groundwater Management Area Local Management Plan, Version 1, April 2023

4.12 Groundwater Quality

The quality of groundwater in the LTA, LMTA and QA has been documented to various degrees and a range of available groundwater salinities (Total Dissolved Solids (TDS)) for each aquifer grouping is provided in **Table 14** below sourced from (Tickell *et al.*, 1991).

Table 14 Salinity Range of Aquifer/Aquitard Groupings

Aquifer/Aquitard Grouping	TDS Range (mg/L)
Otway Group Aquifer	1,000 – 3,000
LTA	200 – 500
LMTD	695 – 2,529*
LMTA Clifton Formation Gellibrand Marl	 500 500 – 1,500
QA	130 – 299*

Notes: - indicates no data available.
* data from Jacobs (2018)

There have been selected studies on the groundwater quality of the LTA in the BDIA including Department of Minerals and Energy (1984); Witebsky *et al.,* (1995); Petrides and Cartwright (2006) and CDM Smith (2022). The findings are summarised:

- The pH of groundwater was generally acidic with an average of 6.01. The acidic groundwater generally correlated with higher iron concentrations, which were attributed to oxidation of pyrite in the upper Dilwyn Formation. Alternativley the acidic pH of groundwater may be due to the oxidation of dissolved iron when the groundwater is pumped to the surface.
- Groundwater in the BDIA was considered to be oxidised with dissolved oxygen concentrations up to 9 mg/L. There did not appear to be a large difference in dissolved oxygen concentrations in bores located on the Barongarook High or within the BDIA at depth. However, there were bores within the borefield area that had low dissolved oxygen, an acidic pH and high concentrations of iron, and as noted above was attributed to oxidation of pyrite in the Dilwyn Formation.
- Petrides and Cartwright (2006) reported TDS concentrations between 80 and 4,353 mg/L and found no real correlation between lower TDS concentrations and bores located in recharge areas.
- Groundwater sampled in the Barongarook High area (i.e. recharge area) were found to be dominated by sodium, chloride and bicarbonate.
- Compared to groundwater surface water in Boundary Creek and Barwon River were found to show a similar composition to groundwater, although TDS concentrations were generally lower in surface waters.
- Fluoride and nitrate concentrations in groundwater in the LTA were found to be low and were considered to be derived from the atmosphere, surface or unsaturated zone, given there were no sources identified in the LTA.
- Groundwater within the Big Swamp West (i.e. not the LTA) was found to be acidic (pH 2.9 – 4), high concentrations of sulfate and high concentrations of metals including aluminium, manganese, nickel and zinc. Comparably groundwater sampled from Big Swamp East was generally less acidic (pH 3.6 – 7), low sulfate concentrations and low metal concentrations.
- Groundwater sampled from the LTA within the vicinity of Big Swamp had a slightly acidic pH (5.1), low sulfate and low metal concentrations.

4.13 Surface Water

4.13.1 Regional Setting

As described above in **Section 4.3**, the BDIA sits within the Otway Coast Basin which extends from just east of Breamlea to just west of Port Campbell. The BDIA sits within the Otway Coast catchment, with the Gellibrand River catchment lying to the west of the BDIA. The predominant surface water body in the Otway Coast catchment is the Barwon River, which originates from the foothills of the Otway Ranges via the east and west branches, before joining and becoming Barwon River main branch in the central western portion of the BDIA.

4.13.2 Local Surface Water Systems

There are 12 key surface water bodies in the BDIA that are focussed on in this report (see **Figure F4**); they are:

- Boundary Creek (which flows through Big Swamp);
- Big Swamp;
- Pennyroyal Creek;
- Deans Marsh Creek;
- Wurdiboluc Channel;
- Matthews Creek;
- Dewing Creek;
- Barongarook Creek;
- Yan Yan Gurt Creek; and
- Barwon River East Branch, West Branch and Main Branch.

A summary of the main surface water catchment areas and surface water bodies (based on information sourced from MapShare Vic, Energy, Environment and Climate Action (EECA) website) and associated available gauges is provided below in **Table 15** and **Table 16**, respectively. It is noted that a number of the surface water bodies mentioned above do not have gauges and/or have limited sets of data.

Table 15 Summary of Surface Water Catchments in BDIA (MapShare (DEECA))

Catchment name	Barwon River						Lake Colac
Sub-catchment name	Boundary Creek (Upstream)	Boundary Creek (Downstrea m)	Deans Marsh Creek	Barwon River East Branch	Barwon River West Branch	Barw on River	Barongaro ok Creek (Yeodene)
Catchment area (km2)	26	24.6	98	90.2	247.6	165.4	73.8
Mean annual flow (ML/day)	14.1	9.4	43.1	40.9	79	52.9	27.2
Maximum daily extraction volume (ML/day)	7.1	4.5	16.4	15.5	47.2	23.6	13.4
MFT (for farm bypass) (ML/day)	6.3	4.2	15.9	20.6	40.6	16.1	11.2
Minimum flow threshold for gauge 1 (ML/day)	8	8.7	8	17.4	8	8	8

Catchment name	Barwon River						Lake Colac
Minimum flow threshold for gauge 2 (ML/day)	17.4	17.4	17.4	11.9	17.4	17.4	17.4
Minimum flow threshold for gauge 3 (ML/day)	11.9	11.9	44.4	44.4	11.9	44.4	44.4

Table 16 Summary of Surface Water Bodies and Associated Gauges in BDIA

Surface Water Body	Stream Gauge	LTA Outcrop	Description	Gauge Record	Used for Trend Analysis[10]
Boundary Creek @ Barongarook	233273	No	Originates from the central section of the Barongarook High and flows east south east before joining Barwon River (main branch) to the east of Colac-Forrest Road.	2014 – 2023	No
Boundary Creek @ U/S of McDonalds Dam	233231	No. However, the LTA is expected to be present beneath a thin layer of Quaternary Sediments within the creek alignment. Bores located adjacent to the creek alignment (e.g. YEO45, ~300 m from the creek) indicate no Quaternary Sediments are present.		1989 – 1990	Yes
Boundary Creek @ D/S of McDonalds Dam	233229	It is expected that there may be small areas along the creek where LTA outcrops, however they would be expected to be localised. A thin layer of Quaternary Sediments are expected to overlie the LTA.		1989 – 2023	Yes
Boundary Creek @ Big Swamp	233275	No Big swamp is indicated to be underlain by Quaternary sediments and then Narrawaturk Marl		2019 – 2023	No
Boundary Creek @ Yeodene	233228	No		1985 – 2023	Yes
Barwon River @ Boundary Creek	233233	No	This gauge is located at the confluence of Barwon River and Boundary Creek. Barwon River flows north / north east towards Birregurra.	2022 – 2023*	No
West Barwon River @ Boundary Road, Forrest	233255	No. Potentially shallow Quaternary Sediments overlying LTA	Originates from the Otway Ranges and flows north / north east before joining the Barwon River East Branch. The joining with the East Branch occurs just upstream of the Boundary Creek, Barwon River confluence.	2021 – 2023*	No

[10] Trend analysis of surface water flow is discussed in **Section 5.3**.

Surface Water Body	Stream Gauge	LTA Outcrop	Description	Gauge Record	Used for Trend Analysis[10]
East Barwon River @ King Creek Junction	233254	Yes, or very shallow Quaternary Sediments overlying LTA	Originates from the Otway Ranges and flows north / north west before joining the Barwon River West Branch. The joining with the West Branch occurs just upstream of the Boundary Creek, Barwon River confluence.	2020 – 2021	No
Goslings Creek @ Murroon	233206	No. However, LTA sediments present up-stream.	Originates from the Otway Ranges and flows north before joining Matthews Creek.	1929 – 1930	No
Pennyroyal Creek @ Railway Culvert	233258	No. However, LTA sediments present up-stream.	Originates from the Otway Ranges and flows north. Pennyroyal Creek merges with Deans Marsh Creek.	2000 – 2023	No
Pennyroyal Channel	233710	No. However, LTA sediments present up-stream.	Originates from the Otway Ranges and flows north. Pennyroyal Creek merges with Deans Marsh Creek.	2002 – 2023	No
Wurdiboluc Channel	233711	No	Originates in the Otway Ranges and flows north east before merging with Matthews Creek.	2002 – 2016	No
Wurdiboluc Inlet Channel	233712	No		2000 – 2016	No
Matthews Creek @ Channel Offtake	233240	No	Originates in the Otway Ranges and flows north west toward the Barwon River	2000-2023	No
Barwon River @ Ricketts Marsh	233224	No	Barwon River originates in the Otway Ranges and flows north / north east, through Birregurra where it turns eastwards. The Barwon River flows to Geelong and discharges to Port Phillip Bay.	1971 – 2017	Yes
Barwon River @ Kildean Lane	233247	No		1993 - 2023	Yes

Notes: * Installed as part of Surrounding Environment Investigation.

4.13.3 Hydrological Characteristics

Catchment characteristics of the Barwon River and Boundary Creek have been summarised from Jacobs (2019) in **Table 17**, below. These characteristics include calculation of 10th, 50th and 90th percentile flows based upon mean annual flow data from relevant stream data. Also summarised are conclusions drawn in Jacobs (2019) in relation to predicted contribution of hydraulic influence from extraction from the Barwon Downs Borefield on streamflow at the nominated gauges based on predictions from a groundwater model. Further discussion regarding potential influence of groundwater extraction compared to other influences is provided in **Section 5.4**.

Table 17 Summary of Flow Barwon River and Boundary Creek (after Jacobs (2019))

Gauge	Length of Record	Minimum Flow (ML/day)	10th Percentile (ML/day)	50th Percentile (ML/day)	90th Percentile (ML/day)	Maximum Flow (ML/day)	Data Infilled	Groundwater Model Predicted Maximum Hydraulic Influence from Pumping (ML/day)
East Barwon River @ King Creek Junction 233254*	2020 – 2021	0	4.9	33.4	499.6	36,783.9	N/A	1.6 ML/day (33% low flow) where flows over LTA and 1.7 ML/day (35% low flow) where flows over LMTD
West Barwon River @ Boundary Road Forrest 233255*	2021 –2023	0	4.9	33.4	499.6	36,783.9	N/A	<0.01 ML/day (<1% low flow) where flows over LTA and 0.1 ML/day (2% of low flow) where flows over LMTD
Barwon River @ Ricketts Marsh 233224 (Barwon River Confluence)	1971 – 2017	0	4.9	33.4	499.6	36,783.9	N/A	0.7 ML/day (14% pre-pumping low flow)
Boundary Creek @ Barongarook 233273^	2014 – 2017	0.1	1.2	3.0	16.0	53.6	N/A	<0.01 ML/day (<1% pre-pumping low flow)
Boundary Creek @ U/S of McDonalds Dam 233231	1989 – 2017	0	0.3	2.8	22.8	235.5	N/A	2.9 ML/day (>100% of pre-pumping low flow)
Boundary Creek @ D/S of McDonalds Dam 233229	1989 – 2017	0	0.15	3.1	25.1	227.1	N/A	2.9 ML/day (>100% of pre-pumping low flow)
Boundary Creek @ Yeodene 233228	1985 – 2017	0	0	1.4	19.4	251.7	N/A	0.3 ML/day (30% of pre-pumping low flow)
	1979 – 1985	0	1	4	32	300	N/A	
	1979 – 2017	0	0	2	21.5	300	Linearly	

Notes: * Jacobs (2019) used Barwon River @ Ricketts Marsh 233224 as proxy for most representative gauge.
^ Indicated by Jacobs (2019) to flow over Otway Group.

4.13.4 Surface Water Quality

Previous studies have generally focussed on the water quality of Boundary Creek and Big Swamp including Austral Research and Consulting (2019 and 2022), CDM Smith (2022) and are summarised below:

- Metal and acidity originating from Big Swamp and Boundary Creek were found to be highly variable, likely linked to flows through Big Swamp. Although it was evident that the quality of surface water declined in the lower reaches of Boundary Creek, post 1997.
- The western portion of Big Swamp appears to have more acidification impacts compared to the eastern portion of Big Swamp.
- pH in the Barwon River downstream of the confluence with Boundary Creek appeared unaffected by low pH in Boundary Creek and were above the Tier 2 pH of 6.0 for Barwon River as detailed in the Ecological Risk Assessment (Nation Partners, 2023, draft).
- Concentrations of aluminium, arsenic, copper and iron concentrations generally exceeded the ANZECC guideline levels at Big Swamp and/or Boundary Creek. Aluminium was also elevated at several locations in Barwon River down-stream of the confluence with Boundary Creek. Zinc concentrations exceeded ANZECC guideline levels in the Barwon River West Branch and along most of the main branch of the river.

4.13.5 Surface Water Utilisation

There are a number of licenced surface water users who are able to utilise surface water in the BDIA for stock and domestic, irrigation and dairy purposes and these are summarised in **Table 18**, below as sourced from the Victorian Water Register website (https://waterregister.vic.gov.au/). Annual licences limits are issued for this purpose. It is noted that the specific location of these licenced users has not been evaluated.

The main known licenced surface water user is the licence associated with McDonalds Dam, located along Boundary Creek. The current licence BEE073711 is active until 30 June 2034 and allows extraction of up to 115 ML from the dam to be used for irrigation as well as domestic and stock, dairy and general non-irrigation farm use. The water may only be harvested between 1 July and 31 October inclusive. The dam is up to 6 m deep and has a capacity of 160 ML.

4.13.6 Environmental Flows

Since 2003 Barwon Water have released supplementary flows from Boundary Creek (upstream of McDonalds Dam), which was prior to the finalisation of the licence in 2006. Between July 2003 and December 2022 a total of 8371 ML has been released. The majority of the flows were released during drier months, however, on some occasions flows have been released during the wetter months of June and/or July (e.g. 2005, 2006, 2008, 2009, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021) when flows of between 0.15 and 2.21 ML were released.

Supplementary flows over the period between 2003 and 2022 have averaged 1.18 ML/day with a peak flow release of 4.18 ML, which occurred in November 2007.

Table 18 Summary of Licenced Surface Water Extraction (sourced from the Victorian Water Register^)

Water Source		Barwon River (Middle Barwon River)	Yan Yan Gurt Creek	Matthews Creek	Pennyroyal Creek	Deans Marsh Creek	Boundary Creek
Total Number of Licences		57	4	6	18	7	11
Tradable extraction licences		54	1	1	8	0	4
Non tradable extraction licences		3	3	5	10	7	7
Use for extracted water	Irrigation	27	4	6	10	251.5	252.8
	Domestic/Stock	22	-	-	-	-	-
	Industrial/commercial	3	-	-	2	-	5
	Dairy	5	-	-	6	5	10
Annual extraction volume (ML)		1051.6	188.5	47.3	211.1	256.5	268
Irrigation	Tradable	825.1	17.5	13.4	133.7	-	135*
	Non Tradable	110.8	171	33.9	77.4	251.6	117.8
Domestic/stock	Tradable	46.2	-	-	-	-	-
	Non Tradable	-	-	-	-	-	-
Industrial/commercial	Tradable	53.2	-	-	2.2	-	5
	Non Tradable	-	-	-	2	-	-
Dairy	Tradable	16.3	-	-	12	-	2.5
	Non Tradable	-	-	-	16.8	5	7.5

Notes: * 115 ML relates to licence BEE073711.

^ **Victorian Water Register website** (https://waterregister.vic.gov.au/)

4.14 GDEs

There is limited data with regards to groundwater dependent ecosystems (GDEs) in the BDIA. A review of the BoM Groundwater Dependent Ecosystems Atlas (2023) and incorporation of data provided by Barwon Water identified small areas of potential GDEs (**Figure F20**).

Previous investigations completed by Eco Logical Australia (2022a) found that identification of GDEs based solely on risk based modelling was difficult and that further works to target areas where the LTA outcrops was recommended. The further works by Eco Logical Australia (2022b) found that the watertables at the investigation areas along Deans Marsh, Barwon River East Branch, Barwon River West Branch were present at an average of 5 m depth. The potential for GDEs in the relevant investigation areas were found to be high for Barwon River East Branch, moderate potential for Deans Marsh and low for Big Swamp. There were no patches of GDE vegetation at Yeodene or Barwon River Main Branch investigation areas.

4.15 Acid Sulfate Soils

4.15.1 Background

Acid sulfate soils (ASS) are generally soils derived from sediments that are rich in sulfide minerals such as pyrite. ASS can exist in either a coastal or inland setting with inland ASS being present within the BDIA. Sulfide rich sediments are often deposited during a time of raised sea levels which provide the ideal environment for their formation due to the abundance of sulfate in seawater. They can also form from the weathering and sedimentation from sulfidic parent rocks, such as the upper portions of the Dilwyn Formation (Department of Minerals and Energy, 1984).

Acid sulfate soils can be classified as either a potential acid sulfate soil (PASS) or actual acid sulfate soil (AASS) depending on whether the soil has undergone oxidation. PASSs are sediments which contain sulfide minerals and have the potential to produce acid with oxidation while AASS are soils which have undergone oxidation and released acidity. The oxidation of these sediments can occur when the water table or stream that is responsible for maintaining anoxic, reducing conditions, is altered or lowered by either natural or anthropogenic processes (for example, drought, climate, through land use change, drainage enhancement, groundwater extraction, physical disturbance etc).

4.15.2 Analytical Results

Investigation conducted by EAL Consulting (2011), Glover (2014) and Jacobs (2015) have confirmed the presence of ASS in the BDIA. Historical ASS samples have been obtained from creeks, riverways and swamp areas throughout the Barwon Downs catchment area and are displayed in **Figure F21**.

The sampling events involved the collection of soil samples and the analysis for Chromium Reducible Sulfur analysis and pH sampling. Results from 31 sample locations were reviewed and compared against the EPA Publication 655.1 criteria values for sandy soils (18 mol H+ / tonne). Of the 31 sample locations, 27 area located within the investigation area and include:

- Barongarook Creek;
- Barwon River;
- Big Swamp;
- Boundary Creek;
- Deans Marsh;
- North Yeodene; and
- Pennyroyal Creek.

A summary of ASS classification and reported analytical results is provided in (**Appendix D**) and summarised in **Table 19** below.

Table 19 Summary of Acid Sulfate Soil Classification

ASS Type*	Sample Locations	Highest Net Acidity Result (mol H+/tonne)
Inside the Investigation Area		
Actual ASS	LBC02, SB3, SB8, SB9, SB13, YS01 and YS04	1,159 (SB13)
Potential ASS	BCBH01/BCBH02, BW, PR and WBBH01/WBBH02	539.8 (BW)#
Actual and Potential ASS	BC1 – BC3, BSBH01 – BSBH12, BSBH13LTA, BSBH14 – BSBH18, LBC01, SB1, SB2, SB4 – SB7, SB10 – SB12, SB14 – SB17, Site2, Site 4, Site 7, Site 9, Site 13, Site 14, YS02, YS03, YS05 and YS06	13,858 (BSBH18)
Possible ASS	DMBH01V/DMBH02V and McD1	N/A
Not Identified	NYBH01/NYBH02 and PCBH01V/PCBH02V	11 (PCBH01V/PCBH02V)
Greater Barwon Downs Catchment		
Actual ASS	PC4	89^
Potential ASS	PC4 and SH1	N/A
Possible ASS	-	-
Not Identified	YH1 and GRBH01/GRBH02	14 (GRBH01/GRBH02)

Notes: * Determined by comparing against a criteria value of 18 mol H+/ tonne

^ Value from maximum reported Titratable Actual Acidity value.

Net Acidity value calculated from sum of titratable actual acidity and potential acidity presented in Table D1 in **Appendix D**

Of the locations analysed, a total of 53 were identified to have AASS present with 52 located within the BDIA. In addition, 51 locations were identified to have potential ASS present with 49 located within our investigation area. Net acidity values reported in Big Swamp are consistently above the EPA criteria value for sandy soils (18 mol H+/tonne) with a maximum net acidity value of 13,858 mol H+/tonne (BSBH18). BlueSphere's findings made from reviewing the above reports are consistent with that made by (Gardiner, 2010).

Samples collected from Deans Marsh and McD1 (Boundary Creek) were determined to have possible ASS based on reported pH concentrations. Soil pH reported at Deans Marsh had a minimum oxidised pH of 3.9 indicating that there is some form of soil acidification process occurring with oxidation however no further Chromium Reducible Sulfur analysis was conducted at the location to determine the actual acid production potential. McD1 (Boundary Creek) results reported by EAL Consulting Services (2011) were noted to have high levels of actual acidity and low levels of potential acidity which may not be indicative of sulfidic acidity. This is similar to results reported at location SB3 (Glover, 2014) which reported levels of acidity inferred to be sourced from sediments transported from up-stream.

4.15.3 Extent

It has been noted that there is a correlation between the presence of ASS and Quaternary sediments within the BDIA, more specifically those sediments likely sourced from the weathering of coastal sediments such as the LTA (sulfidic source) which are present in waterlogged/wetland areas.

A remote mapping exercise conducted by Glover (2014) noted a correlation between low slope and waterlogged and/or swampy environments and the presence of ASS. Two investigation areas within the BDIA were chosen to confirm the validity of the remote mapping which includes the Barwon River (west branch) and a section of Boundary Creek, both shown in **Figure 18** below. Glover (2014) classified the ASS in these investigation areas into four different classes which as summarised into **Table 20** below. Of the ASS mapped within the investigation area, only Type 3 with a small section of Type 1 along Boundary Creek near Big Swamp were noted to be present.

These areas are at risk of acidification due to disturbances such as a reduction in water levels with no natural source of acid neutralisation noted to be present within the Big Swamp area (Glover, 2014). In addition, the role of the marl and other natural acid neutralising materials is not well understood.

Table 20 Inland ASS Classification Types (Glover, 2014)

Classification Type	Characteristics
Uncleared	
1	Flat bottomed valley, waterlogged and/or swampy vegetation, evidence of hummocky ground surface and no obvious drainage channels.
2	Flat bottomed valley, waterlogged and/or swampy vegetation and obvious drainage channels (< 0.5 m deep).
Cleared	
3	Flat bottomed valley, waterlogged and/or swampy vegetation in the past and obvious drainage channels (< 0.5 m deep).
4	Flat bottomed valley, waterlogged and/or swampy vegetation in the past and evidence of current waterlogging.

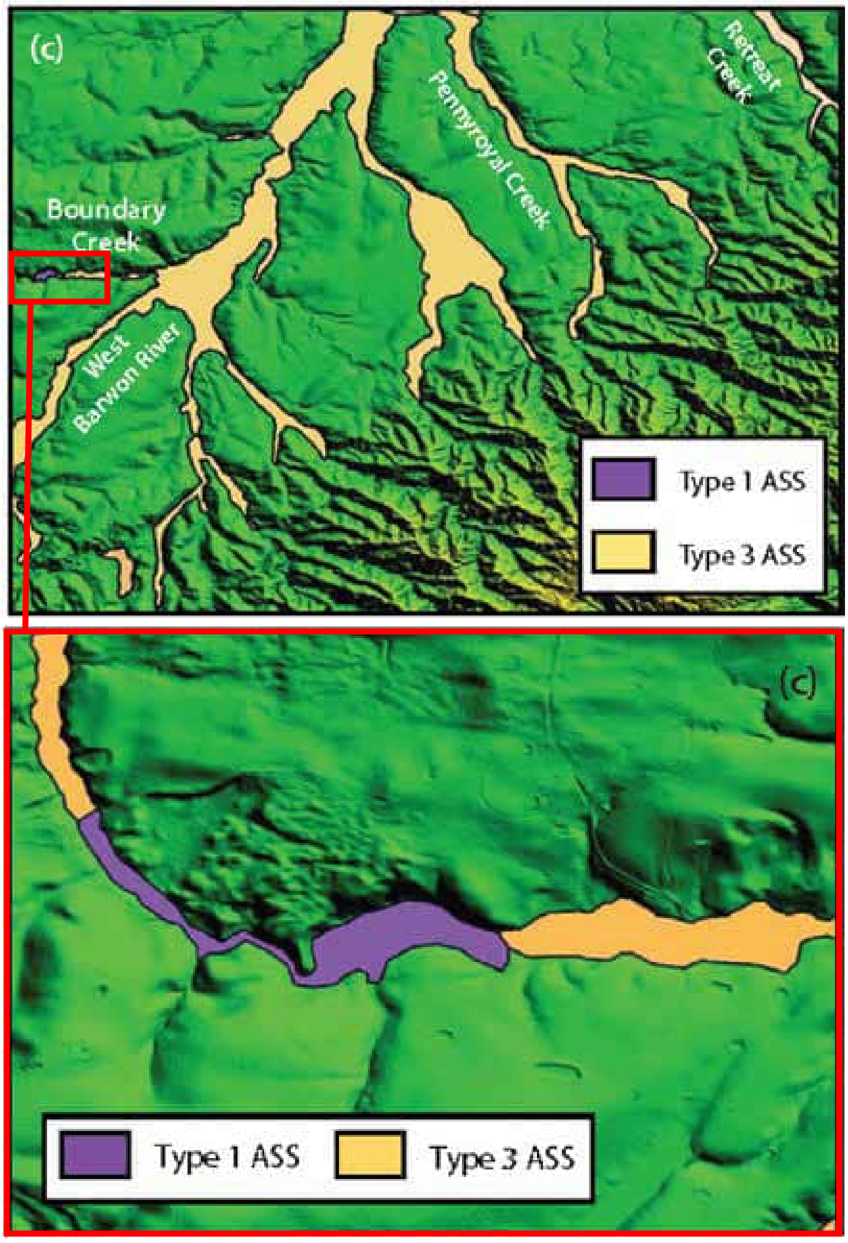

Figure 18 Mapped ASS of Barwon River (West Branch) and Boundary Creek (Glover, 2014)

The available information suggests that there is likely more areas of ASS within the BDIA than those already known, based on the mapped extent of Quaternary sediments in waterlogged/swamp like environments which are liable to ASS formation. Proximity to areas of Dilwyn Formation outcrop is also likely to be a governing factor given it is likely to be a key source of sulfidic sediment.

Some areas within the BDIA that have been cleared and altered have already undergone acidification as a response to a reduction in water levels. Many swamps and wetlands along tributaries have been drained by artificial deepening of channels and land use change (Glover, 2014). Consideration towards impacts on ASS should be given for future surface water and groundwater management.

5 Impact Assessment

5.1 Groundwater Potentiometric Surface Trends

Hydrographs have been prepared for groundwater bores within the BDIA with available long term water level records and are presented in **Appendix C**. Additionally, three potentiometric surface contours for the LTA have been prepared for 1983 (predominantly pre pumping), 2010 (at end of peak pumping period) and 2022 (most recent data set) and are presented on **Figure F16**, **Figure F17** and **Figure F18**, respectively. The water level change recorded in individual bores between 1997 and 2013 is presented on **Figure F22**.

An initial review of the hydrographs shows a number of bores responded substantially to the pumping from the Barwon Downs Borefield, with water levels decreasing by up to 50 m (e.g. G14) during the first extended pumping period of the Millennium Drought. Water levels in those bores that showed a substantial response did show recovery of water levels outside of pumping, however, they did not recover fully. Since 2016 when pumping ceased, water levels have recovered to in some instances 10 m of levels recorded in 1986.

Generally the water level change between 1997 and 2013 (peak pumping period) were highest closest to the borefield and decreased radially from the borefield (**Figure F22**). However, a number of exceptions were noted, and these are discussed below in **Table 21**.

Table 21 Summary of Potentially Anomalous Water Level Changes

Bore ID	Distance from Borefield	Water Level Change between 1997 and 2013	Comment
YEO23 (109114)	~9.2 km	-13.1 m	Would have expected a similar response in YEO44 as has been seen in YEO23 given their proximity. YEO23 is screened within Pebble Point Formation, while YEO44 is screened within Mepunga Formation. The difference could be due to YEO23 being screened within a more transmissive zone of the LTA than YEO44, and this is potentially supported by the thicker sequence of LTA in this portion of the BDIA (**Figure F11**). Additionally, YEO23 lies at the boundary of the BDIA (i.e. the Colac Monocline) and the bore is likely to be exhibiting a boundary effect.
YEO44 (109135)	~8.6 km	-0.5 m	
YEO37 (109128)	~5.4 km	-5.1 m	Both bores are screened within the Dilwyn Formation. While the geological logs have not been interpreted it is inferred that the Dilwyn Formation is intersected at different intervals with YEO38 intersecting the Dilwyn Formation at a higher interval than YEO37, resulting in the difference in response at the two bores.
YEO38 (109129)	~5.4 km	-10.7 m	
YYG217 (107716)	~19 km	-0.8 m	All three bores screened in the Dilwyn Formation, with YYG217 located south of the Bambra Fault and the other two bores north of the fault. LTA appears to be connected either side of the Bambra Fault. All three bores are located in LTA outcrop area. YYG217 is screened at a higher interval than the other two bores and this is considered to explain the different response.
YYG218 (107717)	~19.2 km	3.1 m	
YYG221 (107720)	~18 km	-4 m	
YEO19 (109110)	~5.5 km	-15.8 m	YEO19 is screened in the Pebble Point formation while both YEO20 and YEO39 are screened within the Dilwyn Formation.

Bore ID	Distance from Borefield	Water Level Change between 1997 and 2013	Comment
YEO20 (109111)	~5.5 km	-10.7 m	YEO20 is screened approximately 40 m higher than YEO19, which is considered to explain the different response. However, YEO39 has a similar screen to YEO20 but is shallower than both of the other bores, which may explain the difference at this bore.
YEO39 (109130)	~5.9 km	-12.2 m	
YEO41 (109132)	~5.7 km	-22 m	YEO41 is screened within Pebble Point formation, while G22 is in the Dilwyn formation. G22 is marginally closer to the borefield. Both screens overlap however G22 has a screen length of 17 m while YEO41 has a length of 3 m. Both bores are on LTA outcrop area to the west of Boundary Creek. In the absence of definite reasons for the response difference it would appear that YEO41 is screened within a more transmissive zone of the LTA than G22.
G22 (64238)	~5.3 km	-14.3 m	
G13 (64229)	Within borefield	-25.2 m	G13 is screened within Pebble Point formation while G14 is screened within Dilwyn Formation. Screen length details for G14 are not known. The LTA is encountered at a shallower depth in G13 compared to G14 (by approximately 30 m). Bore bores located in borefield. In the absence of definite reasons for the response difference it would appear that G13 is screened within a more transmissive zone of the LTA than G14.
G14 (64230)	Within borefield	-13.8 m	

The potentiometric surface of the LTA in 2010 (further detailed in **Section 4.9.5**, above) (**Figure F17**) shows a largely similar groundwater flow system to that presented in 1983, however, groundwater flow is now flowing radially inwards to the Barwon Downs borefield from the north east and south east. Additionally, the flow to the south west (shown on the 1983 plan), through the Pipeline Restriction area is now reversed and flow is to the north east towards the borefield. This would have had the effect of intersecting the through-flow that would have otherwise entered the Kawarren area via the Pipeline Restriction.

The potentiometric surface of the LTA in 2022 (further detailed in **Section 4.9.5**, above) (**Figure F18**) has largely reverted to the potentiometric surface shown in 1983 with flow from the Yeodene Recharge Avenue wrapping around to the south west from the BDIA into the Kawarren area. A component of groundwater flow from the Yeodene Recharge avenue continues on to the north east.

There has been a reduction in groundwater levels in the LTA in the BDIA of up to 25 m between 1997 and 2013, which corresponds to the peak groundwater pumping/extraction period and the Millennium Drought. While there is a coincidental correlation with long-term rainfall patterns, high level calculations indicate that the long-term rainfall deficit cannot account for all the groundwater level reductions that have occurred and rather the decreases are likely to be predominantly due to the groundwater extraction from the LTA (refer to **Section 5.7**).

5.2 Identification of Susceptible Water Features

Potentially susceptible water features, based on a regional groundwater numerical model, were identified by Jacobs (2018a). These potentially susceptible water features have been refined based on the CSM of the KIA (as presented in **Section 4**).

Jacobs (2018a) identified both the Barwon River east and west branches as being susceptible pumping where they flow over the LTA. However, based on the CSM the connection of the LTA between the Barwon Downs borefield area and south of the Bambra Fault is considered to be minimal and less than that suggested by the numerical groundwater model (Jacobs 2019). As there is some connectivity the Barwon River east and west branches are considered as being susceptible (albeit to a lesser extent than other areas as a result of the minimal connectivity).

The area north of Murroon, along the Bambra Fault, shows a high degree of connection of the LTA between the Barwon Downs borefield area and south of the fault. The water features in this area are considered to be primary susceptible water features where they flow over the LTA, and secondary susceptible water features where they flow over another unit down-stream of LTA outcrop. Further north along the Bambra Fault the connection across the LTA decreases. It is noted that there are some data to suggest the streams in this area are not in connection with the LTA (e.g. gauging stations 233258 and 233240 which report Q90 stream flows of 0 ML/day for the period 2000-2023), there remains uncertainty in this regard. A conservative approach has subsequently been adopted.

The primary susceptible water features are:

- Pennyroyal Creek and Deans Marsh Creek where it flows over the LTA south of the Bambra Fault given the connectivity of the LTA either side of the fault.
- Boundary Creek where if flows over the LTA. Water levels of groundwater have been observed to have dropped by up to 16 m during the Millennium Drought peak pumping period.
- East and West Barwon Rivers (and tributaries) where they flow over LTA, noting there is limited connectivity across the Bambra Fault in this area which reduces their susceptibility. This is considered as part of the risk assessment documented in **Section 5.6**.

Secondary susceptible water features are considered to be:

- Barwon River downstream of the confluence of Boundary Creek to monitoring site 8 (Austral 2022).

It is noted that Pennyroyal, Matthews and Deans Marsh Creeks down-stream of the Bambra Fault are not considered secondary features given there is evidence to suggest that groundwater and surface water are not in connection in this area (e.g. gauging stations 233258 and 233240 which report Q90 stream flows of 0 ML/day for the period 2000-2023). Should the further investigations recommended in this HA suggest otherwise then this would need to be reconsidered. The susceptible water features are shown on **Figure F22**.

A recharge/discharge area plan for the LTA has been prepared based on the 1983 potentiometric surface contours (i.e. unaffected by pumping) and the topographic elevation contours (see **Figure F23**). There is a degree of uncertainty in the expected discharge areas as they are based on comparison of contours with differing intervals, however, it is noted that along Boundary Creek, where it flows over LTA discharge would be expected to occur. In the far north eastern portion of the BDIA there is a low certainty of the extent of discharge, however, based on the potentiometric surface contours and the topographic elevation contours discharge would be expected to occur at least some of the time along either Yan Yan Gurt Creek of Wurdiboluc Inlet Channel. The remainder of the LTA outcrop is expected to be recharge areas with varying degrees of connectivity to the confined portion of the LTA; for example there is inferred to be limited connectivity in the vicinity of the East and West Barwon River, and strong connectivity in the vicinity of Pennyroyal and Deans Marsh Creeks.

5.3 Observed Surface Water Flow Trends

Publicly available stream monitoring records available on WMIS have been evaluated to identify potential surface water flow trends. Available stream flow data from the following surface water bodies has been considered as per **Table 16** (page 55):

- Boundary Creek @ U/S of McDonalds Dam (station 233231);
- Boundary Creek @ D/S of McDonalds Dam (station 233229);
- Boundary Creek @ Yeodene (station 233228);
- Barwon River @ Ricketts Marsh (station 233224); and
- Barwon River @ Kildean Lane (station 233247).

There are more recent gauging data available for a number of locations within the BDIA, as described in **Table 16** (page 55). Given that the records for these do not span the entire time frame that groundwater extraction from the Barwon Downs Borefield occurred, they do not provide a pre-extraction baseline from which to evaluate the potential hydraulic influence due to the groundwater extraction at these gauging stations. Therefore, they have not been considered further to assess potential hydraulic influence of groundwater extraction.

The stream flow records include a data quality code attached to each data point. A high level review of the data quality indicates that there are a number of instances where the data quality has been flagged. For example, at gauging stations 233229 and 233231 between February 1994 and June 2014 no flow data were recorded. These data have been omitted from the data set. Apart from these instances, BlueSphere has interpreted the data as is and has not undertaken any data modification or corrections.

Streamflow analysis has been undertaken through consideration of mean daily flow on a monthly basis. BlueSphere (2023) utilised the lowest mean daily flow in any given month as it provides the closest approximation of inflows other than those associated with surface water runoff from rainfall (e.g. groundwater, bank storage etc). This approach has been adopted to maintain consistency with Jacobs (2019) so that the results are comparable. It is noted that the risk assessment considers risks based on reductions in baseflow proper and reductions in Q90 (10^{th} percentile) flows, therefore, the difference in methodology is not consequential.

Consideration of the lowest mean daily flow in any given month provides an appreciation of the seasonal variability in baseflow, with the absolute lowest mean daily flow in a given year providing information regarding long-term baseflow trends that are most likely associated with groundwater inflows.

Long-term rainfall trends and extraction totals from the Barwon Downs Borefield are also shown on the figures for comparative purposes. Note the y-axis on these graphs has been truncated (i.e., not all data are shown) as the emphasis is on the absolute minimum values. The lowest daily stream flow on a monthly basis (i.e. minimum monthly stream flow) is presented on **Figure 19** to **Figure 23**.

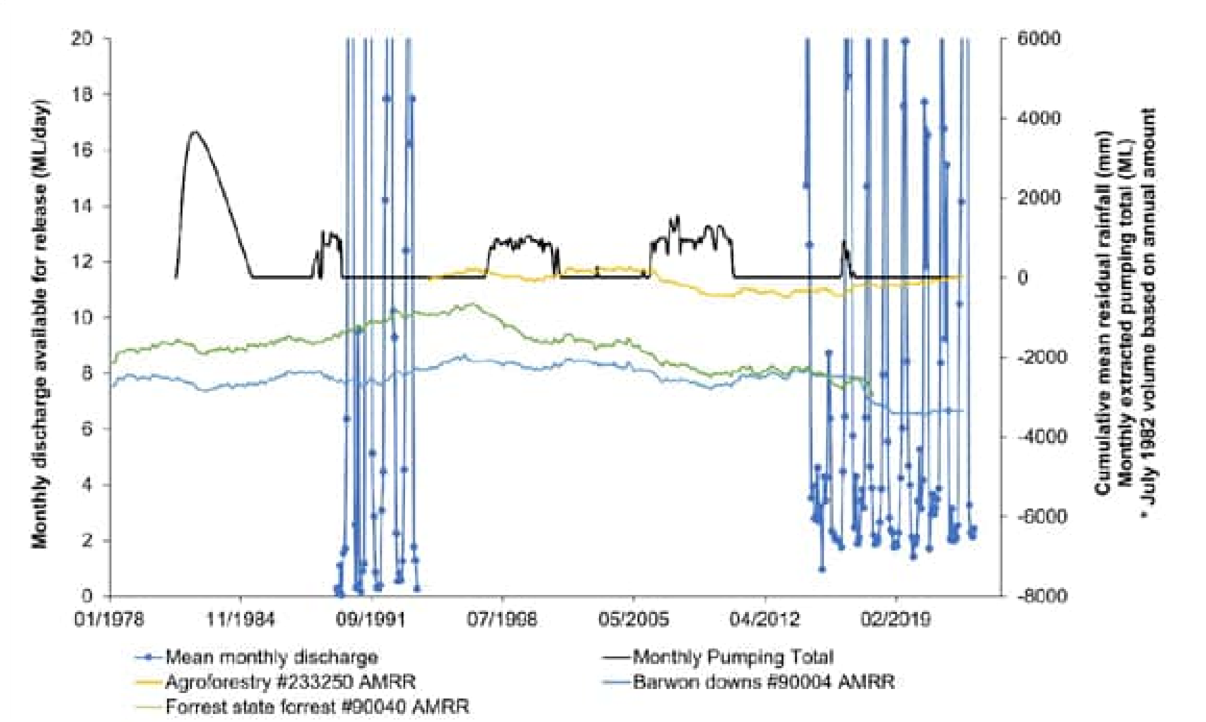

Figure 19 Minimum Monthly Stream Flow – Gauging Station 233231 (Boundary Creek Up-Stream of McDonalds Dam)

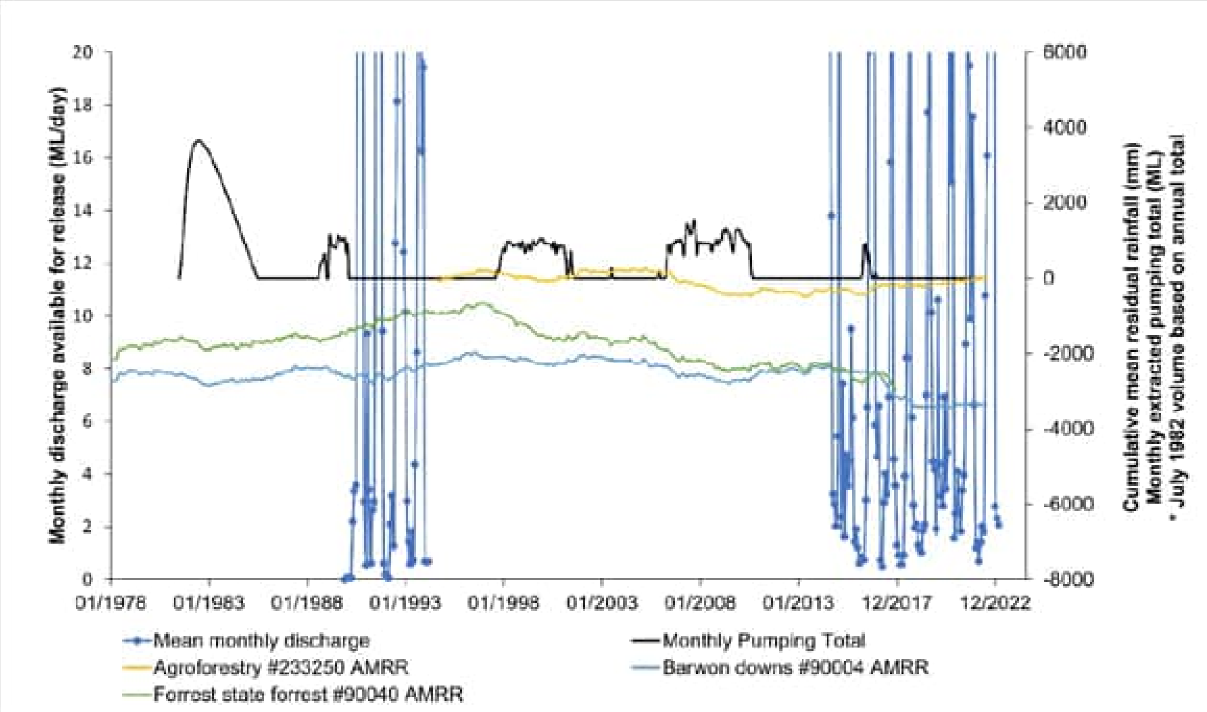

Figure 20 Minimum Monthly Stream Flow – Gauging Station 233229 (Boundary Creek Down-Stream of McDonalds Dam)

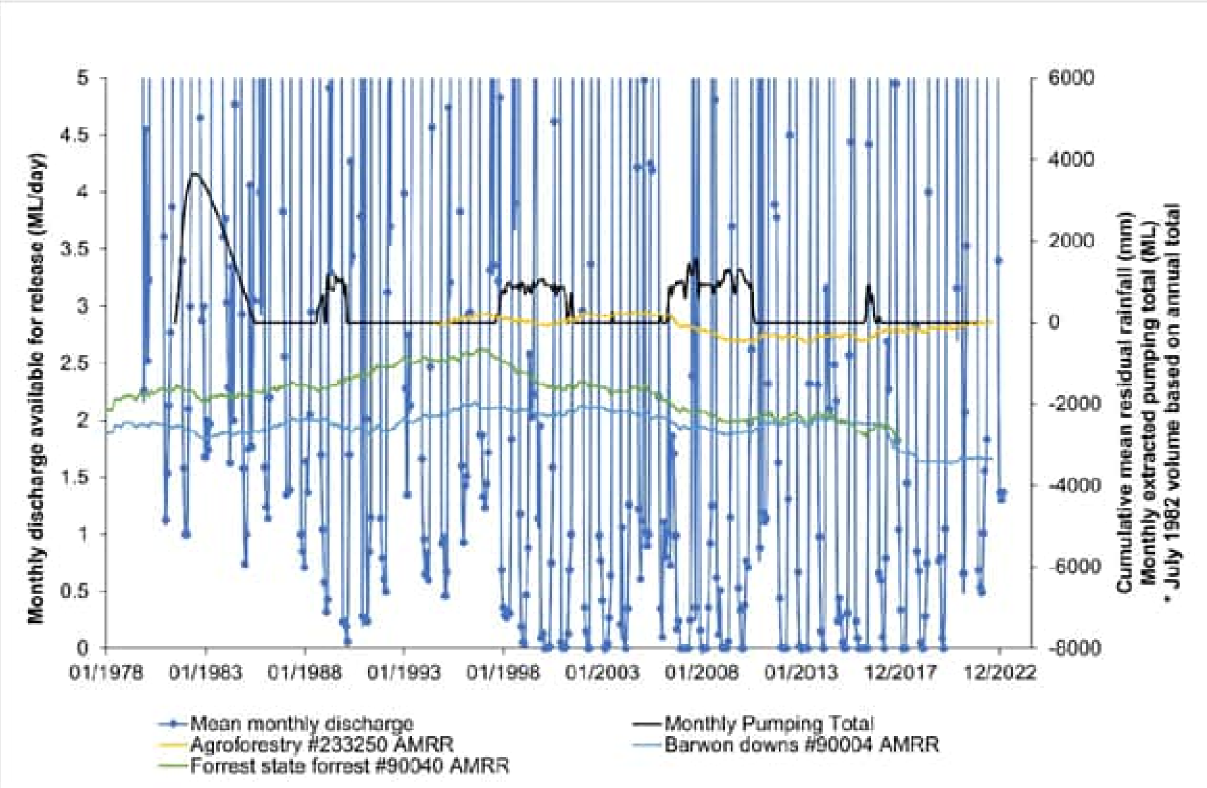

Figure 21 Minimum Monthly Stream Flow – Gauging Station 233228 (Boundary Creek at Yeodene)

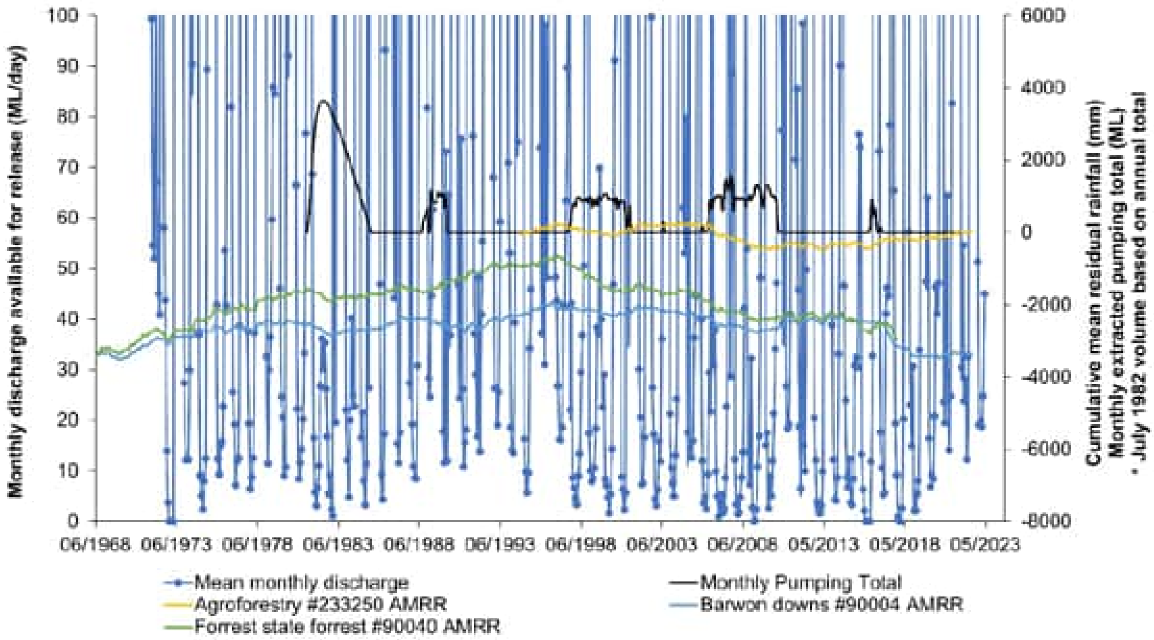

Figure 22 Minimum Monthly Stream Flow – Gauging Station 233224 (Barwon River at Ricketts Marsh)

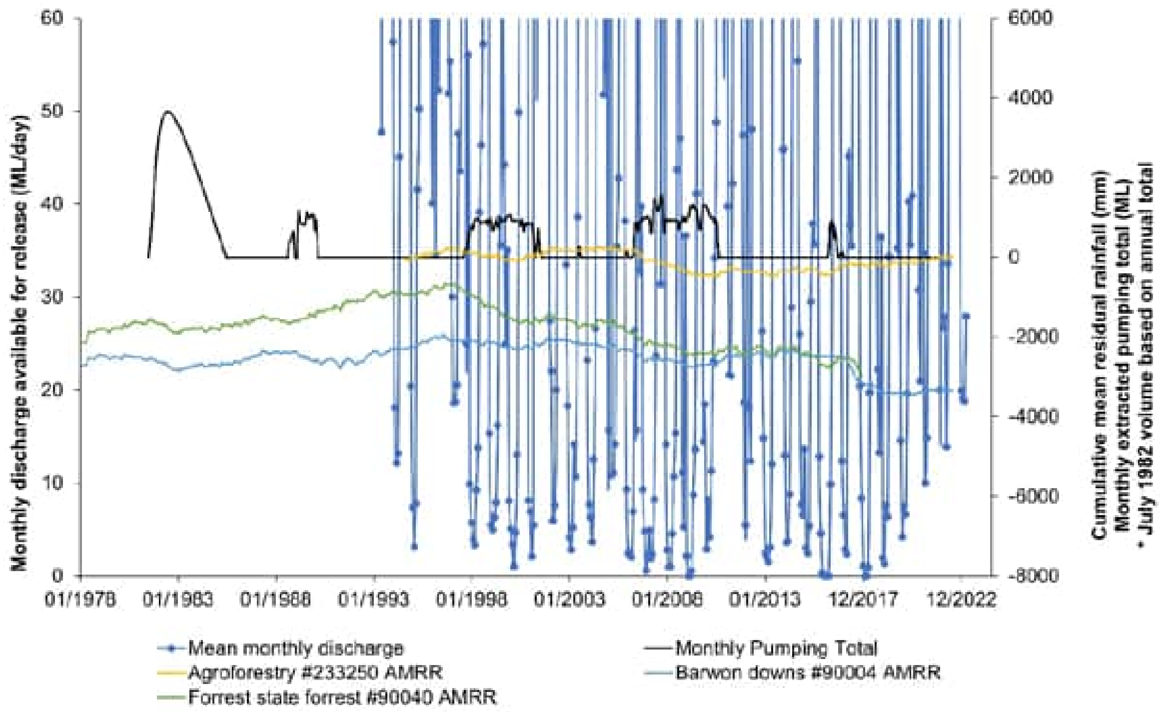

Figure 23 Minimum Monthly Stream Flow – Gauging Station 233247 (Barwon River at Kildean Lane)

The 10th percentile of mean daily flow in any given month (also referred to as the Q90) has been calculated for four distinct time periods to provide a degree of quantification of long-term streamflow trends (where present). The time frames considered are:

- Pre 1997, being all available data from prior to the Millennium Drought;

- Data from 1997 to 2002, being part of the Millennium Drought prior to which environmental flows into Boundary Creek were initiated. During the Millennium Drought ~80% of all extraction from the Barwon Downs borefield occurred.
- Data from 2003 to 2009, representing the period within the Millennium Drought when environmental flows were initiated.
- Data from post 2009 (i.e. 2010 onward), representing the period post groundwater extraction and drought.

A summary of the calculated baseflow within each stream is provided in **Table 22**. This shows that Q90 flows within Boundary Creek at Yeodene reduced by 0.91 ML/day during 1997-2009, which is approximately 99% of Q90 flows. Since 2021 Q90 has been 0.678 ML/day which is ~75% of the pre 1997 Q90 streamflow.

The data also shows that post 2009 the Q90 streamflow at gauges 233231 and 233229 (up-stream and down-stream of McDonalds Dam respectively is higher than prior to 1997, likely due to the influence of supplementary flows to Boundary Creek. The supplementary flows to Boundary Creek were to offset the potential groundwater pumping related impacts to Boundary Creek. However, the influence of supplementary flows is only partly evident in the Q90 data at the bottom end of the Boundary Creek catchment at gauge 233228. The data indicate that since 2009 Q90 has reduced from 1.95 ML/day to 0.97 ML/day, a reduction of ~50%. By comparison, prior to groundwater extraction (and supplementary flows) a 65% reduction in Q90 streamflow was evident downstream of McDonalds Dam; supplementary flows have therefore increased the proportion that is evident downstream of the dam by~15% compared to prior to supplementary flows. This indicates that supplementary flows released up-stream are either captured by McDonalds Dam or presumably are lost to either evaporation or infiltration/recharge. This highlights the complexities associated with the management and regulation of the dam.

In the far eastern portion of the Barwon River surface water catchment within the BDIA at gauges 233224 (Ricketts Marsh) and 233247 (Kildean Lane) Q90 stream flows reduced by between 3.4 ML/day (~35% reduction) and 9.05 ML/day (~64% reduction) between 1997 and 2002 respectively. Slight increases in Q90 stream flow have been observed since 2009 at these gauges. It is noted that the peak Q90 streamflow reduction observed in the Boundary Creek (0.92 ML/day) is ~27% of the reduction observed in the Barwon River at Ricketts Marsh and 10% of the total Q90 reductions observed in at Kildean Lane.

Table 22 River and Creek Q90 (10th percentile) Streamflow Estimates and Streamflow Contribution

Station ID	Location	Q90 Estimate (ML/day)[1]				Observed Reduction in Q90 Streamflow Between <1997 and 2002 (ML/day)	Observed Reduction in Q90 Streamflow Between <1997 and >2009 (ML/day)	Comment
		<1997	>1997-2002	2003-2009	>2009			
233231	Boundary Creek @ U/S of McDonalds Dam	0.29	ID	ID	1.95	ID	-1.66	Increasing trend evident between <1997 and >2009 of 1.66 ML/day, likely due to Barwon Water supplementary flows
233229	Boundary Creek @ D/S of McDonalds Dam	0.1	ID	ID	0.97	ID	-0.87	Increasing trend evident between <1997 and >2009 of 0.87 ML/day likely due to Barwon Water supplementary flows
233228	Boundary Creek @ Yeodene	0.92	0.01	0.00	0.00	0.91	0.92	Decrease of 0.91 ML/day during 1997-2009. Note since 2021 Q90 has been 0.678 ML/day
233224	Barwon River @ Ricketts Marsh	9.8	6.4	2.6	3.7	3.4	6.1	Decrease of 3.4 ML/day during 1997-2002 (~35% reduction).
233247	Barwon River @ Kildean Lane	14.16	5.11	2.19	2.80	9.05	11.36	Decrease of 9.05 ML/day during <1997 and 2002 (~64% reduction).

Notes:

1. 10th percentile of mean annual streamflow. Zero readings associated with equipment malfunction have been removed.

ID – Insufficient data.

5.4 Apportionment of Likely Influences on Observed Flow Trends

Declines in low flows have been observed from streamflow records in Boundary Creek and the Barwon River in the far eastern portion of the Barwon River surface water catchment within the BDIA. There are insufficient streamflow data at the balance of streamflow gauging stations in the BDIA as the data does not cover the period in which extraction occurred from the Barwon Downs Borefield. However, in the absence of streamflow data other factors such as surface geology and expected connection to the LTA have been considered in the apportionment.

The decline in baseflow observed in Boundary Creek as described in **Section 5.3** is potentially due to a number of influences. Apportionment of the likely influences on observed streamflow trends has previously been undertaken (in part) by Jacobs (2019) utilising a numerical groundwater model developed for the Barwon Downs Graben. The numerical model was run under two scenarios: a groundwater extraction scenario and a scenario where no groundwater extraction from the borefield occurred. This was undertaken to allow for differentiation between the influence of pumping itself and the influence of climate related variability that occurred over the same time period.

With regard to the influence of groundwater extraction on surface water, the numerical groundwater only considers climate and extraction from the borefield; it does not consider other potential contributions to streamflow trends. BlueSphere has undertaken high level estimations of the contribution of various sources to the observed streamflow trends (where there are sufficient data) based on the CSM to substantiate the findings of Jacobs (2019) as appropriate and to provide further resolution of the groundwater extraction contribution relative to other factors (where possible). These factors potentially include:

- Long-term decreases in rainfall associated with the Millennium Drought. The effect on recharge to the LTA and subsequent discharge as baseflow has been considered in **Section 5.4.1.**
- Local utilisation of surface water extraction, expected to be heightened during periods of drought. In addition, the establishment of surface water storages, such as McDonalds Dam which was established in 1979 on Boundary Creek. These are considered in **Section 5.4.2**.
- Groundwater extraction from the Barwon Downs borefield between 1982/83 and 2016, and particularly in the period 1997 to 2010 when approximately 77% of total extraction occurred (**Section 4.10.2.2**. This is considered further in **Section 5.4.3**).
- Land use change, such as drainage, forestry etc which can alter recharge and runoff characteristics of the land. This is discussed in **Section 5.4.4**.
- Errors associated with stream gauges, including effects of sedimentation and scouring which can affect the water heights and subsequent calculation of flow rates from stage-flow relationship. For the purpose of this assessment the data are taken at face value.

5.4.1 Long-term Rainfall Deficit on Recharge to LTA

Rainfall deficits were experienced across Victoria during the Millennium Drought, with DELWP estimating that ‘more than half of the Victorian catchments analysed experienced an extra 20–40% decline in their annual streamflow due to the shift in rainfall– runoff relationships (DELWP, 2020). That is, a 20-40% decline in streamflow could be expected due to long-term rainfall deficit in the absence of any other compounding factors such as groundwater extraction.

This decline is understood to be due to the general reduction in moisture within the landscape associated with drought conditions, which influences stream contributions from bank storage, perched water, perched groundwater, local groundwater flow systems, wetland storage etc. Further quantification of these various factors beyond the statewide estimate has not been considered in the following calculations, consistent with the very high level nature of the calculations. Rather, just the potential role of rainfall deficit on groundwater discharges from the LTA has been considered.

In the BDIA, rainfall deficits of between 33 mm/year to 88 mm/year were recorded between 1997 and 2009, including a 61 mm/year deficit at the Barongarook rainfall station (**Section 4.2.3.3**). This correlates to rainfall reduction of between 4% and 9% within the BDIA, with a 7% reduction evident at the Barongarook rainfall station which is most relevant to recharge to the LTA on the Barongarook High.

Based on the rainfall deficit, the amount of recharge that would have otherwise infiltrated to the LTA under average rainfall conditions has been calculated (**Table 23**). This has been calculated for all areas of LTA outcrop within the BDIA.

It is noted that not all LTA outcrop areas are connected to the confined portions of the LTA. For example, only the LTA outcrops on the Barongarook High and in the vicinity of Murroon, and to varying degrees Pennyroyal, Matthews and Deans Marsh Creeks appear to be hydraulically connected to the confined portion of the LTA aquifer from where groundwater extraction has occurred. The other LTA outcrops associated with the West and East Barwon Rivers do not appear to be hydraulically connected, or not appreciably connected. Recharge from those areas is expected to express into local streams as baseflow but not recharge the confined portions of the aquifer to any significant degree.

In relation to the LTA outcrops on the Barongarook High and in the vicinity of Pennyroyal and Deans Marsh Creeks, only a proportion of the recharge potentially expresses into waterways, with the balance infiltrating deeper into the confined portions of the aquifer. This proportion has been estimated in the following calculations.

Table 23 Annual Average Recharge Deficit Estimates to the LTA[1]

	Approx. area of LTA Outcrop (km^2)	Adopted Recharge Rate (%)	Average Annual Rainfall at Nearest Station (mm/year)	Relevant Rainfall Station	Estimated Average Annual Recharge (ML/year)	Average Annual Rainfall Deficit (Millennium Drought) (m/year)	Average Annual Recharge Deficit (Millennium Drought) (ML/year)	Average Annual Recharge Deficit (Millennium Drought) (ML/day)	Comment
Boundary Creek between McDonalds Dam and Big Swamp - North Easterly Component	21	10%	897	Barongarook	1884	0.061	128	0.35	Approx. 20% of recharge is estimated to discharge into Boundary Creek, with the balance migrating deeper into the aquifer
Boundary Creek between McDonalds Dam and Big Swamp - South Westerly Component	18.6	10%	897	Barongarook	1668	0.061	113	0.31	Outcrop hydraulically connected to the confined portion of the LTA
Barwon River (West Branch)	9.9	10%	1009	Forrest	999	0.088	87	0.24	Recharge deficit expected to have minor contribution as there is limited hydraulic connectivity across the Bambra Fault
Barwon River (East branch)	17.53	10%	760	Barwon Downs	1332	0.033	58	0.16	Recharge deficit expected to have minor contribution as there is limited hydraulic connectivity across the Bambra Fault

	Approx. area of LTA Outcrop (km^2)	Adopted Recharge Rate (%)	Average Annual Rainfall at Nearest Station (mm/year)	Relevant Rainfall Station	Estimated Average Annual Recharge (ML/year)	Average Annual Rainfall Deficit (Millennium Drought) (m/year)	Average Annual Recharge Deficit (Millennium Drought) (ML/year)	Average Annual Recharge Deficit (Millennium Drought) (ML/day)	Comment
Barwon River (down-stream of Boundary Creek, West and East Branch Confluence)	0	10%	611	Agroforestry	0	0.046	0	0.00	There is no LTA outcrop in this surrounding investigation area
East Branch of Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks)	12.3	10%	760	Barwon Downs	935	0.033	41	0.11	Outcrop hydraulically connected to the confined portion of the LTA
Barongarook Creek	0	10%	897	Barongarook	0	0.061	0	0.00	There is no LTA outcrop in this surrounding investigation area

Notes: 1. The calculations solely relate to expected annual recharge deficits to the LTA and not other deficits that would be expected due to rainfall-runoff processes.

5.4.1.1 Boundary Creek

BlueSphere has estimated that the recharge rate into the LTA via the north-eastern groundwater flow path (i.e. beneath Boundary Creek) is approximately 1,884 ML/year or 5.16 ML/day. There is no directly comparable stream gauge on Boundary Creek to allow for the proportion of groundwater recharge that becomes baseflow versus that which migrates deeper into the aquifer. However, Witebsky *et al.,* (1995) estimated (as corrected by BlueSphere; refer to **Section 4.9.5.6**) that groundwater discharge into Boundary Creek where it flows over LTA downstream of McDonalds Dam was approximately 383 ML/year or 1 ML/day prior to pumping. Using this value would imply that ~20% of the 5.16 ML/day of recharge expresses as baseflow into Boundary Creek.

It is noted that using its numerical model, Jacobs (2019) predicted the maximum seepage rate to Boundary Creek to be 0.1-0.4 ML/day in the absence of pumping which is less than the Witebsky *et al.,* (1995) estimate. Comparing the recharge rate of 5.16 ML/day to the Jacobs baseflow estimate would suggest that only 2-8% of the total recharge estimate expresses into Boundary Creek under a pre-pumping scenario, which seems unrealistically low based on the CSM. Down-stream gauge 233228 located at Yeodene reports a Q90 stream flow value prior to pumping of ~0.92 ML/day, which accords with the Witesbsky *et al.,* (1995) estimate of 1 ML/day.

Jacobs (2019) previously prepared apportionment estimates relative to stream gauge 233228, which is at the down-stream end of Boundary Creek at Yeodene, beyond Big Swamp. This is considered reasonable on the basis of Witebsky's *et al.,* (1995) baseflow estimate which relates to the portion of Boundary Creek between McDonalds Dam and Big Swamp where the LTA outcrops, and given that the CSM supports the view that the dominant control on baseflow in Boundary Creek is discharge from the LTA up-stream of Big Swamp.

Applying the proportion of recharge that would be expected to become baseflow in Boundary Creek (~20% using the Witebsky *et al.,* 1995 baseflow estimate) to the calculated total recharge deficit of 0.35 ML/day equates to a reduction in Q90 stream flow from the LTA of ~0.07 ML/day. This represents 7% of the baseflow estimate in Boundary Creek where it directly overlies the LTA down-stream of McDonalds Dam (1 ML/day as per Witebsky *et al.,* 1995), and also 7% of the Q90 stream flow at Yeodone prior to extraction (0.92 ML/day). The calculation is summarised in **Table 24**.

Table 24 Calculation of Proportion of Q90 Stream Flow Attributed to Long Term Rainfall Decline

Recharge Estimate (ML/day)	Pre-Pumping Baseflow Estimate (ML/day)	Recharge Deficit (ML/day)	Proportion of Recharge that Becomes Baseflow	Proportion of Total Baseflow
5.16	1.0	0.35	~20%	~7%

For the same segment of creek, Jacob's numerical groundwater model predicted that baseflow levels would reduce due to long-term rainfall decline by between 0.1 ML/day and 0.4 ML/day (Jacobs 2019). The upper end of this range is slightly higher than the estimate above of 0.07 ML/day, but given the high level nature of the calculations, these are considered in broad agreement.

5.4.1.2 Deans Marsh, Matthews and Pennyroyal Creeks

There are limited stream flow records available from which to estimate potential groundwater baseflow contributions to these streams relative to that which infiltrates deeper into the aquifer. At Pennyroyal Creek (gauging station 233258) the Q90 stream flow for the period 2000-2023 is estimated at 0 ML/day, which suggests there is no baseflow component into this stream. It is noted that this is less than the recommended low flow of 0.8 ML/day as derived from hydrological modelling (Alluvium, 2019). Therefore, any recharge in this area would infiltrate into the deeper, confined portion of the aquifer. Therefore, long-term rainfall deficits are unlikely to have affected baseflow levels in Pennyroyal Creek, noting the stream flow record commences in August 2000 and therefore the pre-pumping regime is not known.

There is a gauge along Matthews Creek (gauging station 233240) which has a similar data set as Pennyroyal Creek and indicates that cease to flow is common. Matthews Creek does not flow over LTA outcrops and is unlikely to receive discharge from the LTA.

There are no data for Deans Marsh Creek.

Jacobs (2019) did not estimate the potential contribution of long-term rainfall deficits on Deans Marsh, Matthews and Pennyroyal Creeks.

5.4.1.3 West and East Barwon Rivers

The LTA outcrops associated with the West and East Barwon Rivers appear to have limited hydraulic connection to the confined portion of the LTA within the BDIA from which groundwater extraction occurred. Consequently, the effect of groundwater extraction as predicted by Jacobs (2019) is likely to have been overestimated. It is not possible with the available data to differentiate the extent to which climate affected Q90 stream flow compared to groundwater as there are no stream flow data.

However, the calculations outlined in **Table 23** indicate that streamflow reductions of 0.24 ML/day and 0.16 ML/day could have been experienced in the West and East Barwon Rivers respectively due to long-term climate influences on LTA outcrop. These reductions represent ~8% and ~5% of the reductions observed in the Barwon River at Ricketts Marsh respectively.

5.4.2 Surface Water Extraction

The Q90 streamflow data in **Table 22** showed that, prior to 1997, McDonald's Dam reduced the Q90 streamflow in Boundary Creek from 0.29 ML/day to 0.1 ML/day. That is, the Q90 streamflow at this location is indicated to have been ~65% lower than the pre-dam condition. It is expected that this reduction would have occurred since 1979 when the dam was constructed. Therefore the hydraulic influence of other factors during the Millennium Drought would have therefore been superimposed on this influence.

As outlined in **Section 4.13.5** there are a number of surface water licences within the BDIA. These are differentiated into licences which relate to direct extraction from the creek which are tradable, and licenced dams which are not tradable. For the purpose of this evaluation, consideration has been given to tradable licences. This approach excludes any new licenced on stream dams or unlicenced on-stream dams due to the complexity in assessing the timing and influence of these dams; this is considered reasonable given the very high nature of the calculations. Apart from McDonalds Dam, the location of these extractions relative to the monitoring gauges has not been evaluated.

Estimations of potential contribution to Q90 stream flow has been made under two theoretical scenarios to provide a sense of scale:

- All direct extraction users extract concurrently and utilise their full entitlement within the summer months only (90 days); and
- All direct extraction users spread their extraction evenly across the year.

Table 25 Tradable Surface Water Allocations and Potential Use Scenarios

	Barwon River (Middle)	Yan Yan Gurt Creek	Matthews Creek	Pennyroyal Creek	Deans Marsh Creek	Boundary Creek
Total (ML/year)	871.3	17.5	13.4	133.7	0	27.5*
Scenario 1 (ML/day over 90 days use)	9.7	0.2	0.1	1.5	0.0	0.3
Scenario 2 (ML/day over 365 days use)	2.4	0.0	0.0	0.4	0.0	0.1
Observed Streamflow Reduction (ML/day)	3.4 (station 233224, Ricketts Marsh)	NA	NA	NA	NA	0.92 (Station 223228, Yeodene)

Notes: * Excludes McDonalds Dam, which is an on-stream dam up-stream of Big Swamp with a licence to extract 115 ML/year.

In each scenario, for there to be a demonstrable influence on stream flow during a drought relative to 'normal' conditions, extraction would need to be comparatively higher. It is reasonable to expect that extraction could be at least 10% higher in a drought scenario compared to 'normal' conditions to offset the effects of prolonged rainfall declines. If it is assumed that there is a 10% increase in usage during drought periods (and that there is unallocated volume available in the licence), using the values calculated in **Table 25**:

- Potentially an additional 0.03 ML/day of surface usage could conceivably have been experienced in Boundary Creek (assuming Scenario 1), amounting to ~ 3% in Boundary Creek at Yeodene; and
- Potentially an additional 0.97 ML/day of surface usage could conceivably have been experienced in the Middle Barwon River (assuming Scenario 1), which would equate to ~30% of the Q90 stream flow reduction in the Barwon River observed at Ricketts Marsh.

That is not to say that licenced extraction caused the observed declines, but merely that surface water extraction has the potential to meaningfully contribute to the observed trends. This is consistent with the reasonable expectation that users will more heavily utilise surface water resources when rainfall is lower than normal, such as was experienced in the Millennium Drought.

5.4.3 Groundwater Extraction from the LTA

Jacobs (2019) used its numerical groundwater model to predict streamflow reductions associated with groundwater extraction from the Barwon Downs borefield. A summary of the predicted baseflow reductions attributed to groundwater pumping are summarised in **Table 26** together with BlueSphere's comments in relation to the reliability of the estimates previously made by Jacobs within the context of the updated CSM presented in this report.

Table 26 Summary of Predicted Groundwater Level Changes (after Jacobs 2019)

River Reach	Likelihood of connection to regional groundwater	Max impact historic			BlueSphere Comment
		ML/day	% low flow	Consequence	
Barwon River					
West Branch aquifer	High	<0.01	<1%	Low	Estimate considered reasonable and consistent with updated CSM
West Branch aquitard	Med	0.1	2%	Med	Estimate considered reasonable and consistent with updated CSM
Downstream confluence	Med	0.7	14%	High	Estimate potentially inflated as understood to include a combination of influence from East Branch which is not representative of current CSM.
East Branch aquifer	High	1.6	33%	High	Predicted baseflow reduction is overestimated as the model assumes more connectivity across Bambra Fault than the current CSM has identified.
East Branch aquitard	Med	1.7	35%	High	Predicted baseflow reduction is overestimated as the model assumes more connectivity across Bambra Fault than the current CSM has identified

River Reach	Likelihood of connection to regional groundwater	Max impact historic			BlueSphere Comment
		ML/day	% low flow	Consequence	
Boundary Creek					
Reach 1	Med	<0.01	<1%	Low	Estimate considered reasonable and consistent with updated CSM
Reach 2	High	2.9	>100%	High	Estimate considered reasonable and consistent with updated CSM
Reach 3	Med	0.3	30%	High	Estimate considered reasonable and consistent with updated CSM

With regard to Boundary Creek, the numerical groundwater model predicts a reduction in Q90 stream flow of 2.9 ML/day solely due to pumping (assuming there is sufficient water available in the stream), which based on a Q90 stream flow of 1 ML/day, would result in loss of baseflow entirely due to pumping. Further downstream in Boundary Creek Jacobs predicted a 30% reduction in in low flow. That is, of the 0.92 ML/day decline in Q90 stream flow in Boundary Creek in Yeodene, 0.3 ML/day was attributed to groundwater pumping. These volumes are additional to other demands during the Millennium Drought including climate related effects (recharge deficit to the LTA and rainfall-runoff relationships changes) and surface water extraction.

It is not possible to validate the predictions of Jacobs (2019) numerical groundwater model in relation to the expected influence of groundwater extraction on stream flow using rudimentary 'back of the envelope' calculations due to the complexity of groundwater discharge mechanisms and the available data. BlueSphere is of the view the numerical model is considered to provide a reasonable approximation in Boundary Creek that is consistent with the updated CSM as presented in this report.

By comparison, it is noted that the numerical groundwater model developed by Jacobs (2019) included a degree of connectivity across the Bambra Fault, including in the vicinity of the West and East Barwon Rivers. Consequently the model predicted that groundwater extraction from the Barwon Downs Borefield had the potential to reduce baseflow in the East Barwon River in particular by 1.6 ML/day. Based on the updated CSM developed here, it would appear that the degree of connectivity is lower than the model assumes in this area, with the implication that the predicted baseflow reduction in the East Barwon is likely to be lower than the model predicted. Review of the numerical model calibration documentation further supports this, with numerical modelling showing a marked response to pumping within bores in this area. For example bore 48249 is predicted to have drawdown of in the order of ~15 m, however this is not replicated in the observed data with only a subtle response evident of 5.5m reported (**Figure 24**).

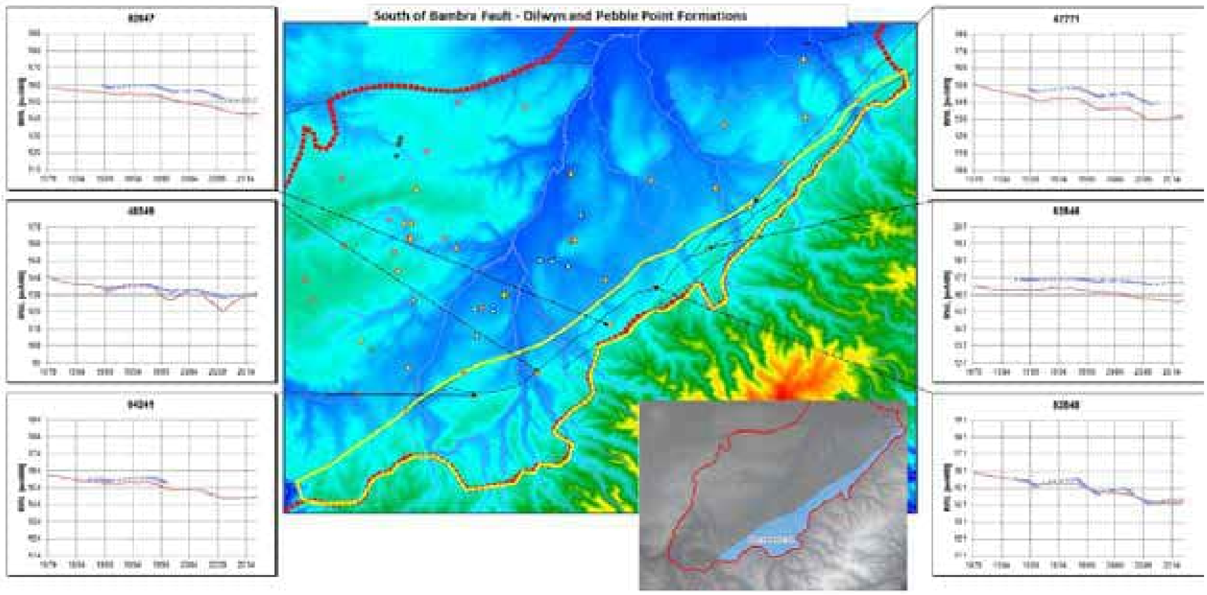

Figure 24 Comparison of Modelled Levels Versus Observed Data (after Jacobs, 2018)
(Blue lines on graph represent observed data and red lines represent modelled data)

5.4.4 Land Use Change

There has been a number of land use changes that are relevant to the BDIA. These include:

- Boundary Creek and Big Swamp were partially drained in ~1946 for agricultural purposes. This would be expected to have influenced the hydrology of these water bodies.
- In 1979 a dam was constructed along Boundary Creek, up-stream of Big Swamp. Again this would be expected to have influenced the hydrology of Boundary Creek and Big Swamp. Comparison of stream flow records indicates that the Q90 stream flow has reduced between upstream and downstream of the dam by ~65% (refer to **Section 5.4.2**).
- Between 1998 and 2010, a sub-surface fire smouldered in the swamp while the swamp was dry. A fire trench was dug in March/April 2010 along the southern and eastern sides of the swamp to contain the smouldering. The trench appears to be above the groundwater level and the fire appears to be a consequence of the swamp drying by other factors rather than causational.

There are also forestry coupes in the down-stream portion of Boundary Creek near the confluence with the Barwon River. As outlined in Section 4.5, Google Earth imagery indicates that in 2002 plantations (pine) to the south west of Barwon Downs township were partially cleared, and by 2003 had been completely cleared. During 2011 the large plantation at the Barwon River confluence had been cleared, and by 2013 it had all been removed. These plantations are located down-stream of Big Swamp. Therefore, they are unlikely to have had any relationship to upstream.

In Boundary Creek at Yeodene Q90 stream flow reductions become evident particularly from 1998 and persisted until 2020. It is noted that in 2011 there was a marked increase in Q90 stream flow, also correlated with an increase in rainfall. It is possible that there was increased runoff to the gauge at that time due to clearing of the plantation. Apart from this, there does not appear to be any correlation with regard to the timing of clearing/establishment of the plantations and decreasing Q90 stream flow trends that is obvious.

5.4.5 Summary

The evaluation of likely influences on the observed Q90 stream flow declines observed during the Millennium Drought indicates that there are a number of factors that have varying levels of contribution, compounding the effects of groundwater extraction. Prior to groundwater extraction from the Barwon Downs Borefield it is apparent that drainage enhancements had likely altered the hydrological characteristics of the BDIA, including Boundary Creek and Big Swamp.

Stream flow monitoring records show that the Q90 stream flow had been reduced by ~65% between up-stream and down-stream of McDonalds Dam since 1979. This influence on low flow conditions in Boundary Creek is likely to have increased its susceptibility to compounding effects such as concurrent drought and groundwater extraction.

From the onset of the Millennium Drought there is expected to have been a progressive loss of moisture from the environment; this effect would have occurred regardless of groundwater extraction. Rainfall deficits were experienced across Victoria during the Millennium Drought, with DELWP estimating that ‘more than half of the Victorian catchments analysed experienced an extra 20–40% decline in their annual streamflow due to the shift in rainfall– runoff relationships (DELWP, 2020). That is, a 20-40% decline in streamflow could be expected due to long-term rainfall deficit in the absence of any other compounding factors such as groundwater extraction.

In Boundary Creek, where if flows over LTA between McDonalds Dam and Big Swamp, contributions to the observed decline are evident from long-term rainfall decline associated with the Millennium Drought (~7%) and to a lesser degree surface water extraction via licenced extraction (theoretically could be in the order of ~3% depending on usage patterns, extraction location and availability of water). Due to the confounding nature of these factors, these estimates should be approached with a degree of caution. Rather, they demonstrate the combined effects of various influences on available water.

The CSM indicates that groundwater extraction is likely to be the predominant contributor to the observed Q90 stream flow decline observed in Boundary Creek during the Millenium Drought; this would have compounded pre-existing water demands such as the upstream dam, surface water extraction and climate related influences that would have occurred irrespective of groundwater extraction. This conclusion is consistent with the numerical groundwater model previously developed by Jacobs (2019). Consequently BlueSphere is of the view the numerical model is considered to provide a reasonable approximation of relative contribution of groundwater induced stream flow decline in Boundary Creek and is fit for purpose in terms of making management decisions to address the requirements of the Section 178 and REPP.

The Q90 stream flow decline observed in Boundary Creek at Yeodene that is attributed to groundwater extraction (~0.3 ML/day) would represent ~9% of the observed decline in baseflow observed down-stream in the Barwon River at Ricketts Marsh (3.4 ML/day).

The influence of groundwater extraction relative to other factors such as surface water extraction and land use change etc within the other surrounding areas identified for further investigation are difficult to quantify based on the available information. Rather, a conceptual assessment has been undertaken.

The CSM indicates that the influence of groundwater extraction on the East Barwon River in particular is likely to have been overestimated in the existing numerical groundwater model (Jacobs 2019) as the model assumes a greater degree of connectivity across the Bambra Fault than observed. The influence in relation to the West Barwon River is also low due to the limited hydraulic connectivity in this area.

In contrast the CSM indicates that there is hydraulic connection between the confined portion of the LTA and the LTA outcrops associated with Pennyroyal, Matthews and Deans Marsh Creeks. However, there is a paucity of suitable historic surface water data that spans both the pre-and post-groundwater extraction phases to appraise the degree of potential hydraulic influence in these areas. The identified data gaps are discussed further in **Section 6**.

5.5 Significance of Observed Hydraulic Influence

As outlined in **Section 5.4**, the impact assessment has identified that the historical groundwater pumping activities have had or have the potential to have had varying degrees of inferred influence on stream flow within the BDIA. The influence of factors such as climatic variability and licenced surface water usage, compounded during periods of drought, are also evident. The impact of baseflow reduction is most profound during periods of low rainfall (i.e. summer) when the waterways are typically sustained principally by groundwater inflows.

The significance of the observed hydraulic influences with regard to each surrounding investigation areas within the BDIA is provided in **Table 27**. This indicates that there is demonstrable evidence of environmentally significant impacts within Boundary Creek, including oxidation of acid sulfate soil, vegetation and macroinvertebrate community decline, and water quality impact. There is also evidence of minor water quality and macroinvertebrate community decline within the Barwon River directly downstream of the confluence with Boundary Creek relative to up-stream locations; Austral (2022) report that the down-stream effect in the Barwon River is very limited, with overall stream health regarded as good down-stream of the Boundary Creek confluence. These impacts are well known and the REPP addresses the remediation of Boundary Creek and Big Swamp to alleviate these impacts.

There is no evidence of environmentally significant impacts in the Barwon River (East and West branches) despite the presence of acid sulfate soils. This finding is consistent with the updated CSM which indicates that the risks of environmentally significant environmental impacts occurring is likely to be overestimated based on the results of the numerical groundwater model.

By contrast there is indicated to be hydraulic connectivity across the Bambra Fault in the vicinity of Pennyroyal and Deans Marsh Creeks. However, there is a general paucity of data that spans both the pre-and post-groundwater extraction phases from which conclusions can be drawn regarding resultant environmentally significant impacts that can be associated with extraction from the Barwon Downs Borefield at this location. Whilst there are some data to suggest the streams in this area are not in connection with the LTA (e.g. gauging stations 233258 and 233240 which report Q90 stream flows of 0 ML/day for the period 2000-2023) there is an absence of suitable groundwater wells in the LTA to corroborate the nature of groundwater surface water interaction and therefore there remains uncertainty in this regard.

In Barongarook Creek (west of Barwon River as defined by Jacobs, 2019) the CSM update, which includes the findings of recent drilling by Jacobs, indicates that there is limited LTA outcrop in this area and elsewhere the LTA is confined with limited surface connectivity expected. Therefore, environmentally significant impacts at the surface in this area are not expected. In addition, the potential for environmentally significant impacts to GDEs west of Barwon River (Barongarook Creek) is considered to be low. However, there remains an element of uncertainty regarding the hydraulic connection across the Colac Monocline and resultant hydraulic influence further to the north as there are few bores to the north of the monocline to confirm.

Table 27 Significance of Observed Hydraulic Influence

Surface Water Body	Initial Rationale for Identification as 'High Risk Area'[1]	Relationship with the LTA	Maximum Reduction in Q90 Stream Flow	Vegetation	Acid Sulfate Soils[2]	Water Quality, Macroinvetebrates and Fish	Comment
Boundary Creek between McDonalds Dam and Big Swamp	Area of known impact	Receives groundwater discharge from LTA in or adjacent to LTA outcrops	0.92 ML/day	Vegetation impact has been observed in Boundary Creek and Big Swamp (monitoring locations TB1 and TB2)	Actual and potential AAS identified. Oxidisation of acid sulfate soil has been identified in Big Swamp, with acidification events increasing in intensity occurring during the 2000s	The creek up-stream of Big Swamp is in very good condition. The macroinvertebrate community down-stream of Big Swamp has been rated as poor but had been improving over the past 3 years (Austral 2022)	The presence of AAS generating acid and vegetation impacts is consistent with the various hydrological and hydrogeological influences in the catchment including groundwater pumping. These impacts are well known and the REPP addresses the remediation of Boundary Creek and Big Swamp to alleviate these impacts.
Barwon River (West Branch)	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction.	LTA outcrop has limited hydraulic connection across the Bambra Fault. Therefore, influence of pumping subdued.	NA	No monitoring conducted	Sampling at one location identified the presence of potential acid sulfate soil (location WBBH01/WBBH02)	No evidence of water quality impacts, however, the upper reaches do not meet environmental quality objectives due to other factors (Austral 2022)	The presence of potential acid sulfate soil only (i.e. unoxidized) indicates that impacts are unlikely to have occurred at this location. This is consistent with the limited hydraulic connection across the Bambra Fault identified by the updated CSM which includes the findings of recent drilling by Jacobs.

Surface Water Body	Initial Rationale for Identification as 'High Risk Area'[1]	Relationship with the LTA	Maximum Reduction in Q90 Stream Flow	Vegetation	Acid Sulfate Soils[2]	Water Quality, Macroinvetebrates and Fish	Comment
Barwon River (East branch)	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction.	LTA outcrop has limited hydraulic connection across the Bambra Fault. Therefore, influence of pumping subdued.	NA	No monitoring conducted	Monitoring conducted at two locations in East branch (PASS2 and BD3) and one on Dewing Creek (site 2) confirmed presence of potential and actual AAS.	No evidence of water quality impacts. The upper reaches do not meet environmental quality objectives but progressively improve downstream (Austral 2022)	The updated CSM which includes the findings of recent drilling by Jacobs indicates that the LTA outcrop in this area has limited hydraulic connection across the Bambra Fault. Therefore, influence of pumping subdued.
Barwon River Confluence	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction.	Does not receive groundwater discharge from the LTA, but is fed from areas that receive discharge from the LTA (e.g. Boundary Creek)	NA	No monitoring conducted	No ASS sampling undertaken.	It is understood that fish kill events have been realised in this area due to the release of acidity from the oxidisation of ASS in Boundary Creek/Big Swamp. There is also evidence of limited impact on macroinvertebrate communities immediately downstream of the confluence with Boundary Creek, albeit much lower than Boundary Creek with the stream condition still	The updated CSM which includes the findings of recent drilling by Jacobs does not indicate that there is a direct hydraulic connection between the LTA and surface at this location. However, this area could potentially be impacted due to up-stream influences in Boundary Creek which enter the Barwon River in this area.

Surface Water Body	Initial Rationale for Identification as 'High Risk Area'[1]	Relationship with the LTA	Maximum Reduction in Q90 Stream Flow	Vegetation	Acid Sulfate Soils[2]	Water Quality, Macroinvetebrates and Fish	Comment
						rated as good (Austral 2022).	
Potential GDEs east Branch of Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks)	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS.	Outcrop associated with Pennyroyal Creek hydraulically connected to the confined portion of the LTA	NA	No monitoring conducted	No data available (Analysis has been conducted from one location installed on the Narrawaturk Marl, not LTA).	No data available	The CSM update affirms the findings from Jacobs (2019) numerical groundwater model that there is a high likelihood of connection to the confined regional groundwater system in this area. However, there is a general paucity of data from which conclusions can be drawn regarding resultant environmentally significant impacts that can be associated with extraction from the Barwon Downs Borefield at this location.
Potential GDEs west of Barwon River (Barongarook Creek)	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable	There is no LTA outcrop in this surrounding investigation area	NA	No monitoring conducted	Monitoring conducted at two locations (BCBH01/BCBH02 and NYBH01/NYBH02). Marginal PASS was identified at one location only.	No data available	The CSM update which includes the findings of recent drilling by Jacobs indicates that there is limited LTA outcrop in this area and elsewhere the LTA is confined with limited surface connectivity expected. Analysis of hydrographs and the numerical

Surface Water Body	Initial Rationale for Identification as 'High Risk Area'[1]	Relationship with the LTA	Maximum Reduction in Q90 Stream Flow	Vegetation	Acid Sulfate Soils[2]	Water Quality, Macroinvetebrates and Fish	Comment
	as a result of historic groundwater pumping adversely impacting GDEs & PASS.						groundwater modelling suggest there is limited transmissivity across the Colac Monocline and therefore impact beyond the BDIA are not expected. However, there remains an element of uncertainty regarding the hydraulic connection across the Colac Monocline as there are few bores to the north of the monocline to confirm.

Notes: NA = Not available

1 As per Barwon Water (2019)

2 As per Section **4.15** and **Figure F21**

5.6 Risk Assessment

Jacobs (2019) conducted a risk assessment in relation to historical pumping from the Barwon Downs Borefield utilising a numerical groundwater model developed for the Barwon Downs Graben. The numerical groundwater model was used to evaluate risks to surface water, vegetation and ASS/PASS within the BDIA and KIA.

The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (Department of Environment, Land, Water and Planning (DELWP), 2015) provide a framework for the classification of potential impacts of groundwater extraction on GDEs. This process is applied during the application stage for a new groundwater extraction. In this case the framework has been applied retrospectively here to provide a point of comparison to aid in future management and to categorise the susceptibility of GDEs in a consistent and transparent manner.

Importantly, the purpose of the risk assessment process is to in essence identify the susceptibility of the environment to an extraction proposal. The risk assessment does not provide that environmentally significant impacts have or will occur. Discussion regarding the significance of observed hydraulic influence in this particular case is provided in **Section 5.5**.

The risk assessment process includes the following key elements that are of relevance here:

- Evaluate if the aquifer is confined or unconfined, and therefore if it has the potential to interaction with high value ecosystems. In this case the CSM has established that the LTA has the potential to interact with high value ecosystems associated with Boundary Creek, West and East Barwon River (albeit in a limited manner), and Pennyroyal, Deans Marsh and Matthews Creeks. Barwon River down-stream of the confluence with Boundary Creek is also susceptible as it receives inflows from Boundary Creek. It has been assumed that each waterway is a high value ecosystem as defined in the Ministerial Guidelines.
- Determine the likelihood that the proposed groundwater extraction will interact with a high value ecosystem.
- Determine the consequence of the proposed groundwater extraction on a high value ecosystem.
- Determine the risk to the high value ecosystems dependent on groundwater.

The risk assessment outcome is summarised in **Table 28**. In summary, the risks to Boundary Creek, Barwon River at its confluence with Boundary Creek by virtue of receiving inflows from Boundary Creek. The risks to Pennyroyal, Deans Marsh and Matthews Creeks are classified as ‘high’ under the framework, which is likely to be very conservative. Whilst there are some data to suggest the streams in this area are not in connection with the LTA (e.g. gauging stations 233258 and 233240 which report Q90 stream flows of 0 ML/day for the period 2000-2023) there is an absence of suitable groundwater wells in the LTA to corroborate the nature of groundwater surface water interaction and therefore there remains uncertainty in this regard. A conservative approach has therefore been adopted in the risk assessment, highlighting the need for additional information rather than indicating risks are truly high.

The risks to the East Barwon River is lower than that ascribed by Jacobs (2019) as this area is indicated to have a lower degree of hydraulic connection than the numerical groundwater model predicted. For the West Barwon River the risks are the same as that previously ascribed by Jacobs (2019). A low risk has also been ascribed to potential GDEs west of Barwon River (Barongarook Creek).

Table 28 Risk Assessment for Protection of GDEs

Waterway	Likelihood that groundwater will interact with waterway		Consequence – Depth to Water Table		Consequence – Surface Flow		Risk
	Rating[1]	Comment	Rating[1]	Comment	Rating[1]	Comment	
Boundary Creek between McDonalds Dam and Big Swamp	Certain	Groundwater extraction has been shown influence groundwater levels significantly	Significant	The potentiometric surface in the LTA has been measured to have reduced up to 15.8 m. This would correspond to a 'significant' consequence	Significant	Q90 stream flow has been observed to have reduced from ~1 ML/day to 0 ML/day. Whilst there is evidence of contribution from climate, direct extraction and stream flow reduction due to an up-stream dam, groundwater extraction is the predominant influence.	High
Barwon River (West Branch)	Unlikely	The areas of LTA outcrop are shown to have limited hydraulic connection across the Bambra Fault based on geological interpretation and drawdown response.	Moderate	The potentiometric surface in the LTA has been measured to have reduced up to 0.8 m on the southern side of the Bambra Fault. This would correspond to a 'moderate' consequence.	Moderate	There are no stream flow data by which to verify surface water influence. Based on the CSM including no or limited hydraulic connection across the Bambra Fault, a 'moderate' rating is considered to be sufficient conservative.	Low
Barwon River (East branch)	Unlikely	The areas of LTA outcrop are shown to have limited hydraulic connection across the Bambra Fault based on geological interpretation and drawdown response.	Moderate	The potentiometric surface in the LTA has been measured to have reduced up to 5.5 m approximately 1 km from the river. However, given the limited connectivity in this area, the drop attributed to pumping is expected to be much less. A consequence of 'moderate' is considered more appropriate.	Moderate	There are no stream flow data by which to verify surface water influence. Based on the CSM including limited hydraulic connectivity, relatively minor amount of drawdown reported and absence of environmentally significant impacts, a 'moderate' rating is considered to be sufficiently conservative.	Low

Waterway	Likelihood that groundwater will interact with waterway		Consequence – Depth to Water Table		Consequence – Surface Flow		Risk
	Rating[1]	Comment	Rating[1]	Comment	Rating[1]	Comment	
Barwon River (down-stream of Boundary Creek, West and East Branch Confluence)	Possible	This location is not hydraulically connected to the LTA but receives influence from Boundary Creek which is strongly connected.	Significant	The potentiometric surface in the LTA in the vicinity of Boundary Creek up-stream of this area has been measured to have reduced up to 15.8 m. This would correspond to a 'significant' consequence	Significant	Q90 stream flow has been observed to have reduced due to groundwater extraction by ~30% in Boundary creek at Yeodene, up-stream of this area. This would correspond to a rating of 'significant'.	High
Potential GDEs east Branch of Barwon River (Matthews, Deans Marsh and Pennyroyal Creeks)	Possible	The confined portion of the LTA is indicated to be hydraulically connected to the LTA outcrop in this area.	Significant	The potentiometric surface in the LTA in the vicinity of this area has been measured to have reduced up to 12.2 m. This would correspond to a 'significant' consequence	Significant	There are no stream flow data relating to pre-and post-extraction period by which to verify surface water influence. Based on the CSM including the identified hydraulic connectivity and paucity of data in relation to environmentally significant impacts, a 'significant' rating is considered to be appropriate (albeit conservative).	High
Potential GDEs west of Barwon River (Barongarook Creek)	Unlikely	The CSM update which includes the findings of recent drilling by Jacobs indicates that there is limited LTA outcrop in this area and elsewhere the LTA is confined with limited surface connectivity expected.	Moderate	The potentiometric surface in the LTA in this area has been measured to have reduced up to 13.1 m, however, this is not proximal to any surface waterways given the LTA is confined at this location. A consequence of 'moderate' is considered appropriate.	Moderate	There are no stream flow data relating to pre-and post-extraction period by which to verify surface water influence. Given there is limited LTA outcrop in this area and elsewhere the LTA is confined with limited surface connectivity, a 'moderate' rating is considered sufficiently conservative.	Low

Notes: 1. Likelihood and consequence definitions adopted in accordance with Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).

5.7 Overview of Changes Since Extraction Cessation

Groundwater levels within the LTA in the BDIA have shown recoveries of up to 80% in the central confined portion of the BDIA, while in the unconfined portions of the BDIA recoveries have been on average ~40% (Barwon Water, 2022).

The majority of bores that showed a substantial response to pumping (as discussed in Section **5.1**, above and shown on hydrographs presented in **Appendix C**) show a continued upwards recovery to date. However, those bores which showed a subdued response have largely stabilised and show minimal upwards recovery. Further, the groundwater flow direction has largely returned to pre-pumping system (i.e., 1983) conditions with the groundwater flow path through the Pipeline Restriction having returned since 2010 worst case conditions (see **Section 5.1** for further detail).

There is insufficient data for the surface water bodies east of Barwon River, including Pennyroyal, Deans Marsh and Matthews Creeks relating to pre- and post-extraction conditions to establish any trends, if indeed hydraulic influence occurred as a result of historical extraction from the borefield. Further, there is insufficient data for surface water bodies west of Barwon River, including Barongarook Creek.

Stream flows within Boundary Creek were observed to show a marked increase in 2011, which was associated with an increase in rainfall. However, overall, the baseflow reductions observed in 1998 have persisted until 2020 despite supplementary flows being released by Barwon Water.

5.8 Predicted Future Recovery

Jacobs (2018) predicted groundwater recovery in the LTA following cessation of pumping using its numerical groundwater model. In summary Jacobs (2018) considered:

- The aquifer to have recovered once water levels recovered to 90% of pre-pumping water levels.
- Levels closer to the borefield would have higher drawdowns, however, would recover faster than those further away.
- The aquifer was predicted to have recovered to 90% in the immediate vicinity of the Barwon Downs borefield (e.g. G14) after ~5 years of no further pumping.
- The aquifer was predicted to have recovered to 90% along Boundary Creek after ~20 years of no further pumping.
- Potentially lower than average rainfall would slow the predicted recovery rates.

Based on 2022 water level data the recovery at the Barwon Downs borefield (i.e., G14) has remained at 80%, while along Boundary Creek water levels have recovered by up to 59%.

6 Data Gaps

During the course of this report preparation a number of data gaps have been identified, which are summarised below:

- The hydrogeology associated with the north eastern portion of BDIA where the LTA outcrops is unclear in terms of flow direction and as to whether this area represents a recharge or discharge area. Further, is it unclear where groundwater from the BDIA that flows to the north east discharges. However, if this area is a recharge area it is considered to contribute a relatively minor amount compared to the Barongarook High.
- There is some inconsistency between groundwater ages from dating and aquifer parameters. This suggests there are elements of the groundwater flow system that are not fully resolved, notably the nature of groundwater flow paths in the north-eastern portion of the BDIA.
- There is uncertainty regarding the significance of the hydraulic connection across the Colac Monocline. Whilst it is indicated to be minor there are very few bores to verify the stratigraphy and hydraulic connectivity.
- There are limited groundwater and surface water data particularly in Pennyroyal, Deans Marsh and Mathews Creeks that spans both the pre-and post-groundwater extraction phases from which the relatively influence of groundwater extraction on streamflow can be estimated. There is also uncertainty regarding the degree of uncertainty between these streams and the LTA. Whilst groundwater/surface water modelling could be conducted, it is BlueSphere's view that direct assessment of environmentally significant impacts would be more effective. Alternatively further hydrogeological investigations could be undertaken to further establish the likely degree of groundwater/surface water interaction (if any).
- There is insufficient data to complete the impact assessment, at this time, in relation to environmentally significant impacts in Pennyroyal, Deans Marsh and Mathews Creeks in relation to ASS, vegetation and water quality.
- The recharge area and groundwater flow direction for the Clifton Formation is not known.
- The nature and extent of LTA sediments across the Pipeline Restriction is not well defined. This underpins the estimates of throughflow across the Pipeline Restriction to the KIA and subsequent sustainability of the aquifer. This data gap would be of importance for any future assessment of sustainability.
- Whilst the surface water licences are known, the surface water utilisation regime in the BDIA is not well quantified (for both existing and potentially unregistered users). Licenced extraction is at a level that could materially affect baseflow levels in concert with other competing influences.
- There are some aspects of the numerical groundwater model that could be improved, notably in the vicinity of the East and West Barwon Rivers and Barongarook Creek (areas west of Barwon River). It is BlueSphere's view that this would only be warranted should groundwater extraction above the PCV be considered in the future. Further modelling is not considered to be warranted as part of the surrounding areas investigations as it would not change the outcomes.

7 Conclusions and Recommendations

7.1 Conclusions

BlueSphere has prepared this HA report on behalf of Barwon Water in order to assist Barwon Water with meeting the requirements of the Section 78 Notice issued pursuant to the Water Act 1989. The objectives of the HA were to:

- Develop a robust CSM based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics; and
- Use the CSM to evaluate if any impacts that may have resulted from historical groundwater pumping activities at the Barwon Downs borefield have occurred.

The CSM was developed by desktop review of publicly available information in relation to the BDIA setting including geology, hydrogeology, climate, topography, hydrology, GDEs and ASS. An inspection of the BDIA was also completed. The CSM has been developed with a focus on the LTA in the BDIA, and is in large agreeance with previous investigations.

The CSM developed for the BDIA was used to evaluate if impacts have resulted from historical groundwater pumping activities at the Barwon Downs borefield based on the current state of knowledge and the best available data. The following conclusions are made:

- The evaluation has identified that the historical groundwater pumping activities have led to a decrease of water levels in the LTA in the order of 60 m in the BDIA. Water levels in the BDIA are showing signs of recovery with up to 80% recovery within the confined areas of the LTA and up to 59% recovery in unconfined areas of the LTA.
- Declines in low flows (Q90 stream flow) have been observed from streamflow records in Boundary Creek and the Barwon River in the far eastern portion of the Barwon River surface water catchment within the BDIA between 1997 and 2013. The available stream flow data for other surrounding investigation areas does not include pre-extraction conditions and therefore is not suitable for the evaluating the potential influence of groundwater extraction on these areas.
- There is demonstrable evidence of environmentally significant impacts within Boundary Creek, with limited downstream effect within the Barwon River directly downstream of the confluence with Boundary Creek. These impacts are well known and the REPP addresses the remediation of Boundary Creek and Big Swamp to alleviate these impacts.
- The evaluation of likely influences on the observed Q90 stream flow decline in Boundary Creek observed during the Millennium Drought indicates that prior to groundwater extraction from the Barwon Downs Borefield it is apparent that drainage enhancements had likely altered the hydrological characteristics of the BDIA, including Boundary Creek and Big Swamp.
- Stream flow monitoring records show that the Q90 stream flow had been reduced by ~65% between up-stream and down-stream of McDonalds Dam since 1979. From the onset of the Millennium Drought there is expected to have been a further progressive loss of moisture from the environment; this effect would have occurred regardless of groundwater extraction.
- In Boundary Creek, where if flows over the LTA between McDonalds Dam and Big Swamp, contributions to the observed stream flow decline are evident from long-term rainfall decline associated with the Millennium Drought and potentially to a lesser degree surface water extraction via licenced extraction. However, the CSM indicates that groundwater extraction is likely to be the predominant contributor to the observed Q90 stream flow decline observed in Boundary Creek. This is consistent with the numerical groundwater model previously developed by Jacobs (2019). That is, groundwater extraction is indicated to have compounded pre-existing water demands such as the upstream dam, surface water extraction and climate related influences that would have occurred irrespective of groundwater extraction.
- The influence of groundwater extraction relative to other factors such as surface water extraction and land use change within the other surrounding areas identified for further investigation are

difficult to ascribe based on the available information. Rather, a conceptual assessment has been undertaken.

- The CSM indicates that the influence of groundwater extraction on the East Barwon River in particular is likely to have been previously overestimated given the CSM indicates that connectivity is limited in this area based on geological and hydrogeological data. The risks to the East Barwon River are also assessed as being low on the basis that the hydraulic connectivity is limited and that there is no demonstrable evidence of environmentally significant impacts in the East Barwon River. It is considered, based on the CSM, that the influence of groundwater extraction on the East Barwon River is insignificant.
- There is hydraulic connection between the confined portion of the LTA and the LTA outcrops associated with up-stream portions of Pennyroyal, Matthews and Deans Marsh Creeks, located east of the Barwon River. Jacobs (2019) identified downstream areas of the Pennyroyal, Matthews and Deans Marsh Creeks as being impacted from groundwater pumping, however this report has identified that the areas that are potentially susceptible to groundwater pumping related impacts are upstream of the areas identified by Jacobs (2019). However, there is a paucity of suitable historic surface water data that spans both the pre-and post- groundwater extraction phases to appraise the degree of potential hydraulic influence in these areas. Whilst there are some data to suggest the streams in this area are not in connection with the LTA there remains uncertainty in this regard.
- The framework documented in the Ministerial Guidelines for Groundwater Licensing of High Value GDEs was applied retrospectively to provide a point of comparison to aid in future management and to categorise the potential susceptibility in a consistent and transparent manner. The framework identified that the risks to Boundary Creek, Barwon River at its confluence with Boundary Creek by virtue of receiving inflows from Boundary Creek are classified as ‘high’ under the framework. For the up-stream portions of Pennyroyal, Deans Marsh and Matthews Creeks where they flow over LTA up-stream of the Bambra Fault, the risk are also classified as ‘high’ reflecting the need for further information rather than indicating risks are truly high
- The risks to the West Barwon River are assessed as being low which accords with Jacob (2019). A low risk has also been ascribed to potential GDEs west of Barwon River (Barongarook Creek).

The findings from this HA should be used to form the basis for the subsequent management decisions in the catchment. Any change to the existing PCV should consider cumulative effects of any pumping, climate change, land use and existing hydrological stressors to relevant surface water receptors, together with the interconnectivity between the BDIA and surrounding environments, including the KIA to the south-west.

7.2 Recommendations

Based on the findings of the HA, the following recommendations are made for consideration by Barwon Water:

- Continued monitoring of groundwater and surface water assets in the BDIA to monitor the recovery of groundwater levels in the LTA.
- Continue to implement the remediation and rehabilitation activities in Boundary Creek in accordance with the REPP.
- Conduct further investigations in relation to acid sulfate soil, vegetation and water quality for the up-stream portions of Pennyroyal Creek, Deans Marsh Creek and Matthews Creek where they flow over LTA outcrops up-stream of the Bambra Fault (i.e. proximal to primary susceptible water features) to establish if there is any evidence of environmentally significant impacts that could be attributed to historical groundwater extraction from the Barwon Downs Borefield. Alternatively further hydrogeological investigations could be undertaken to further establish the likely degree of groundwater/surface water interaction (if any) in these area.

In addition to the recommendations listed above, the following recommendations are provided with regard to the future management of groundwater resources in the BDIA:

- Future management decisions consider the cumulative effects and interconnectivity of surface water and groundwater resources. This may involve updating the existing numerical groundwater model to incorporate the findings from the updated CSM. It is BlueSphere’s view that an update to the existing numerical groundwater model is not considered to be warranted as part of the surrounding areas investigations as it would not change the outcomes of this investigation.

- Conduct further hydrogeological assessment to the north of the Colac Monocline to validate the limited connectivity across the monocline; and
- The identified data gaps be addressed and data continue to be collected to allow for a robust and continuous data set, as well as a baseline condition as part of any proposed future extraction, should the PCV be raised in the future.

8 Limitations

This report was prepared for the sole use of Barwon Water and should not be relied upon by any other person. None of BlueSphere Environmental Pty Ltd or any of its related entities, employees or directors (each a BlueSphere Person) owes a duty of care (whether in contract, tort, statute or otherwise) to any third party with respect to or in connection with this report and no BlueSphere Person accepts any liability for any loss or damage suffered or costs incurred arising out of or in connection with the use this report by any third party.

The report has been prepared with the objectives and scope of work outlined in the proposal dated 9 February 2023. The work was carried out in accordance with the existing contract between BlueSphere and Barwon Water.

The conclusions and recommendations provided in this report are based on available information (including third party data and reports) and it is possible that different conclusions and recommendations could be made should new information become available, or with changing site conditions over time. These opinions, conclusions and recommendations are subject to uncertainty given the potentially complex nature of any subsurface environment. Variation in soil and groundwater conditions may vary significantly between the specific sampling and testing locations and other locations at the site.

The report will not be updated if anything occurs after the date of this report and BlueSphere Environmental Pty Ltd will not be obliged to inform any person of any matter arising or coming to its attention after that date.

9 References

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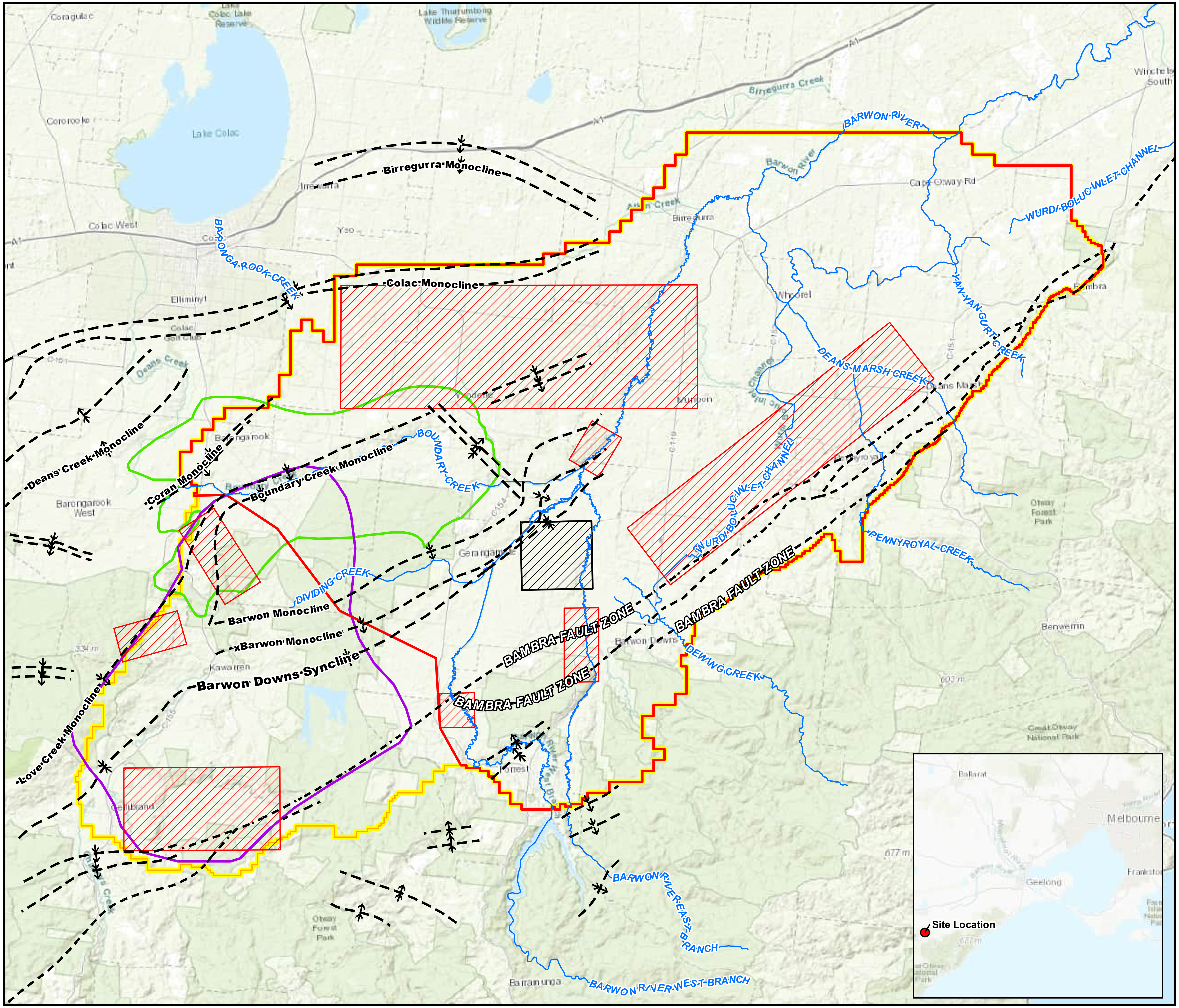
Figures



PROJECT ID 31155.02
DATE 13/07/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Surrounding Environment Investigation Area
- Areas for Further Investigation
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield
- Watercourse

Structural Features

- Geological Faults
- Monocline
- Syncline

Service Layer Credits: 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

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REGIONAL SETTING

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F1

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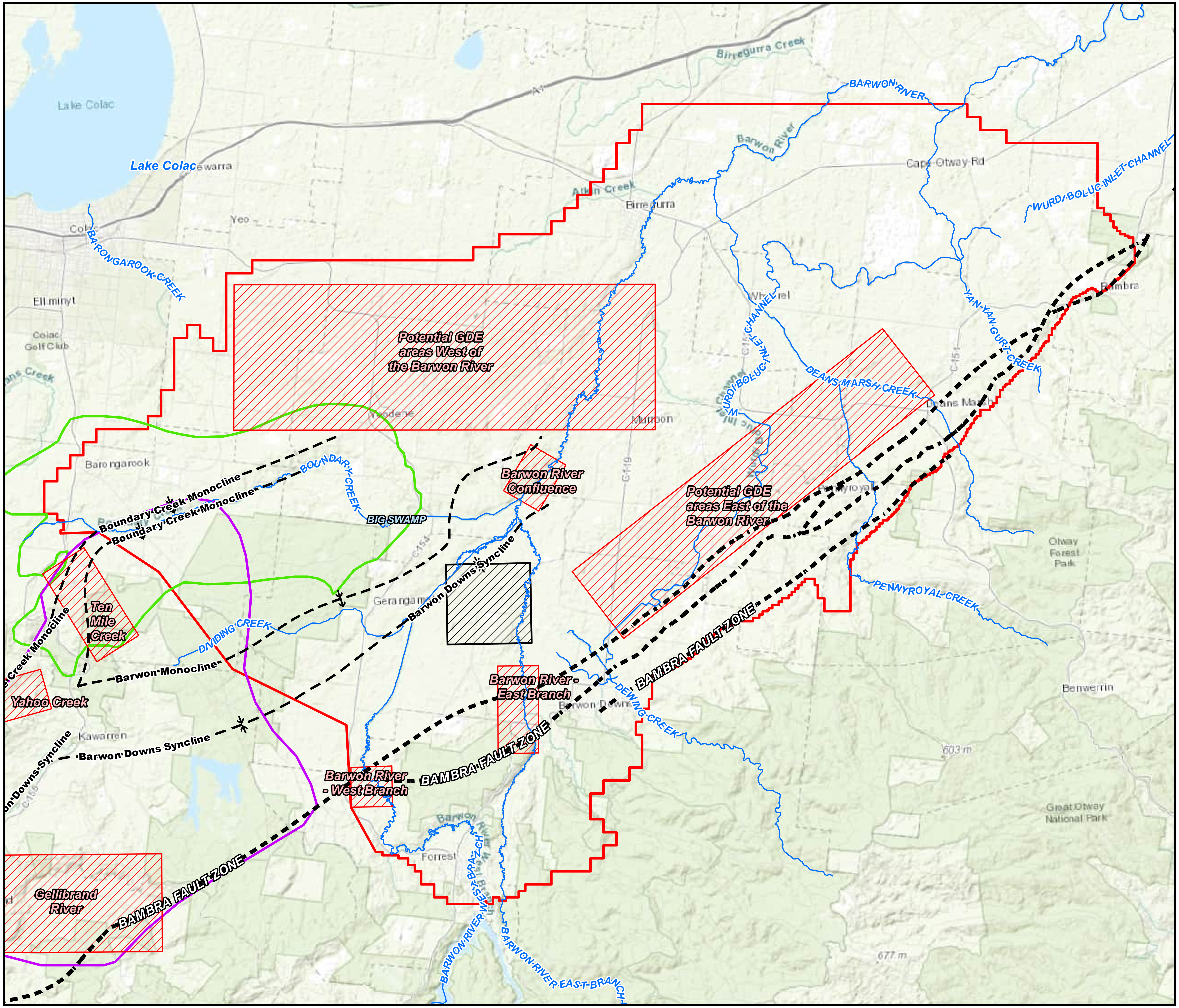

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DATE 13/07/2023
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BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Areas for Further Investigation
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield
- Watercourse

Structural Features

- Monocline
- Syncline
- Geological Faults

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BARWON DOWNS SUB-BASIN INVESTIGATION AREA

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F2

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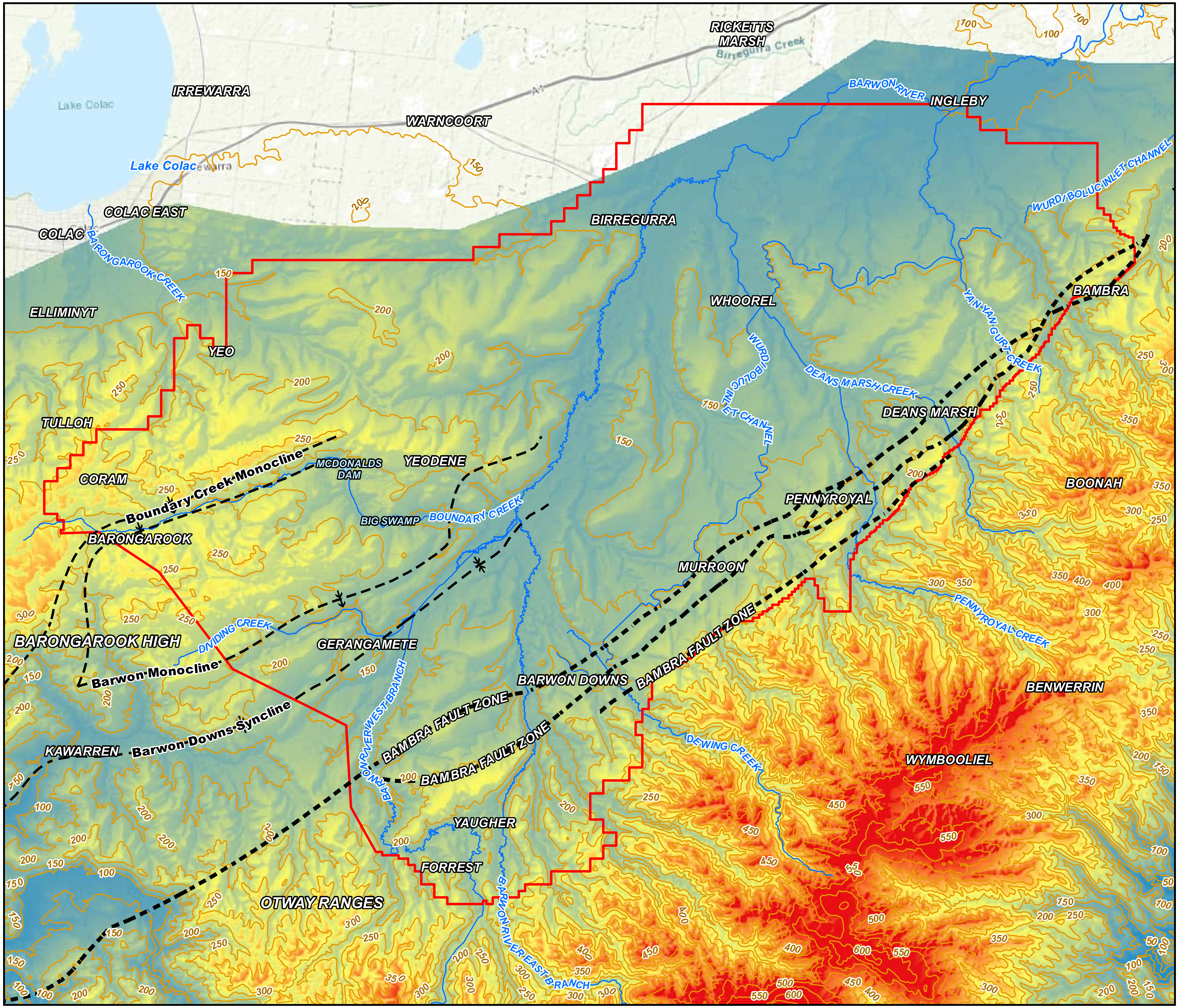

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Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Regional Elevation Contours (mAHD)
- Watercourse

Structual Features

- Monocline
- Syncline
- Geological Faults

Elevation (mAHD)

High : 658.764

Low : 50

Note: Digital Elevation Model provided by Barwon Water

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TOPOGRAPHY

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area

Barwon Water

Figure **F3**

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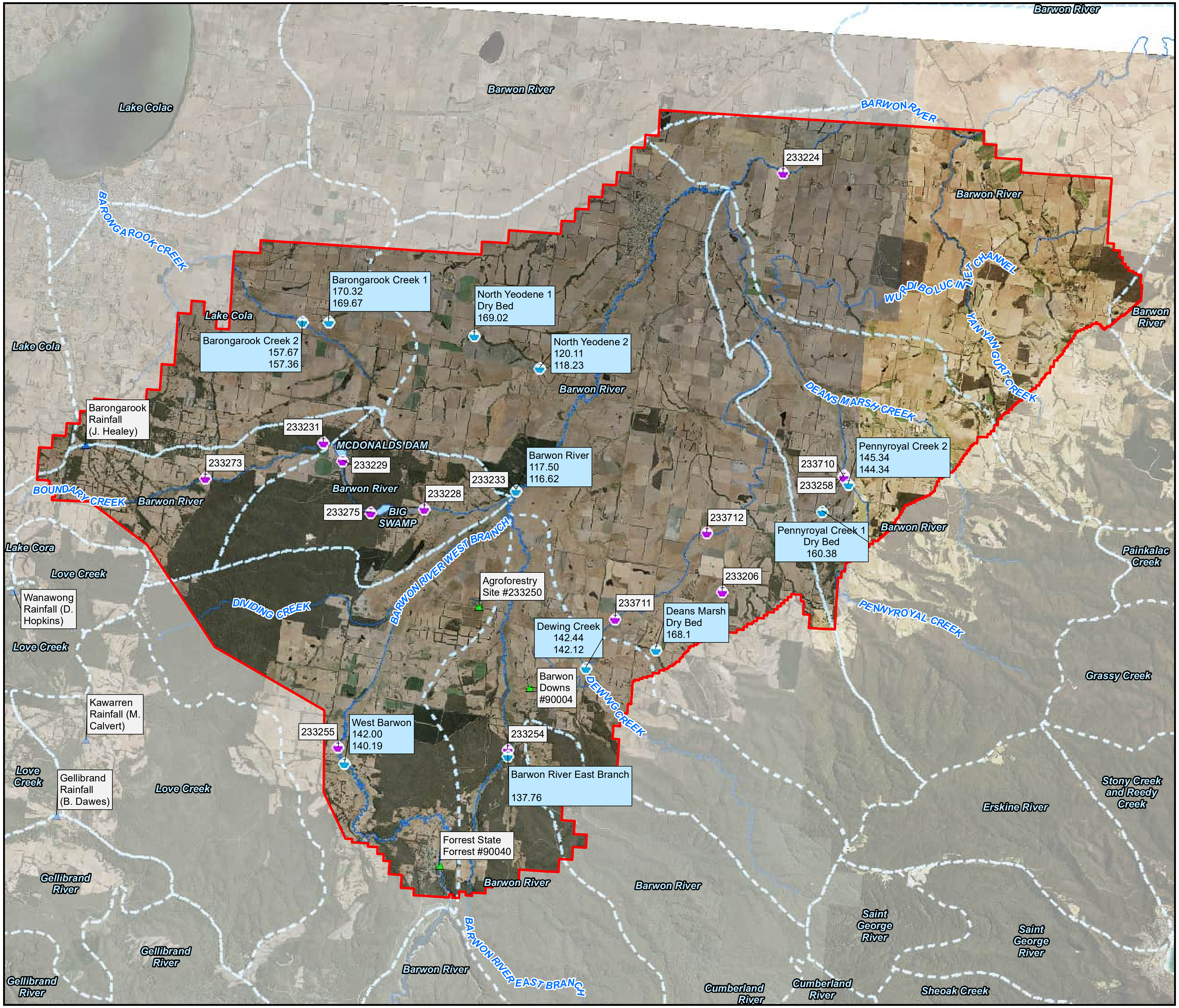

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Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- SDL Catchment Areas
- Watercourse
- Stream Survey Locations
- Stream Gauges

Rainfall Stations

- Formal Stations
- Community Gathered Rainfall Data

Location ID
Water Level (mAHD)
Invert Level (mAHD)

Note: Stream Survey provided by Barwon Water and collected between March and August 2022

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Imagery: Nearmap 2019

HYDROLOGY AND RAINFALL STATIONS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F4

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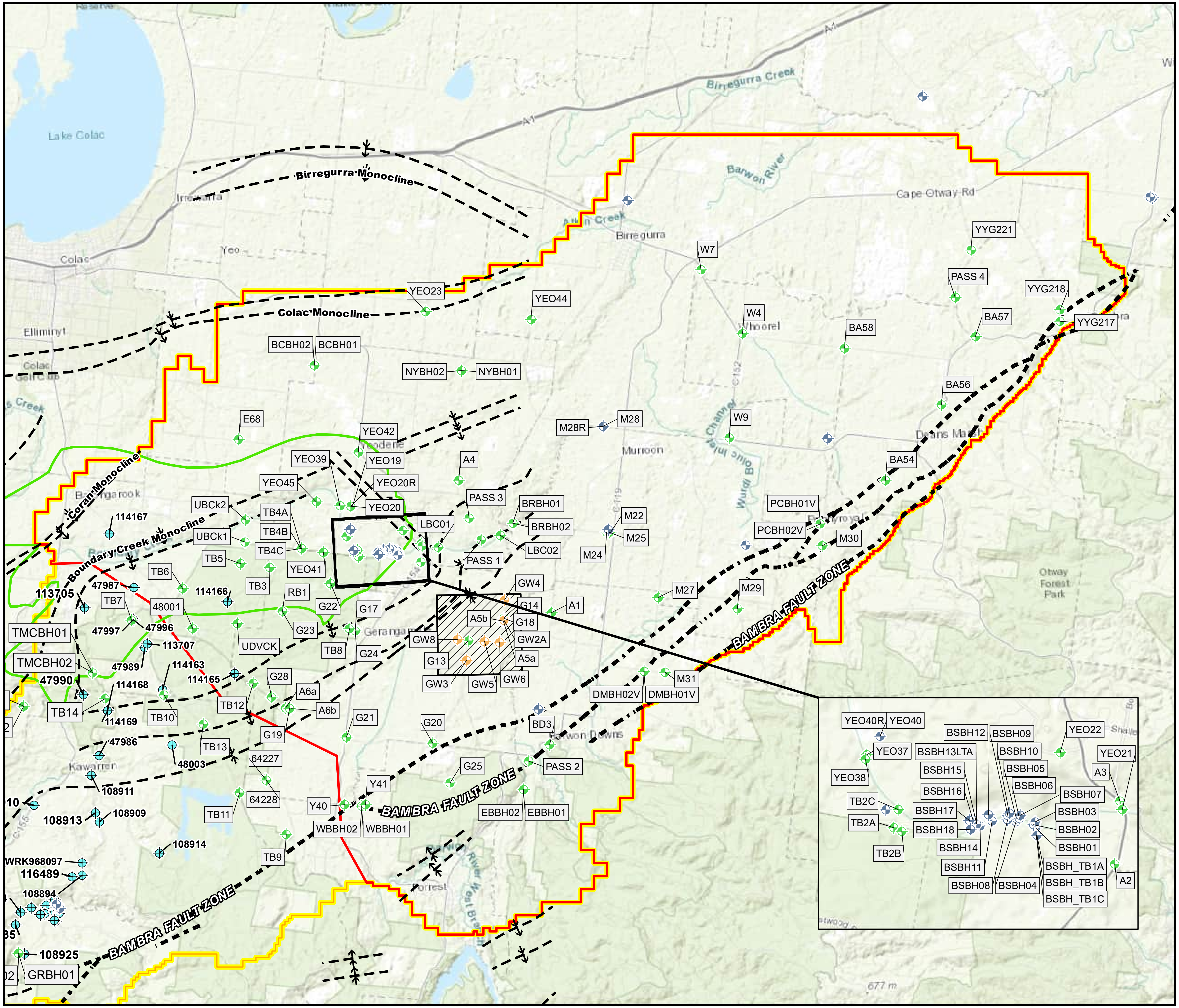

PROJECT ID 31155.02
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BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield

Structural Features

- Monocline
- Syncline
- Geological Faults

Barwon Water Monitoring Assets

- Production Bores
- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation

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Imagery: Nearmap 19/02/2022

BARWON DOWNS MONITORING NETWORK

Hydrogeological Assessment - Barwon Downs Sub-basin

Figure **F5**

Barwon Downs Sub-basin Area
Barwon Water

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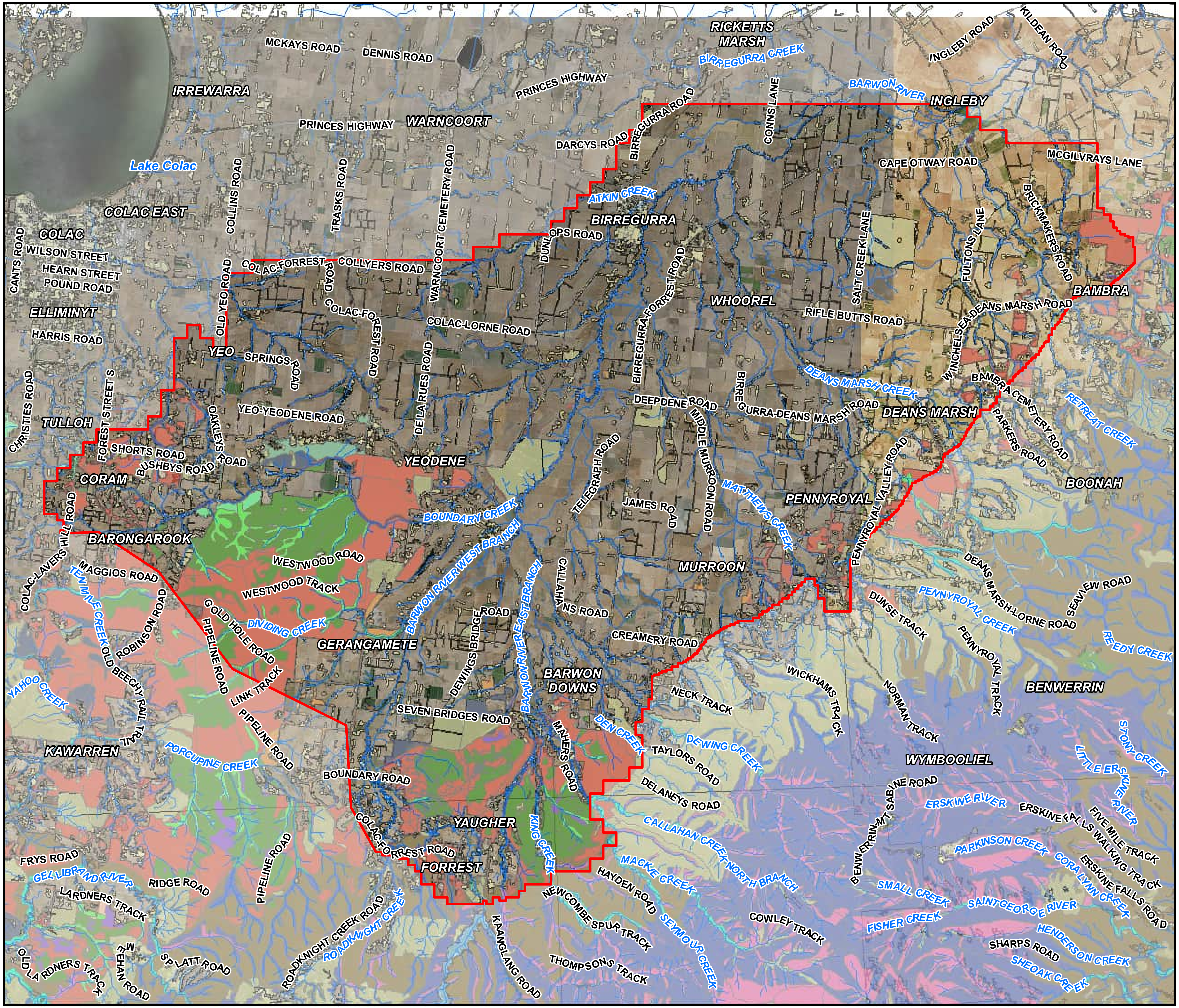

PROJECT ID 31155.02
DATE 13/07/2023
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BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Watercourse

Ecological Vegetation Classes (NV2005, DELWP)

- 3, Damp Sands Herb-rich Woodland
- 8, Wet Heathland
- 16, Lowland Forest
- 17, Riparian Scrub/Swampy Riparian Woodland Complex
- 18, Riparian Forest
- 23, Herb-rich Foothill Forest
- 30, Wet Forest
- 45, Shrubby Foothill Forest
- 48, Heathy Woodland
- 56, Floodplain Riparian Woodland
- 83, Swampy Riparian Woodland
- 128, Grassy Forest
- 165, Damp Heath Scrub
- 175, Grassy Woodland
- 198, Sedgy Riparian Woodland
- 201, Shrubby Wet Forest
- 998, Water Body - man-made
- Non Native Tree Areas

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GDA 1994 MGA Zone 55

Imagery: Nearmap 19/02/2022

ECOLOGICAL VEGETATION CLASSES

Hydrogeological Assessment - Barwon Downs Sub-basin

Figure **F6**

Barwon Downs Sub-basin Area

Barwon Water

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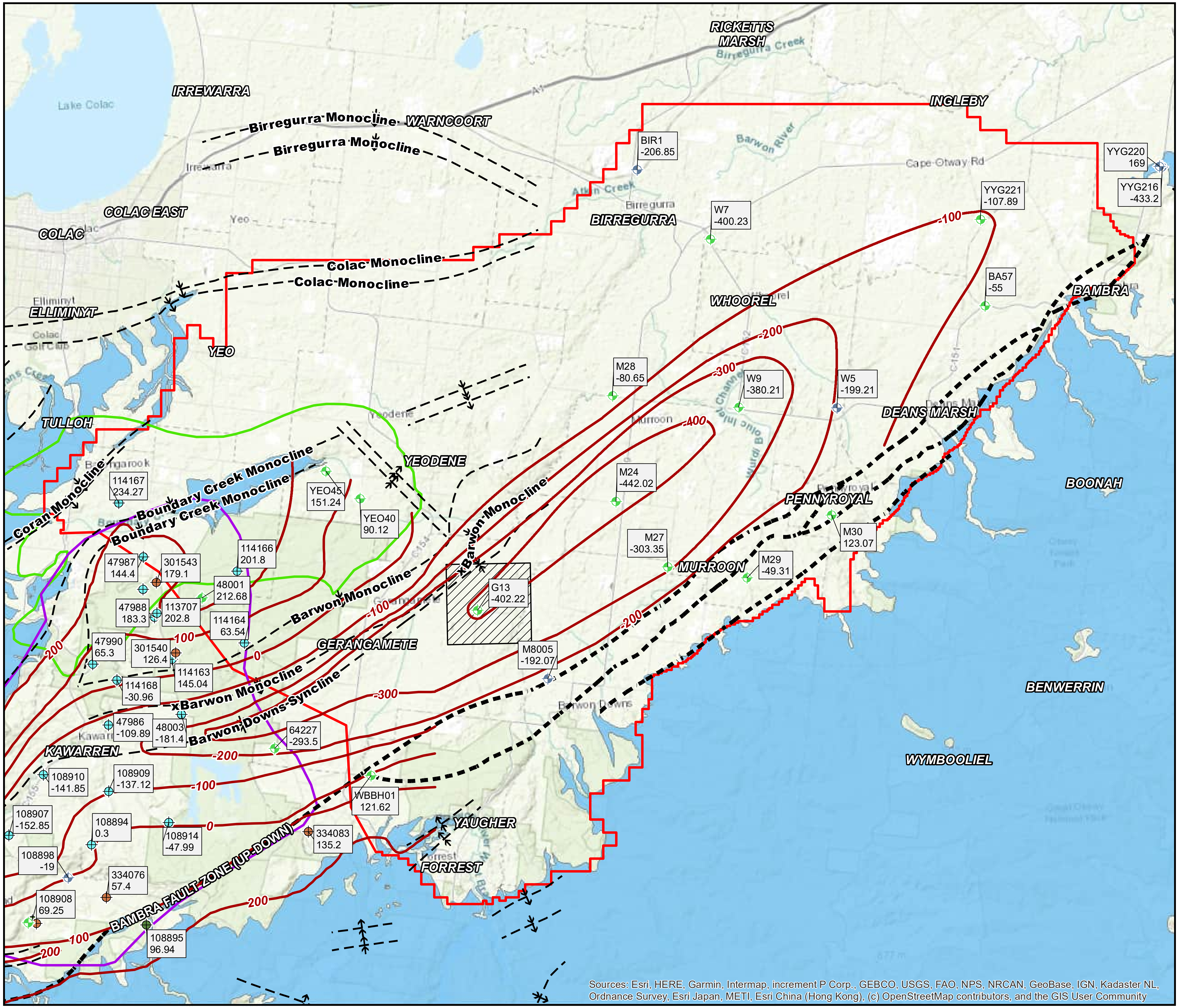

PROJECT ID 31155.02
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CREATED BY AF
UPDATED BY WC

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Otway Group

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Non Groundwater
- Observation
- Unknown

Bore ID
Top of Otway Group Elevation (mAHD)

...ours (mAHD)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89

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Kilometres
1:110,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

OTWAY GROUP SURFACE CONTOURS

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F7

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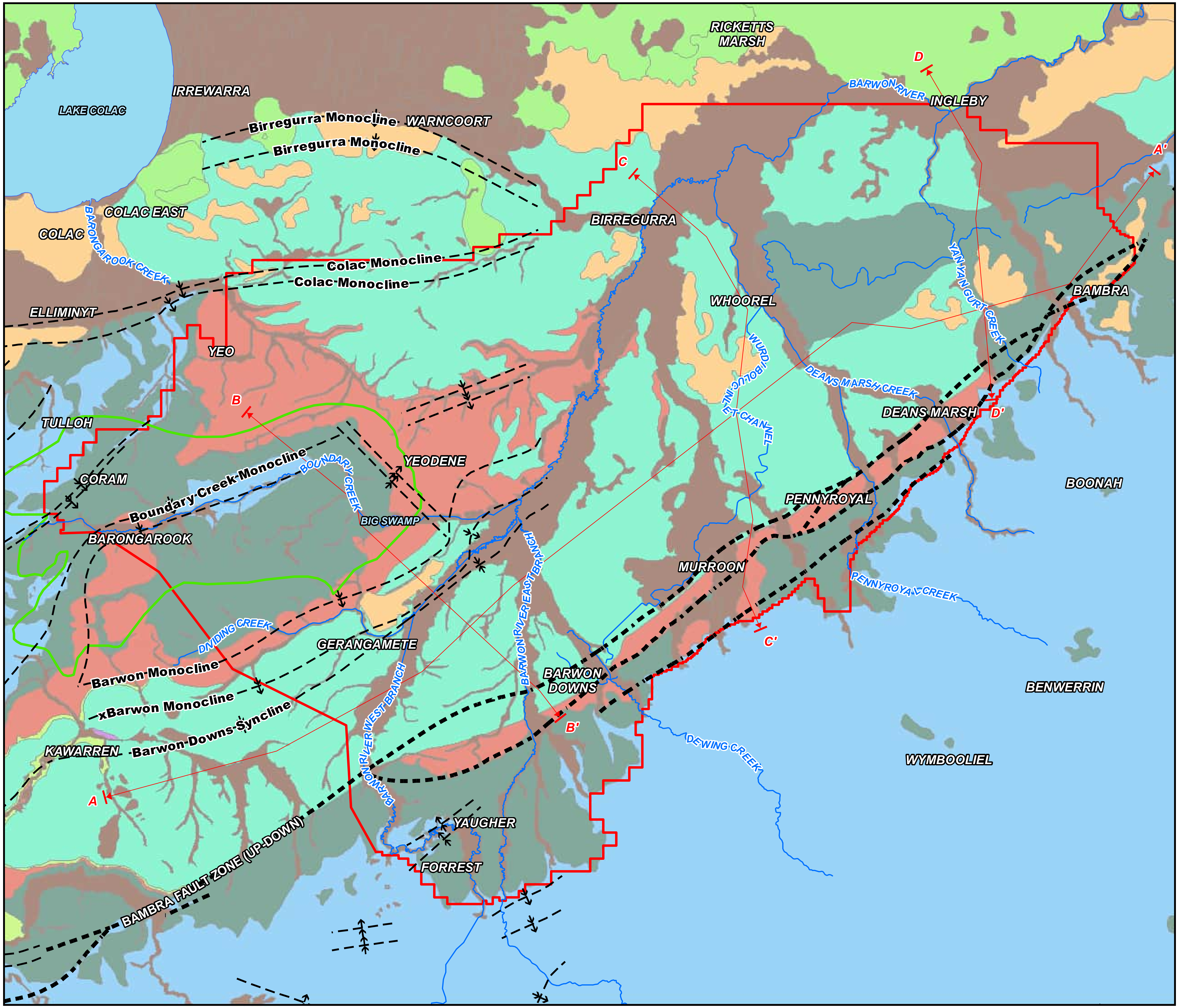

PROJECT ID 31155.01
DATE 13/07/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Watercourse
- Cross Section Alignments

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Newer Volcanics
- Sandringham Sandstone
- Gellibrand Marl Formation } Heytesbury Group
- Clifton Formation } Heytesbury Group
- Older Volcanics
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Note: Modified surface geology nomenclature.

N

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Kilometres
1:110,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

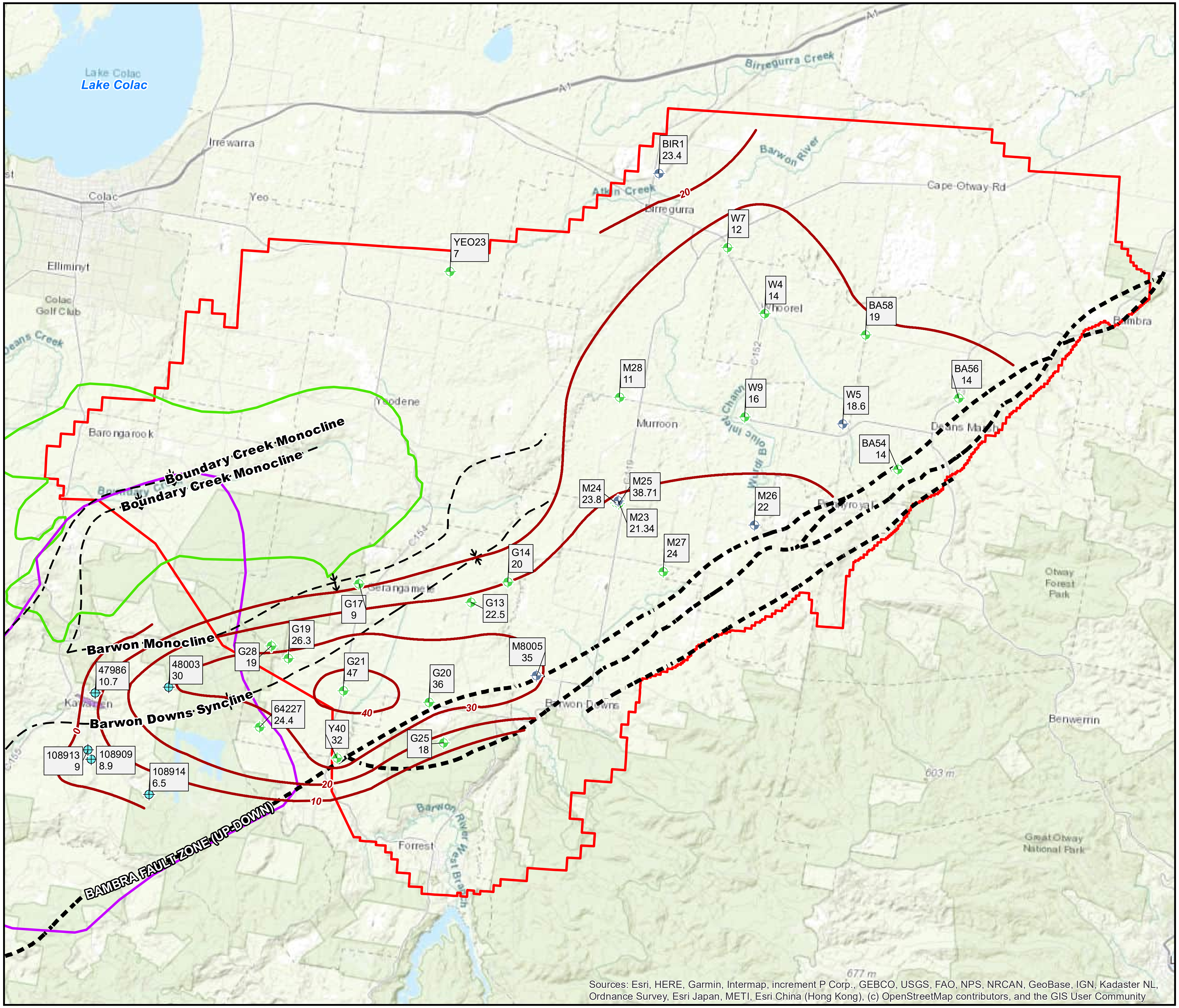
SURFICIAL GEOLOGY

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F8

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig08_SurficialGeology.mxd.mxd



PROJECT ID 31155.01
DATE 13/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

Approximate Extent of Barwon Downs Sub-basin Investigation Area
Kawarren Sub-basin Investigation Area (approx. extent)
Approximate Area of Barongarook High (Intake areas)

Structural Features

Monocline
Syncline
Geological Faults

Surface Geology (1:50,000) (DELWP)

Clifton Formation

Barwon Water Monitoring Assets

Groundwater Observation Bores
Groundwater Monitoring Bore

WMIS Groundwater Bores

Observation
Clifton Formation Contours (m) (modified from Tickell et al. 1991)

Bore ID
Clifton Formation Thickness (m)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89

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Kilometres
1:110,000 when printed at A3
GDA 1994 MGA Zone 54

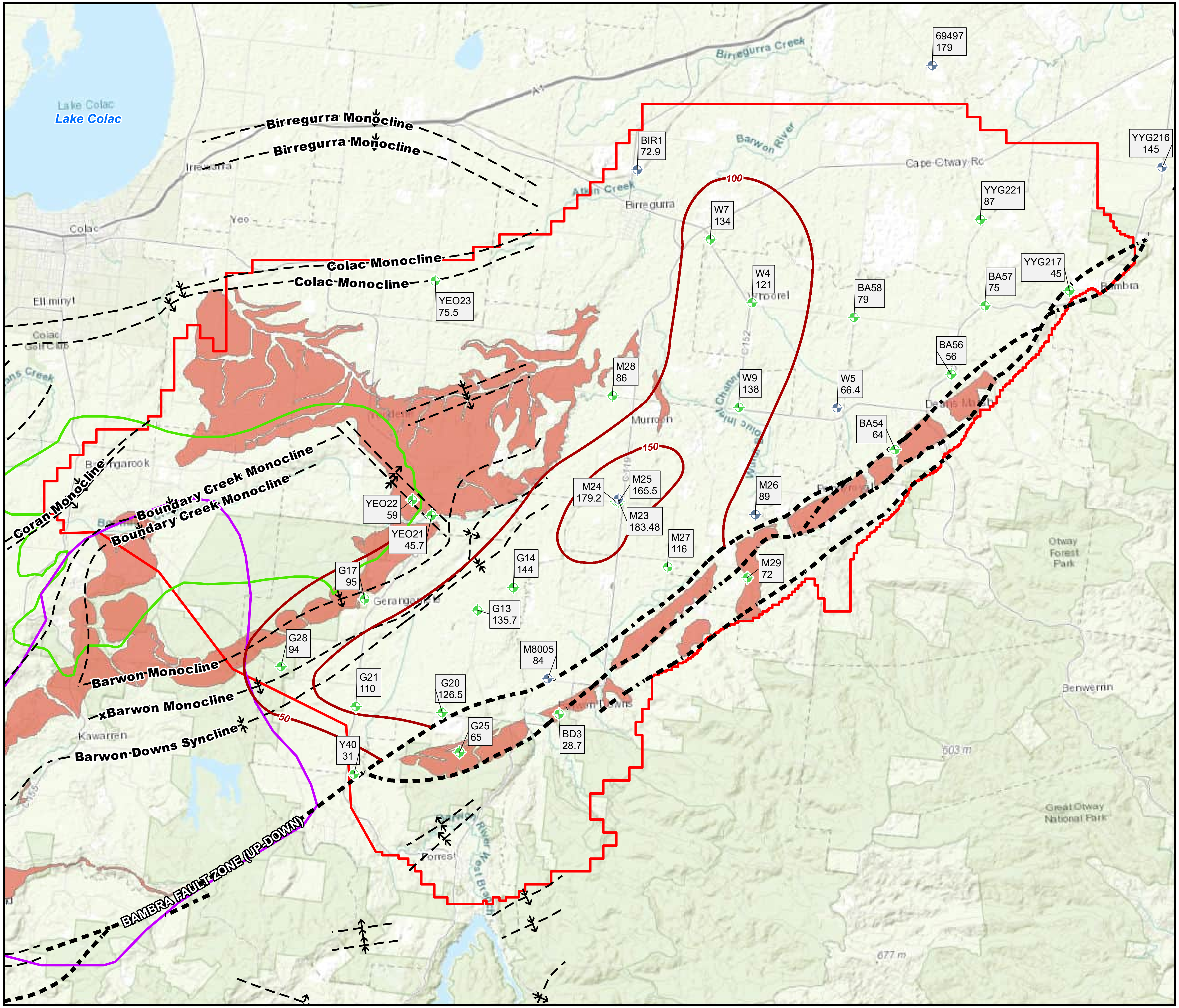
CLIFTON FORMATION THICKNESS

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F9

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig09_CliftonFormation.mxd.mxd



PROJECT ID 31155.01
DATE 13/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Monocline
- Syncline
- Geological Faults

Surface Geology (1:50,000) (DELWP)

- Nirranda Group (Narrawaturk Marl)

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore
- Narrawaturk Marl Thickness Contours (m)

Bore ID
Narrawaturk Marl Thickness (m)

Source Files: Trickell et al.1991, Colac 1:50,000 Map, Geological Report, GSV Report No.89
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

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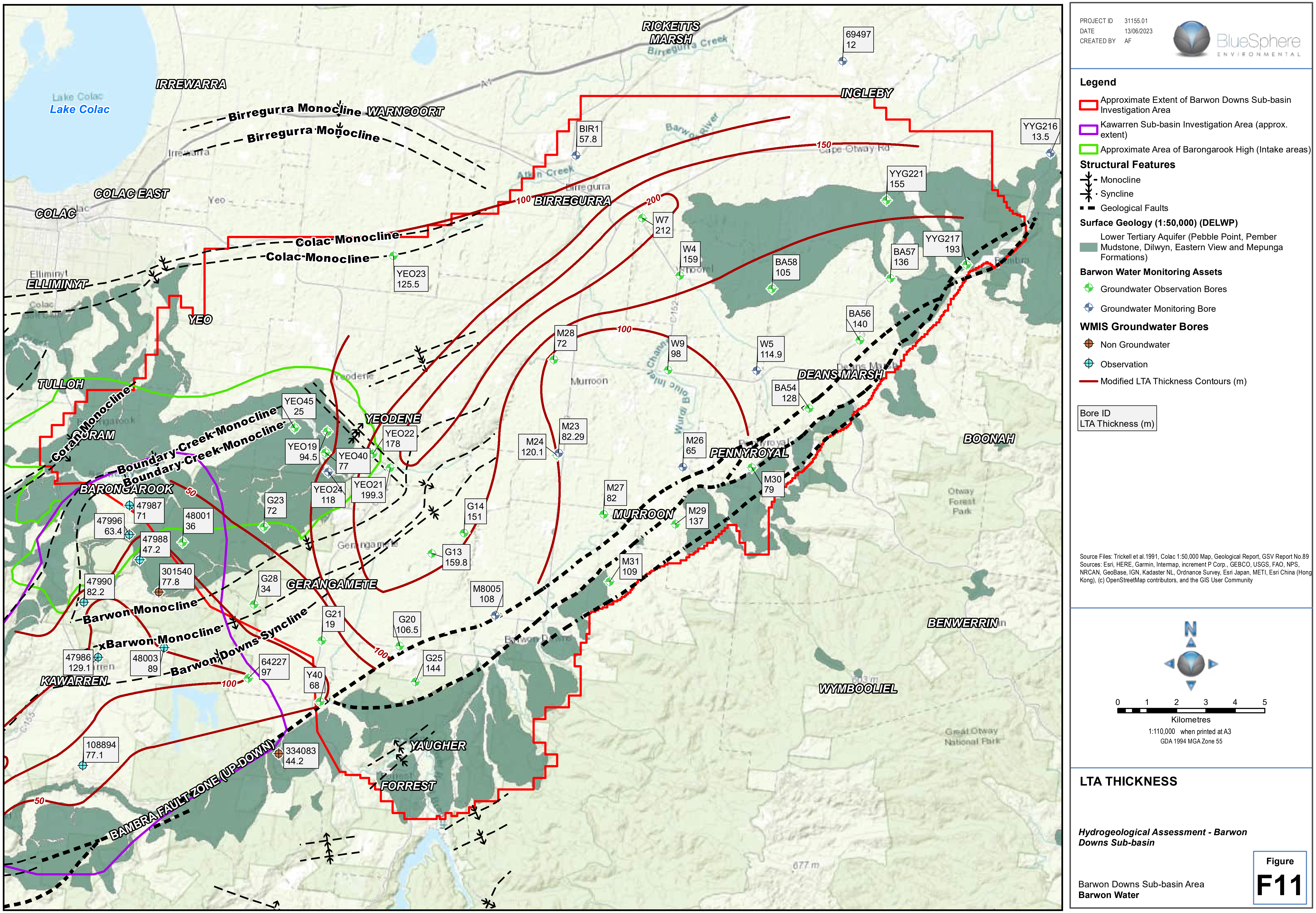
Kilometres
1:110,000 when printed at A3
GDA 1994 MGA Zone 55

NARRAWATURK MARL THICKNESS

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F10



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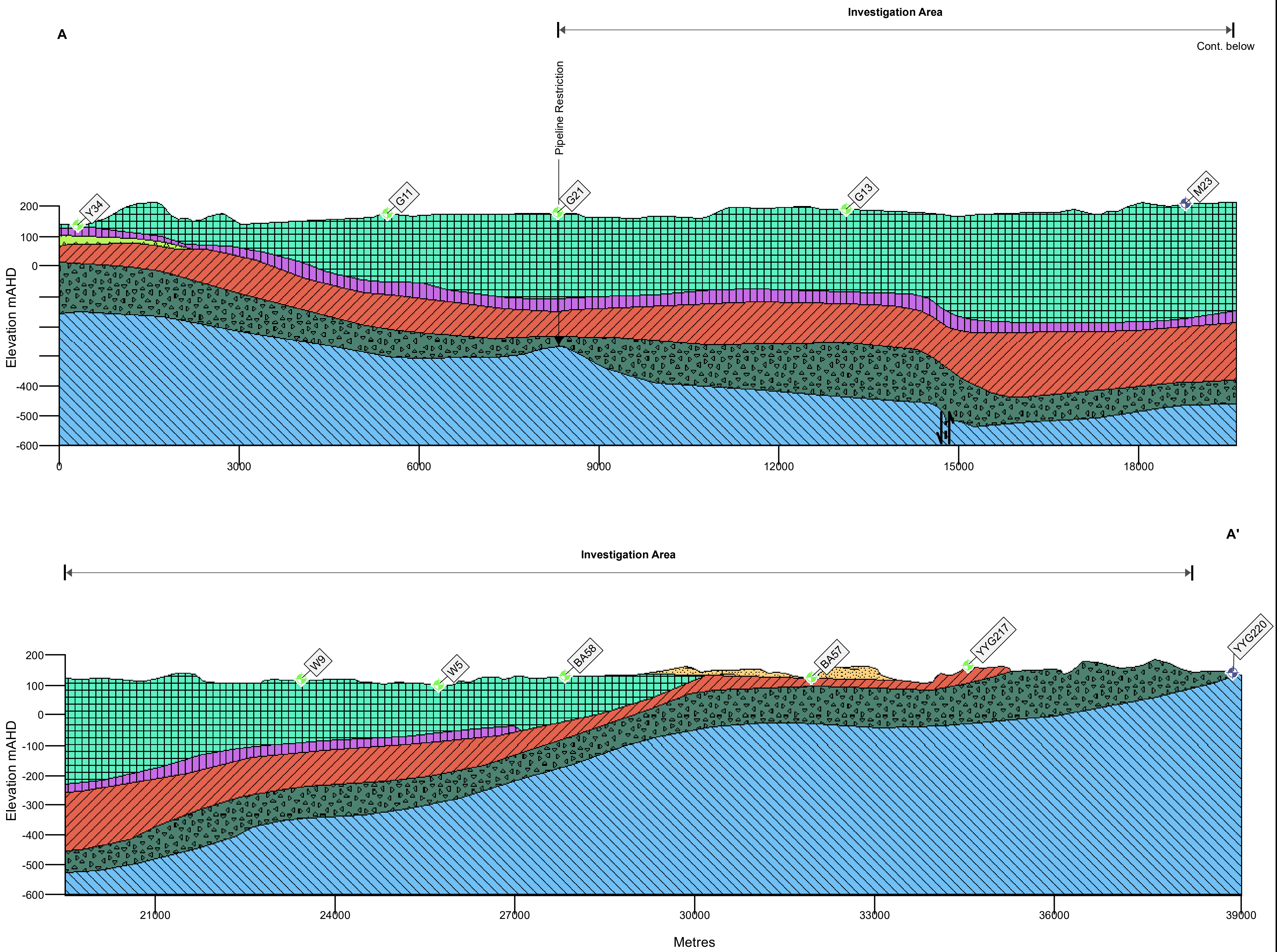


PROJECT ID 31155.02
DATE 2/06/2023
CREATED BY AF

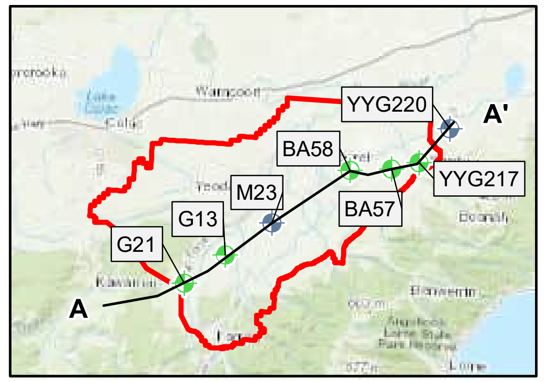
BlueSphere ENVIRONMENTAL

Legend

- Fault
- Quaternary Sediments
- Sandringham Sandstone
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Barwon Water Monitoring Assests

- Groundwater Monitoring Bore
- Groundwater Observation Bores



Service Layer Credits: 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

GEOLOGICAL CROSS SECTION A-A' AFTER WITEBSKY (1995)

Hydrogeological Assessment - Barwon Downs Sub-basin

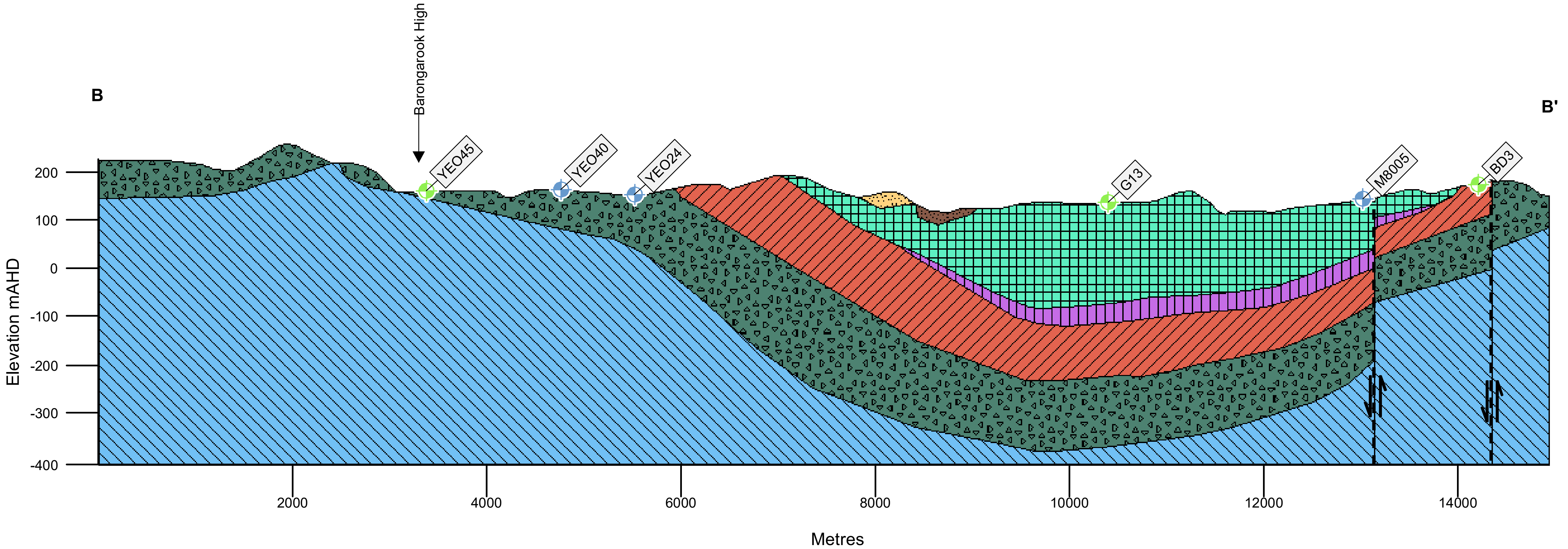
Barwon Downs Sub-basin Area
Barwon Water

Figure
F12

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig12_XSection_AA.mxd.mxd

PROJECT ID 31155.01
DATE 5/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

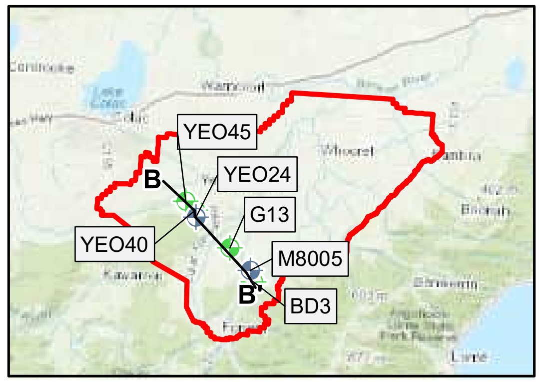


Legend

- Fault
- Quaternary Sediments
- Sandringham Sandstone
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Barwon Water Monitoring Assests

- Groundwater Observation Bores
- Groundwater Monitoring Bore



GEOLOGICAL CROSS SECTION B-B' AFTER WITEBSKY (1995)

Hydrogeological Assessment - Barwon Downs Sub-basin

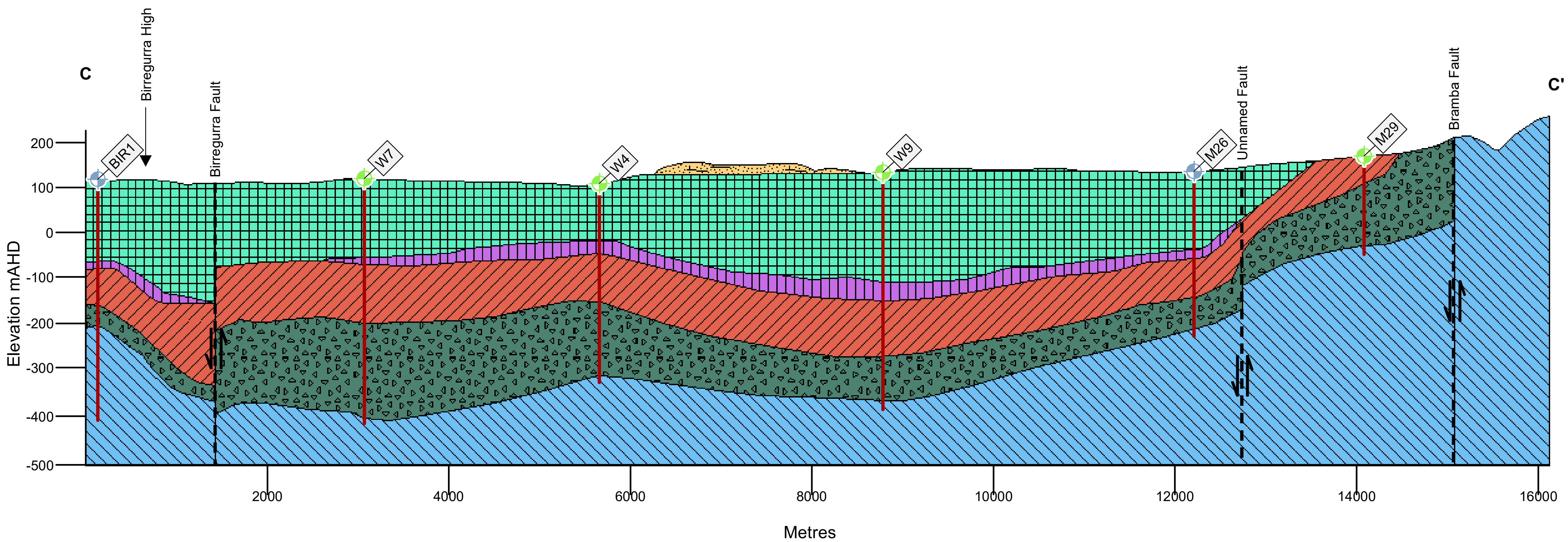
Barwon Downs Sub-basin Area
Barwon Water

Figure
F13

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig13_XSection_BB.mxd.mxd

PROJECT ID 31155.02
DATE 5/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

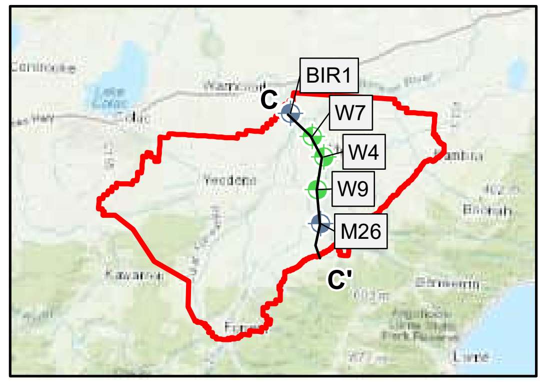


Legend

- Fault
- Borehole
- Quaternary Sediments
- Sandringham Sandstone
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Barwon Water Monitoring Assests

- Groundwater Observation Bores
- Groundwater Monitoring Bore



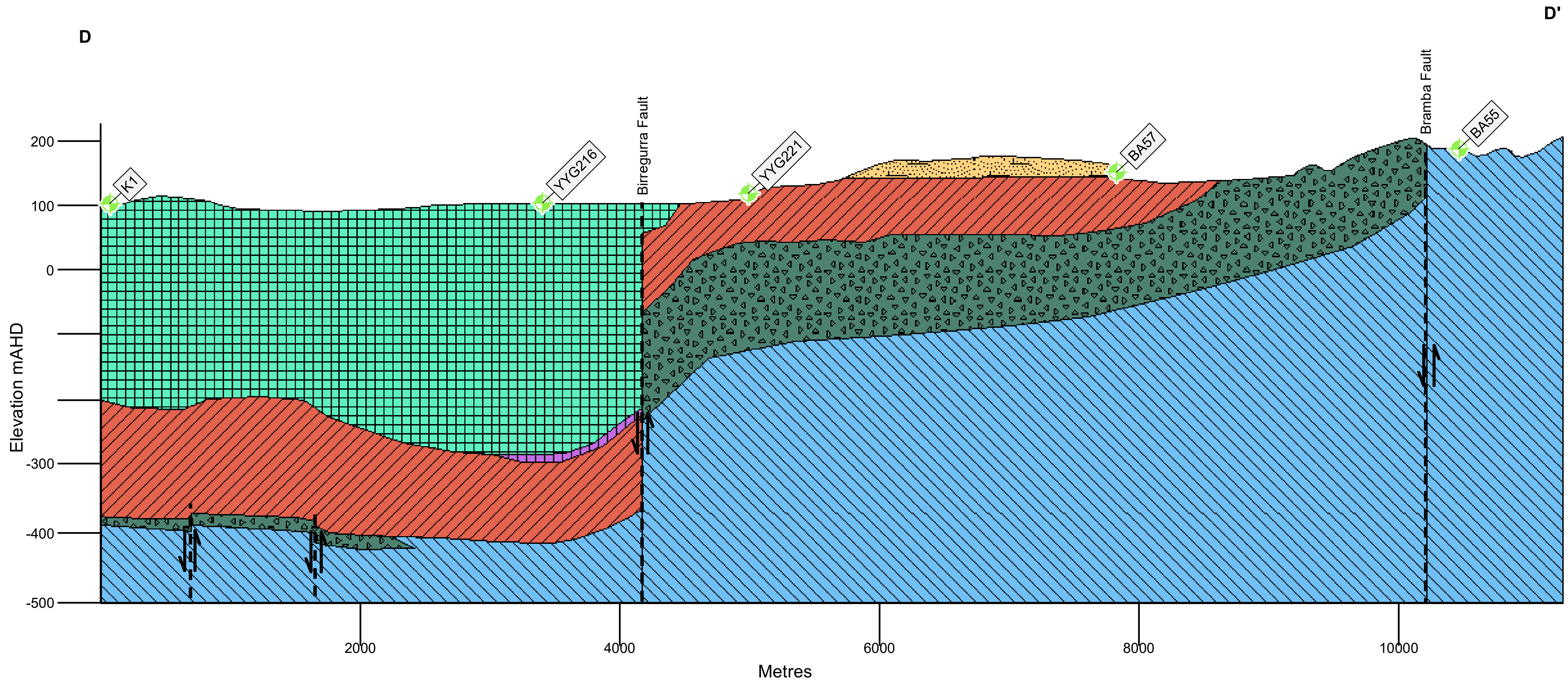
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

GEOLOGICAL CROSS SECTION C-C' AFTER WITEBSKY (1995)

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F14



PROJECT ID 31155.01
DATE 2/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

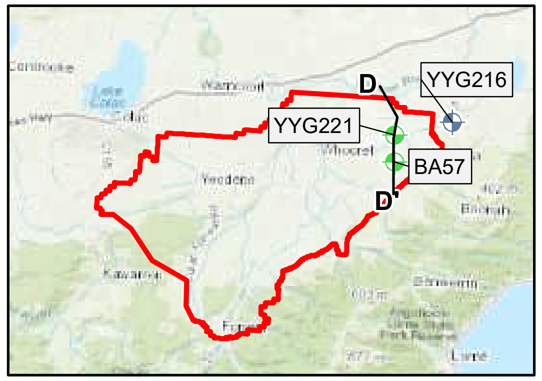
Legend

- Fault
- Quaternary Sediments
- Sandringham Sandstone
- Gellibrand Marl Formation
- Clifton Formation
- Yaugher Volcanics
- Narrawaturk Marl
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Barwon Water Monitoring Assests

- WMIS Groundwater Observation Bore
- Groundwater Observation Bores

Cross section geology has been determined using interpreted geology provided on borelogs and varies from the 1:50,000 DWELP surface geology map.



Service Layer Credits: 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

GEOLOGICAL CROSS SECTION D-D' AFTER WITEBSKY (1995)

Hydrogeological Assessment - Barwon Downs Sub-basin

Figure
F15

Barwon Downs Sub-basin Area
Barwon Water

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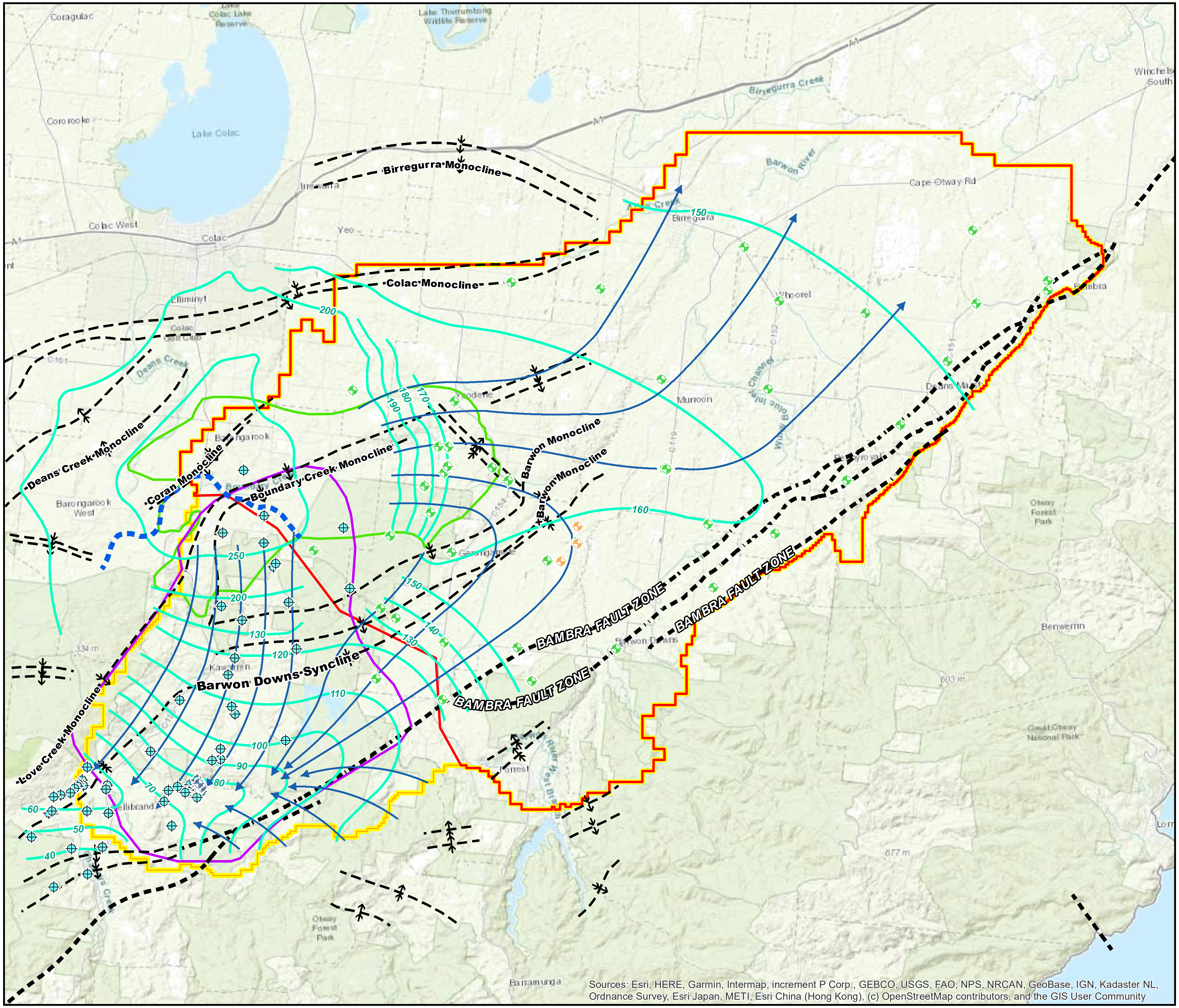


PROJECT ID 31155.02
DATE 13/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)

Structual Features

- Monocline
- Syncline
- Geological Faults

Barwon Water Monitoring Assets

- Production Bores
- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD) (Leonard, 1983)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Source Files: Leonard, J., Lakey, R., & Blake, R. (1983). Hydrogeological Investigation and Assessment, Barwon Down Graden, Otway Basin, Victoria. International Conference on Groundwater and Man Sydney, 1983. Unpublished.

N

0 1 2 3 4 5
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55

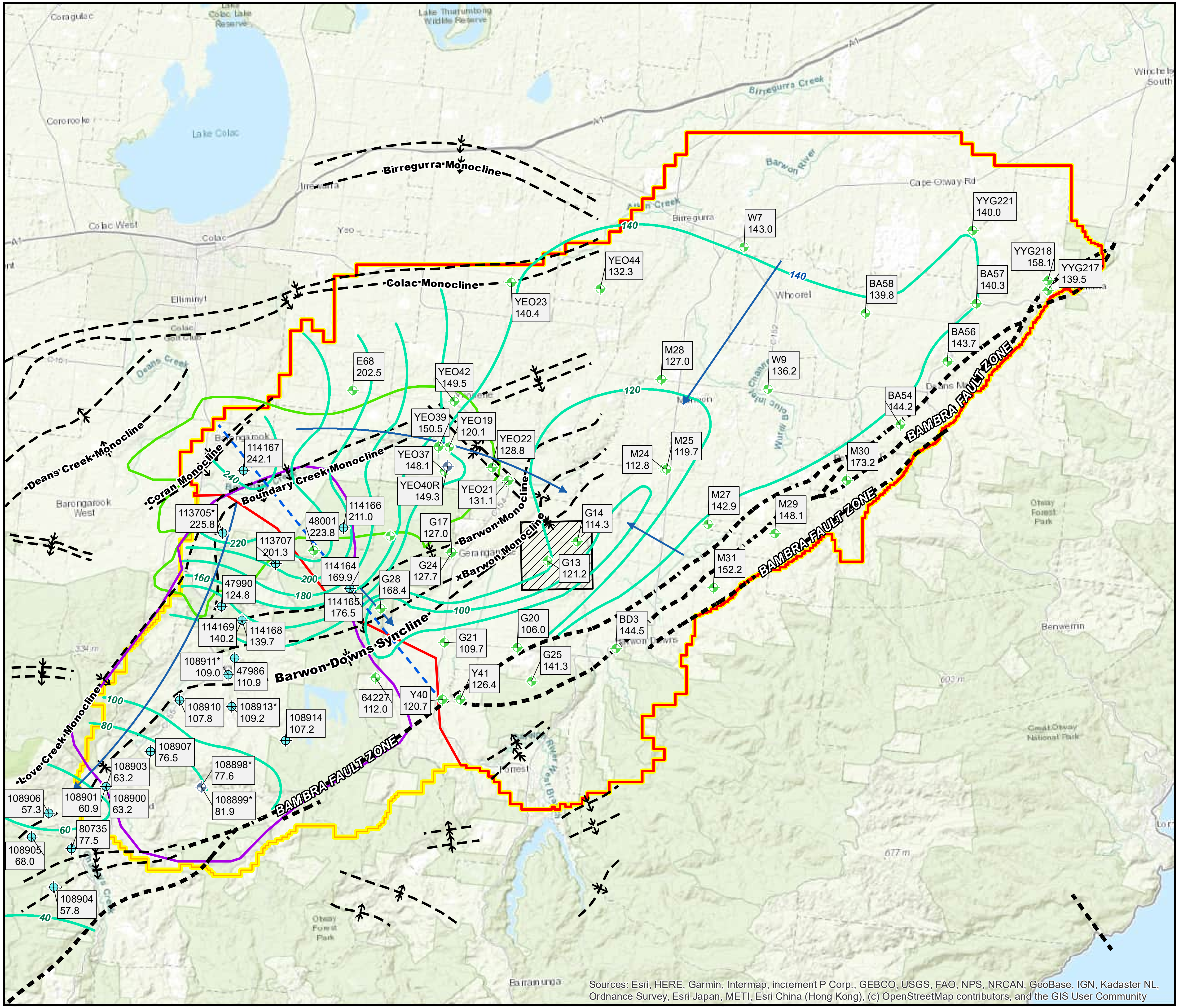
POTENTIOMETRIC SURFACE CONTOURS – LTA AFTER LEONARD, 1983

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F16

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig16_LTA_Leonard.mxd.mxd



PROJECT ID 31155.02
DATE 13/07/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield

Structural Features

- Monocline
- Syncline
- Geological Faults

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD)(May, 2010)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Well ID
RWL mAHD

Note:
* Indicates potentiometric surface value taken from nearest available date to May 2010

N

0 0.95 1.9 2.85 3.8 4.75
Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55

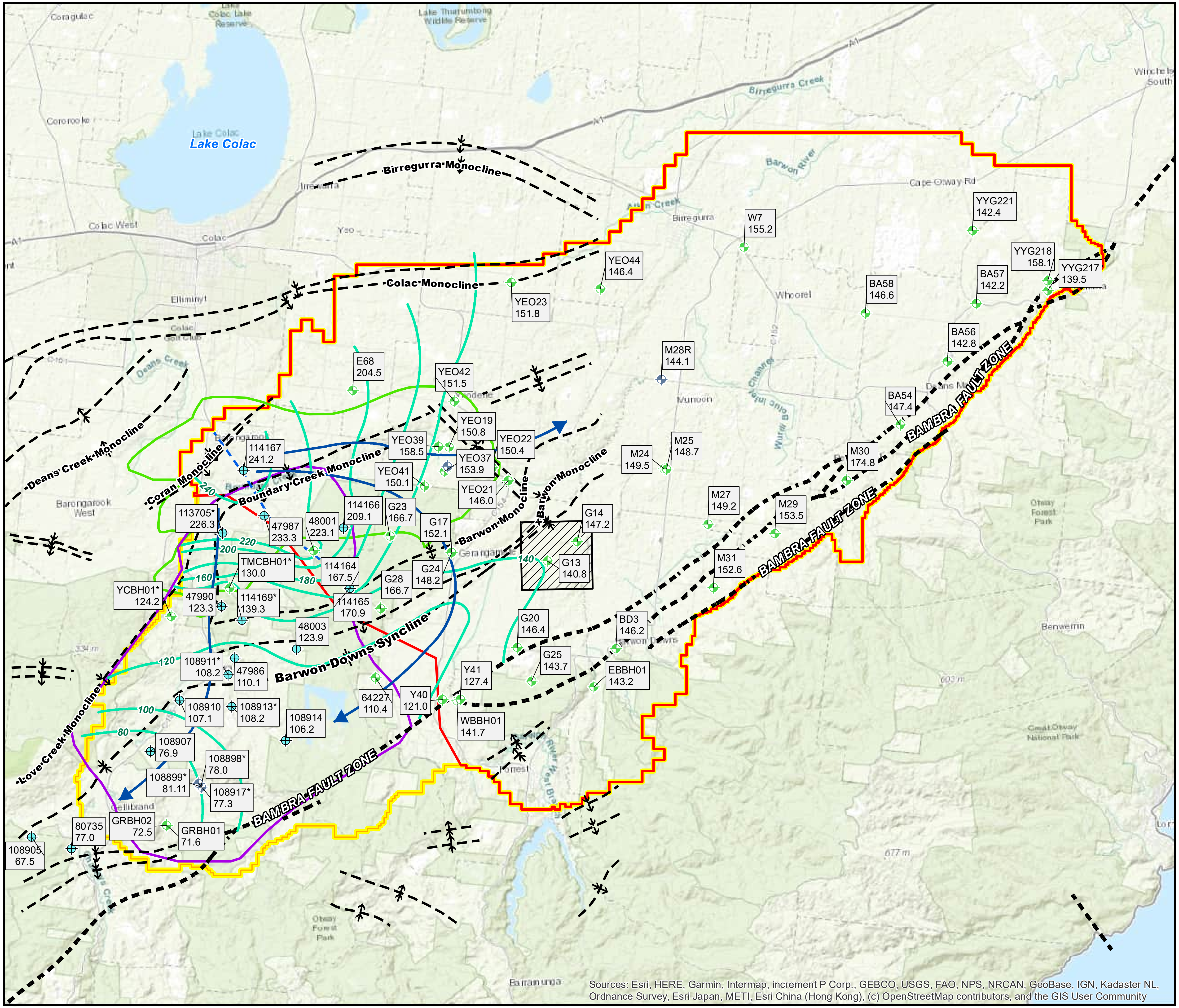
POTENTIOMETRIC SURFACE CONTOURS – LTA (MAY 2010)

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F17

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig17_LTA_Surface_May2010.mxd.mxd



PROJECT ID 31155.02
DATE 13/07/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield

Structural Features

- Monocline
- Syncline
- Geological Faults

Barwon Water Monitoring Assets

- Groundwater Observation Bores
- Groundwater Monitoring Bore

WMIS Groundwater Bores

- Observation
- LTA Potentiometric Surface (m AHD)(May, 2022)
- Inferred Groundwater Flow Direction
- Groundwater Divide

Well ID
RWL mAHD

Note:
* Indicates potentiometric surface value taken from nearest available date to May 2022

N

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Kilometres
1:130,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

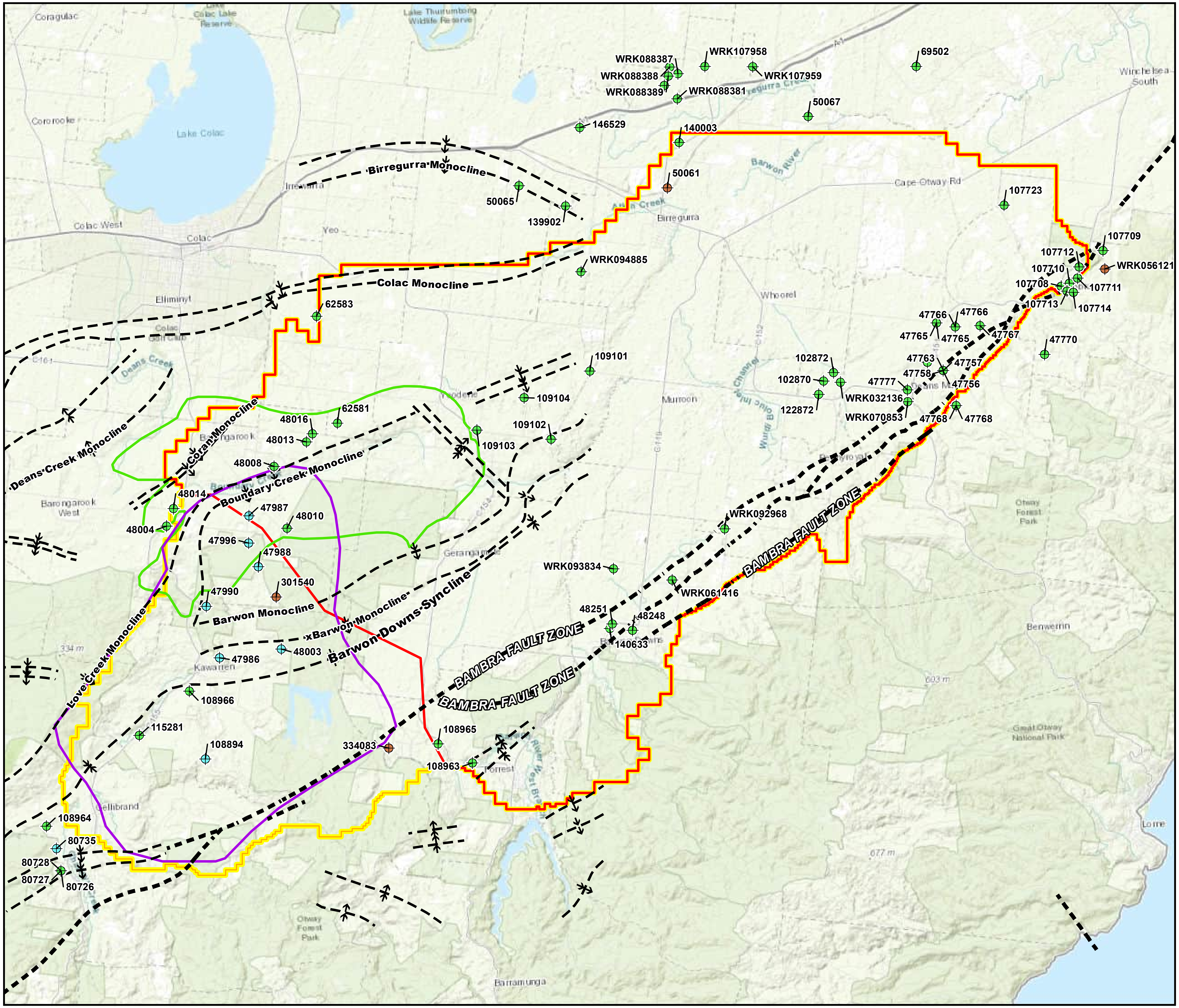
POTENTIOMETRIC SURFACE CONTOURS – LTA (MAY 2022)

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F18

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig18_LTA_Surface_May2022.mxd.mxd



PROJECT ID 31155.02
DATE 13/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Kawarren Sub-basin Investigation Area (approx. extent)
- Surrounding Environment Investigation Area
- Approximate Area of Barongarook High (Intake areas)

Structural Features

- Monocline
- Syncline
- Geological Faults

Registered or Licenced Groundwater Bores

- Domestic/Stock
- Non Groundwater
- Observation
- Unknown

N

0 1 2 3 4 5

Kilometres

1:130,000 when printed at A3

GDA 1994 MGA Zone 55

Imagery: Nearmap 19/02/2022

REGISTERED EXTRACTIVE USE BORES

Hydrogeological Assessment - Barwon Downs Sub-basin

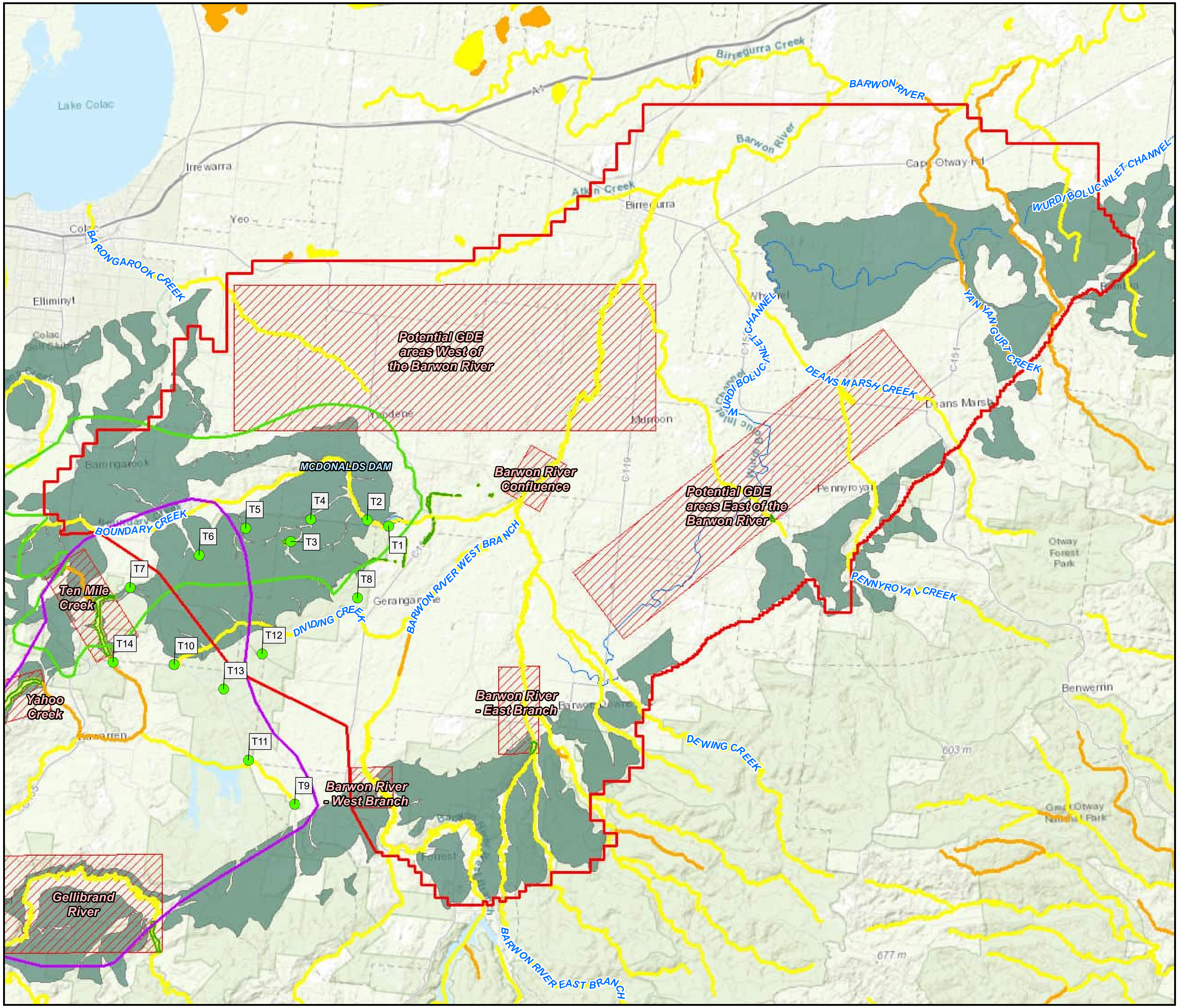
Barwon Downs Sub-basin Area

Barwon Water

Figure

F19

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig19_ExtractionBores.mxd.mxd



PROJECT ID 31155.02
DATE 13/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Approximate Area of Barongarook High (Intake areas)
- Approximate Extent of Kawarren Sub-basin
- Watercourse

Validated Vegetation

- Native - remnant

GDE Likelihood of Vegetation

- High

Likelihood of Groundwater Interaction (DELWP 2018b)

- High
- Moderate
- LTA Outcrops - Expected LTA Recharge
- Vegetation Transect Points (Jacobs, 2015)

Service Layer Credits: 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 Bureau of Meteorology, Geoscience Australia and State/Territory lead water agencies.

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Metres

1:110,000 when printed at A3

GDA 1994 MGA Zone 55

Imagery: Nearmap 19/02/2022

GROUNDWATER DEPENDENT ECOSYSTEMS - BARWON RIVER WEST BRANCH

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F20

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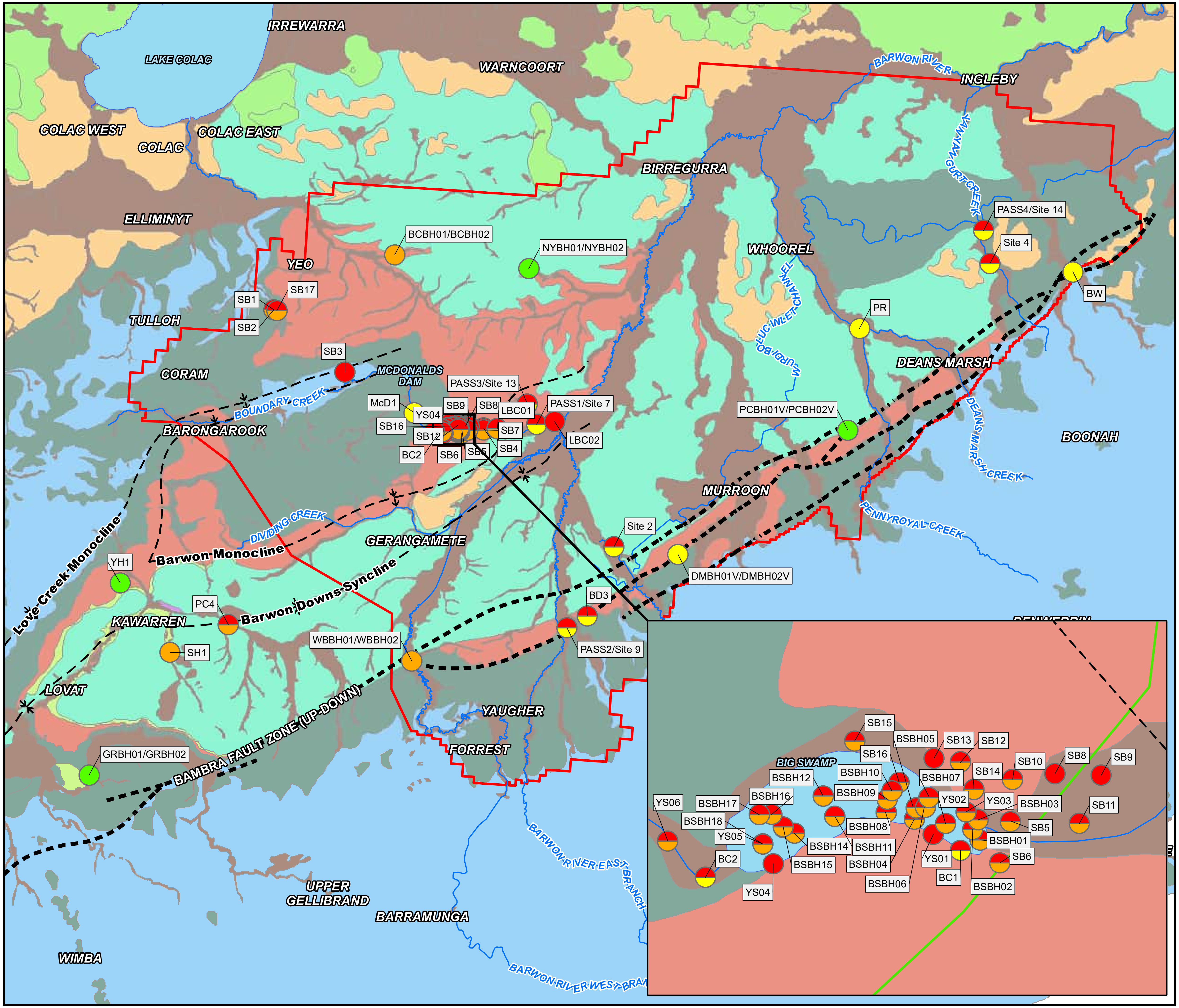

PROJECT ID 31155.02
DATE 15/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Watercourse

Structural Features

- Monocline
- Syncline
- Geological Faults

Acid Sulfate Soil Sampling Locations (Barwon Water)

ASS Classification

- Actual ASS
- Potential ASS
- Possible ASS
- Not identified

Surface Geology (1:50,000) (DELWP)

- Quaternary Sediments
- Newer Volcanics
- Sandringham Sandstone
- Gellibrand Marl Formation } Heytesbury Group
- Clifton Formation } Heytesbury Group
- Older Volcanics
- Narrawaturk Marl (Nirranda Group)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn, Eastern View and Mepunga Formations)
- Otway Group

Note: Modified surface geology nomenclature.
Possible acid sulfate soil identified from field indicators indicative of acid sulfate soils, however follow up laboratory analysis to confirm presence was not undertaken

N

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Kilometres
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Imagery: Nearmap 19/02/2022

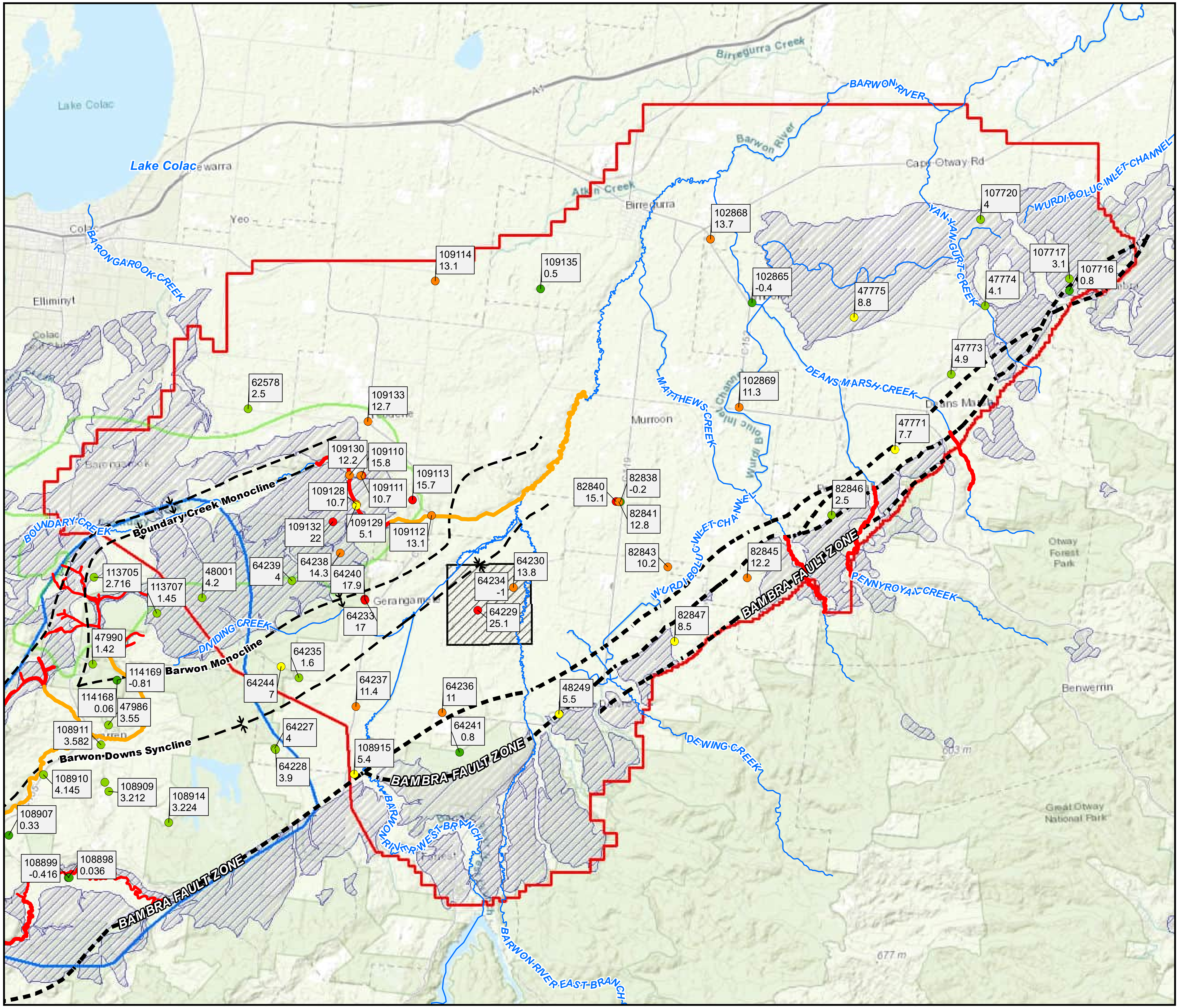
ACID SULFATE SOILS DISTRIBUTION

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F21

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig21_ASS.mxd.mxd



PROJECT ID 31155.02
DATE 16/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Approximate Extent of Kawarren Sub-basin
- Approximate Area of Barongarook High (Intake areas)
- Barwon Downs Borefield
- LTA (Pebble Point, Dilywn, Eastern View and Mepunga Sands Formations)
- Primary Susceptible Water Features
- Secondary Susceptible Water Features
- Watercourse

Structural Features

- Monocline
- Syncline
- Geological Faults

Water Level Change (Nov 1997 - Nov 2013)

- < 1m
- 1m - 5m
- 5m - 10m
- 10m - 15m
- > 15m

Site Code
Change in WL (Nov 1997-Nov2013)

N

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Kilometres
1:110,000 when printed at A3
GDA 1994 MGA Zone 55
Imagery: Nearmap 19/02/2022

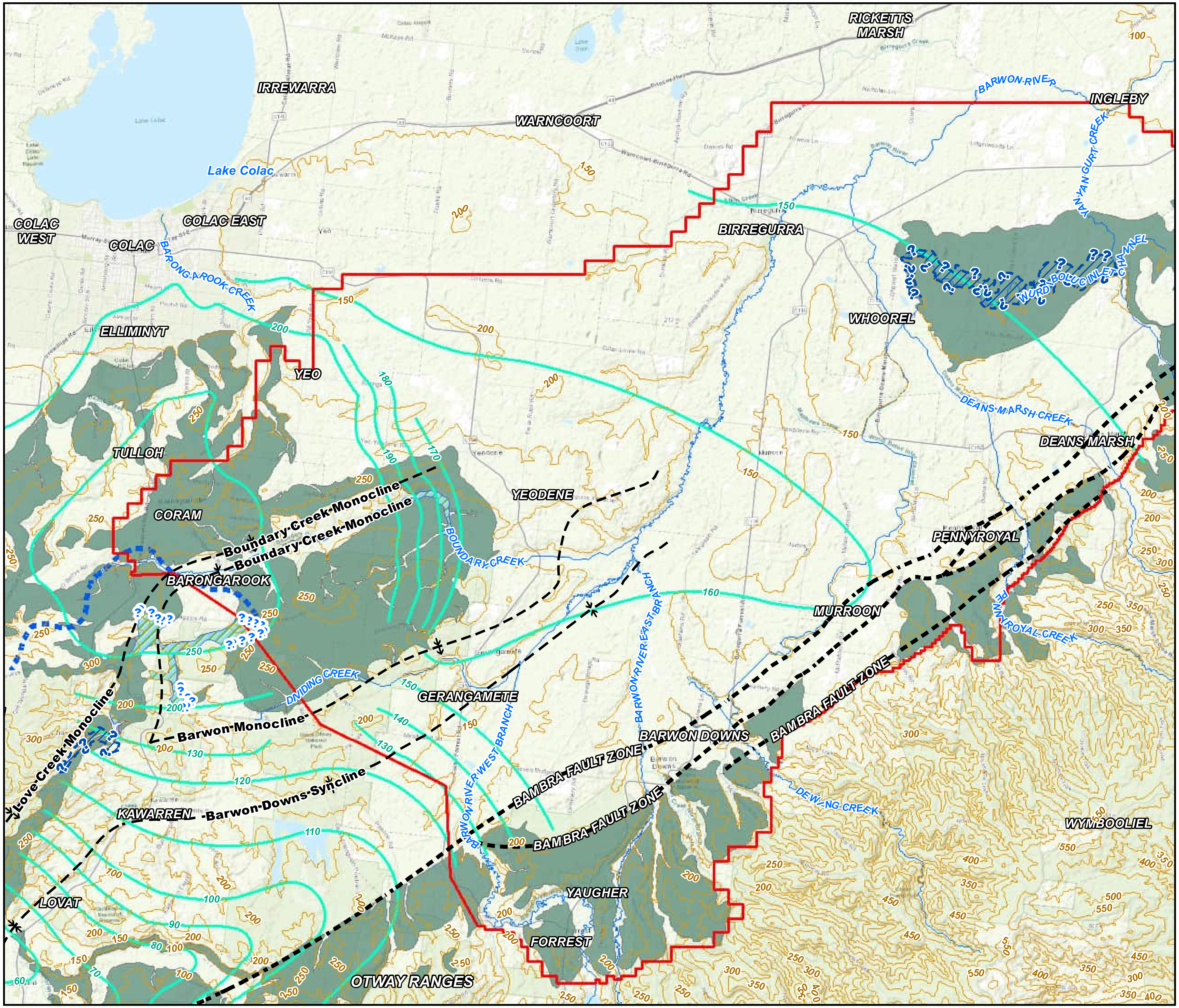
WATER LEVEL CHANGE IN BARWON DOWNS SUB-BASIN INVESTIGATION AREA: 1997 - 2013

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F22

G:\BlueSphere\Projects\31155_BW_LovesCreek\01\31155_02_Fig22_WaterLevel.mxd.mxd



PROJECT ID 31155.01
DATE 5/06/2023
CREATED BY AF

BlueSphere ENVIRONMENTAL

Legend

- Approximate Extent of Barwon Downs Sub-basin Investigation Area
- Expected Groundwater Discharge (LTA)
- Expected Groundwater Discharge (LTA) (Low certainty as to extent)
- LTA Outcrops - Expected LTA Recharge
- Regional Elevation Contours (mAHD)
- Watercourse
- LTA Potentiometric Surface (m AHD) (Leonard, 1983)
- Groundwater Divide

Structual Features

- Monocline
- Syncline
- Geological Faults

Service Layer Credits: 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

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Kilometres
1:100,000 when printed at A3
GDA 1994 MGA Zone 55

EXPECTED RECHARGE AND DISCHARGE AREAS - LTA

Hydrogeological Assessment - Barwon Downs Sub-basin

Barwon Downs Sub-basin Area
Barwon Water

Figure
F23

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Appendix A

Section 78 Notice

Southern Rural Water
Managing Water. Serving Communities.

MINISTERIAL NOTICE

Issued pursuant to Section 78 of the Water Act 1989

Issued to:	Barwon Region Water Corporation (Barwon Water)
Property Address (the Property):	

BW asset name	Bore ID	Address
GW4	64248	Dewing Bridge Road, Gerangamete VIC 3243
GW2a	64246	Dewing Bridge Road, Gerangamete VIC 3243
GW6	S56301/01	Dewing Bridge Road, Gerangamete VIC 3243
GW5	64245	Dewing Bridge Road, Gerangamete VIC 3243
GW8	S56301/02	Dewing Bridge Road, Gerangamete VIC 3243
GW3	64247	Dewing Bridge Road, Gerangamete VIC 3243

Property Description:	Gerangamete Groundwater Field
Licence Number:	BEE032496
Legal Reference:	*Water Act 1989* (Vic) s.78

Trevor McDevitt (Delegate)
Manager Applications
Groundwater & Rivers

11/9/2018.
Date Notice Issued

Preamble

Who we are: Southern Rural Water (SRW) is a government-owned statutory Corporation, governed by a skill based Board appointed by the Minister for Water as outlined in "Water Corporations and Former Water Authorities" outlined in Column 1 Schedule 1 of the *Water Act 1989* (Vic).

Our purpose: The Groundwater & Rivers Group within SRW services over 8,000 groundwater and river users across southern Victoria in a region stretching from the SA border to the NSW border south of the Dividing Range. This function includes managing licences and ensuring compliance to protect the resource, the environment and other users as outlined in the purposes of the *Water Act 1989* (Vic).

Why we serve Section 78 directions: SRW is acting as a delegate of the Minister for Water. The Minister for Water may, by notice in writing direct the occupier of any works on a waterway or of a bore-

- To operate or alter those works in compliance with the conditions specified in the notice;
- To take measures specified in the notice; being measures that the Minister thinks necessary to protect the environment, including the riverine and riparian environment

What happens if you do not comply: The occupier of works or of a bore must comply with any direction given under section 78. Penalty provisions are described in Section 3 of this notice.

What to do if you need more time: Make a formal request to SRW giving reasons for any extension and providing at least 7 days notice prior to the compliance date.

What are your appeal rights: If you feel you are affected by a decision under the *Water Act 1989* (Vic) an application for review of the decision can be made to the Victorian Civil and Administrative Tribunal (VCAT) within 28 days of receipt of the decision.

Southern Rural Water

Managing Water. Serving Communities.

Notice structure

1. Background and reasoning

This section outlines background and reasoning that led to the issuing of the s78 notice.

2. Requirements of the notice

Considering the view that has been formed, this section lists the requirements or actions to address the environmental risk(s) or impact(s).

3. Penalty Provisions

Outlines the penalty provisions should there be failure to comply.

1. Background and reasoning

1.1 The Minister for Water, the Hon Lisa Neville wrote to SRW on 7 August 2018 requiring SRW, as a delegate, issue a notice (under Section 78 of the *Water Act 1989* (Vic)) requiring Barwon Water to:

a) continue no extraction, other than for maintenance and emergency response, and
b) prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and
c) describe the environmental outcomes for the waterways to be achieved by the remediation plan.

1.2 It is acknowledged that:

a) Barwon Water has operated the Barwon Downs Borefield under groundwater extraction licence BEE032496. Barwon Water has undertaken a monitoring and assessment program over the past six years, with input from a Community Reference Group, to improve the understanding of the impacts of operation of the borefield.
b) Barwon Water has been working to address confirmed impacts and has commenced the development of a remediation plan for Boundary Creek and Big Swamp with input from community, stakeholders and independent technical experts nominated by the community and stakeholders.

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

1.4 A further report commissioned by Barwon Water titled "*2016-2017 Technical Works Program Yeodene Swamp Study*" (Jacobs, November 2017) found that the current groundwater licence condition requiring the release of the 2 ML/d of supplementary flow into Boundary Creek has not been effective at offsetting the impacts of operation of the borefield on groundwater base flows in Boundary Creek.

1.5 This led to the swamp drying, acid sulphate soils being generated and the release of acid water downstream of the swamp and impacting the downstream environment.

1.6 On this basis, and considering the observations previously stated, I have formed a view and I am satisfied that a process or activity which is being/or has been carried out at the property has caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment and legal enforcement of protective works is required under s78(1).

2. Requirements of the notice

Barwon Water must undertake the following requirements.

2.1 Barwon Water must not extract from the works for any purpose other than maintenance or emergency access until this notice is rescinded (as defined by the requirements outlined in section 2.11 of this notice).

For the purpose of this notice, emergency access is defined as circumstances resulting in the need for Barwon Water to declare a water shortage under s33AAA of the Water Act 1989. Under these circumstances Barwon Water should notify SRW of their intention to make this application to the Minister.

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

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

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

2.5 By 20 December 2019 Barwon Water must submit to SRW the Plan which includes:

a) A description of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environment; this will include:
   - Hydrogeological conditions (groundwater levels and quality)
   - Hydrology (Surface water quality and flow monitoring)
   - Ecological assessment
   - LIDAR topographic mapping
   - Results of soil sampling program (Soil chemistry, peat profile, incubation tests)
   - Additional matters arising from the scope contemplated in Item 2.4.

b) An outline and risk assessment of the processes/activities on the Property which may impact on Boundary Creek, Big Swamp and the surrounding environment (including, but not limited to hydrogeology, hydrology and soil chemistry);
c) A range of controls and actions that could be practicably carried out to protect and improve the condition of Boundary Creek and Big Swamp and the surrounding environment, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;
d) A comprehensive risk assessment of proposed controls and actions documented in c);
e) The controls and actions to be implemented, including reasonable targets and/or measures of success to be adopted for the purposes of the implementation of the Plan;
f) A monitoring program to check the controls and actions documented in e);
g) Contingency measures designed to address any issues identified from monitoring results;
h) A schedule of timeframes by which the controls and actions documented in e) will be carried out; and
i) A reporting schedule, whereby Barwon Water will provide a minimum of quarterly updates to SRW which report on the progress of the Plan, as well as an Annual Report. The Annual Report must be submitted to SRW and made publicly available by 30 September each year.

2.6 In preparing both the scope of works and the Plan, Barwon Water must:
a) Identify all appropriate hydrogeological, hydrological and geochemical assessments to support the development of the Plan (during the scope of works process);
b) Carry out appropriate hydrogeological, hydrological and geochemical assessments to support the assumptions, controls, actions and targets described in the scope of works (during the development of the Plan);
c) Provide quarterly updates on progress to SRW;
d) Consult with the Corangamite Catchment Management Authority;
e) Consult with the SRW appointed Expert Reviewer;
f) Engage with the local community to seek their ideas and feedback;
g) Ensure the State Environmental Protection Policy (Victorian Waters) are considered and;
h) Present each of the points in 2.5 under separate headings (in the Plan).

2.7 Barwon Water must submit the scope of works and the Plan prepared in accordance with this notice to SRW for review by the independent expert or panel of experts (Expert Reviewer) appointed by SRW. SRW will consider the advice provided by the Expert Reviewer in order to:
a) Confirm any changes to the Plan that are required to be made by Barwon Water;
b) Confirm and accept the scientific methodology used to prepare the Plan; and
c) Verify and accept the preferred controls and actions presented in the Plan.

2.8 If requested under Section 2.7(a), Barwon Water shall update the Plan and resubmit it under Section 2.7 for review by the Expert Reviewer appointed by SRW. Note that this resubmission process can occur on more than one occasion until it is accepted by SRW under Section 2.9.

2.9 Upon acceptance of the Plan by SRW, Barwon Water must finalise the Plan (Including any changes required by SRW) by 1 March 2020 and implement the Plan. Nothing in this clause prevents earlier implementation.

2.10 Timelines may be varied by SRW, at our discretion or upon request, in order to achieve compliance with the nominated objectives.

2.11 This notice will remain in effect until such time that Barwon Water can demonstrate to the satisfaction of SRW that the Plan has been implemented and the measures and outcomes have been achieved as outlined in section 2.5.

2.12 Further to Section 2.11 in order to resume extracting groundwater pursuant to the conditions on Licence Number BEE032496 Barwon Water must:

a) seek express written permission from SRW; and

b) provide sufficient scientific evidence to support the request.

3. Penalty Provisions

3.1 Failure to comply with this notice is an offence – 20 penalty units, calculated at the time of the offence.

3.2 If you fail to comply with this direction the Minister may arrange to carry out the works and recover costs from the occupier.

Appendix B

Report Reviews

Item	Details
Ministerial Notice, Issued pursuant to Section 78 of the Water Act 1989, Licence Number: BEE032496, 11 September 2018	
Scope of Work	N/A
Key Findings	On 7 August 2018 the notice was issued requiring Barwon Water to: *a) Continue no extraction, other than for maintenance and emergency response, and* *b) Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and* c) *Describe the environmental outcomes for the waterways to be achieved by the remediation plan.* • A report (Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts, Jacobs June, 2017) found that the operation of the borefield over 30 years was responsible for 2/3 of the reduction of groundwater base flow into Boundary Creek. • An additional report (2016-2017 Technical Works Program Yeodene Swamp Study, Jacobs, November 2017) indicated the licence condition requiring the release of 2 ML/d of supplementary flow into Boundary Creek had not been effective at off setting the impacts of the borefield operation on groundwater base flows in Boundary Creek. This resulted in the creek drying out, generation of acid sulfate soils and release of acid water into downstream systems. • SRW (acting on behalf of the Minister) formed the view that the borefield had caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment. • Barwon Water was required to prepare and implement the '*Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan*'. Which was to (among others) include: – Identification of appropriate hydrogeological, hydrological and geochemical assessments to support the plan; – Consult with CCMA; – Consult with SRW appointed expert reviewer; and – Engage with the local community and seek ideas and feedback. • The notice remains in effect until Barwon Water can demonstrate to satisfaction of SRW that the plan has been implemented and measures and outcomes (per Section 2.5 of the document) have been achieved.
Barwon Water, 2019, Boundary Creek, Big Swamp and surrounding environment – Remediation and Environmental Protection Plan, December 2019	
Scope of Work	Preparation of REPP to address and meet the requirements of the section 78 Ministerial Notice.
Key Findings	The following findings were noted regarding Boundary Creek and Big Swamp. • Barwon Water was issued with a groundwater extraction license in 1975. Groundwater extraction did not occur until 1982. The borefield was used intermittently to supplement water supply during dry periods between 1982 and 2016. Pumping primarily between 1998-1989, 1997 – 2001, 2005 – 2010 and 2016 – 2017. ~119,000 ML extracted from borefield between 1982 and 2016/17. • Licence renewal process in 2002. Amended in 2004 to accommodate environmental provisions such as release of 2 ML/day of supplementary flows. • 2017 Barwon Water acknowledged groundwater pumping activities had resulted in environmentally significant impacts to the Boundary Creek catchment. BW withdrew application to extend groundwater extraction licence.

Item	Details
	• May 2018 a community and stakeholder working group was established by Barwon Water to participate in the development of the REPP. • Two objectives working in parallel: – Boundary Creek & Big Swamp RP – address remediation of confirmed impact in Boundary Creek Catchment. – Surrounding Environment Investigation – to investigate if other areas within regional groundwater system have been impacted by extraction. • Permissive Consumptive Volume set for Gerangamete and Gellibrand Groundwater Management Areas by Minister for Water. • Numerical groundwater model initially developed in 1994 by BW which has evolved. 2019 the model was used to assess historical impacts of pumping and identify potential high risk areas. The layers modelled included: Layer 1: Gellibrand Marl; Layer 2: Clifton Formation; Layer 3: Narrawaturk Marl; Layer 4: Dilwyn Formation; Layer 5: Pember Mudstone; Layer 6: Pebble Point Formation; Layer 7: Basement. Model had a Scaled Root Mean Square error of 4.9%. • Resulted in identifying eight high risk areas: – Boundary Creek b/w McDonalds Dam and Big Swamp; – Barwon River (East branch); – Barwon River (downstream of the confluence); – Gellibrand River and associated GDEs; – Ten Mile Creek; – Yahoo Creek; – GDEs west of the Barwon River (near Yeodene); and – GDEs east of the Barwon River (b/w Barwon Downs and Yeodene). • Big Swamp is also known as Yeodene Swamp covers an area of ~11 hectares and is understood to be a GDE. • Boundary Creek was divided into three reaches as shown on Figure 6 (Barwon Water, 2019). Reach 1 includes a private dam on-stream (160 ML) constructed in 1979. Reach 2 downstream of the private dam and the end of Big Swamp. Reach 3 is downstream of Big Swamp to the confluence of Boundary Creek and Barwon River. • Investigations have confirmed that drawdown associated with pumping from the Barwon Downs borefield was the main cause of reduction of stream flows within Boundary Creek and Big Swamp. This resulted in a reduction of surface water and groundwater interaction, evaporation and dewatering of Big Swamp and Boundary Creek and oxidation of naturally occurring acid sulfate soils. Reaches 2a, 2b and 2c of Boundary Creek Catchment are only areas at this stage that have shown impacts. • The pumping of groundwater from the borefield contributed to the frequency and duration of no flow periods in Boundary Creek, further the passing flow conditions was not managed effectively. Overall the impacts identified (focus of REPP) were reduction in surface water/groundwater levels; increased occurrence of 'no flow' events; progressive loss of wetland species and increase of other vegetation classes; and oxidation of naturally occurring Acid Sulfate Soil (ASS) (see Figure 8 from (Barwon Water, 2019)). • Remedial actions for Boundary Creek and Big Swamp included: – Cessation of groundwater pumping in LTA; – Use of supplementary flows to maintain minimum flow of 0.5 ML/day in Reach 3 of Boundary Creek; – Construction of hydraulic barriers to distribute flows across swamp to prevent wet-dry cycling; – Infilling of fire trenches and agricultural drain to allow swamp to retain more water over winter months; and

Item	Details
	– Prevent encroachment of dry vegetation classes (e.g. Swamp Gump in the Big Swamp area. • Monitoring plan in Appendix A of REPP. • Investigating approaches to neutralise pH and remove metal and acidity loads including Upstream treatment option involving a semi-passive treatment system using caustic magnesia rock to increase soluble alkalinity; and Downstream treatment option using a sodium hydroxide dosing plant. Completed Surrounding Environment Investigation findings: • Limited data sets for each of the 8 areas. • Information gaps: – *Has historic groundwater pumping activities caused a reduction in baseflow to rivers from the Lower Tertiary Aquifer system (either directly or indirectly)? If so, how much and is it significant?* – *Has historic groundwater pumping caused a decline in water levels in areas where there are high value GDEs? And if so, how much and is it significant?* • Installation of site specific monitoring assets including 212 groundwater bores, 5 stream gauges and 6 new vegetation monitoring sites. • Outcomes of the Surrounding Environment Investigation provided to SRW by 31 July 2023. Technical Response to Notice: • Climatic setting indicates several periods of drought. • High modification of land use in the Boundary Creek catchment has occurred. • Main stratigraphic groups in the area are: – Quaternary sediments; – Sandringham Sandstone; – Heytesbury Group; – Demons Bluff Group; – Nirranda Group (Narrawaturk Marl; Mepunga Fm); – Wangerrip Group (Dilwyn Fm, Eastern View Fm; Wiridjil Gravel; Moomowroong Sand; Pebble Point Fm) and – Otway Group. • Key Aquifers: – Upper Aquifer system (Quaternary alluvium; Sandringham Sandstone; Gellibrand Marl & Clifton Fm); – Lower mid-Tertiary Aquitard: (Demons Bluff Group & Narrawaturk Marl); – Lower Tertiary Aquifer (Mepunga Fm & Wangerrip Group – primarily Mepunga, Dilwyn and Pebble Point formations; and – Basement (Otway Group). • Water levels in Reach 2a and Reach 2b of Boundary Creek (underlain by LTA) dropped by up to 14.7 m b/w 1987 and 2012. • Model considered to overestimate losses associated with impact of pumping. • Aquifer properties of bores installed in and around Big Swamp presented in Table 13 of REPP. • Acid sulfate soils within Big Swamp are variable. Elevated concentrations of existing acidity are relatively high in the upper soil profile (2 m >0.5%) while the potential acidity are low (0.1%S) in the upper profile but increase with depth (>2%S below 1.5 m). Table 15 in REPP provides potential acidity with depth of soils from installed groundwater bores.

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<tr><th>Item</th><th>Details</th></tr>
<tr><td></td><td>Big Swamp has had a significant reduction/change in vegetation cover and type over the past 30 years.</td></tr>
<tr><td colspan="2">Blake, W.J.R., 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area (unpublished)</td></tr>
<tr><td>Scope</td><td>Study of the groundwater resources of the Otway Ranges.
Study of the recharge areas of the Lower Tertiary Aquifers on flanks of the Otway Ranges to potentially develop the area as a water supply supplement for Geelong Waterworks and Sewerage Trust (now Barwon Water).
Works included:
Drilling bores for both stratigraphic and hydrogeologic purposes (15 bores); and
Interpretation of magnetic, gravity and seismic data.</td></tr>
<tr><td>Key Findings</td><td>Barwon Downs basin is the area between the Otway uplifted block and the Barongarook uplifted block in the eastern end of the Otway Basin. The Otway basin is delineated by a series of North-East/South-West trending faults.
Barwon Downs graben has a sediment thickness (based on gravity data) of approximately 12,000’ (~3,658 m). Faulting took place while sediments were being deposited.
Four sedimentary cycles occurred between Upper Cretaceous to Middle Miocene. First two characterised by quartz-clastic, deltaic sedimentation separated by a marine transgression in the middle Paleocene (i.e. Wangerrip Group). Third and fourth characterised by limestone-marl shelf deposition, separated by a minor regression-transgression in upper Oligocene (ie. Nirranda Group and Heytesbury Group.
Pebble Point Formation (upper cretaceous deltaic sediments) absent in Barwon Downs.
Barwon Downs basin ~196 square miles, with approximately 46 sq. miles identified as intake or potential intake area – defined by outcrop of Dilwyn Formation. ~150 sq. miles is the estimated area of confined aquifer.
The Dilwyn Formation was considered main aquifer, within the sands. Sands are described as fine to medium grained, poorly to moderately sorted with moderate permeability (based on pump test). Thickest section of Dilwyn Fm. encountered at Yeo 16 bore (~600’ / 183 m), with coarser sands than at Barwon Downs graben. Dilwyn Fm thicker on north western edge of graben than on south eastern edge.
Mepunga Formation – unlikely to exceed 100’ (30.5 m) thickness.
Main recharge (intake) area was on Barongarook High where Dilwyn Fm outcrops, in areas where sands outcropped. Dilwyn Fm also comprised of silts, ligneous clays, clays and minor coals.
Recharge also occurs along southern edge of graben from Barwon downs – Forrest area to Gellibrand.
Groundwater flows in two directions:
Southwest to Gellibrand River.
East and north east towards Bambra Fault
Estimated to be ~4 mill. gals/day flowing through aquifer in SW direction. Estimated to be 1-2 mill.gals/day flowing through aquifer in north /north east direction.
Salinity of GW in Dilwyn Fm ranged between 250 mg/L – 350 mg/L. Total iron concentration ~20 mg/L (although samples sat for several weeks before analysis).
Mepunga Fm salinity ~201 mg/L, iron ~34 mg/L.</td></tr>
<tr><td colspan="2">Leonard, J.G., Lakey, R.C., and Blake, W.R., 1983, Hydrogeological Investigation and Assessment, Barwon Downs Graben, Otway Basin, Victoria, Unpublished.</td></tr>
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<tr><td>Scope</td><td></td></tr>
<tr><td>Key Findings</td><td>
Seismic and gravity data indicated the Otway Group basement is block faulted and tilted to form half grabens. Some faults extend subsurface. The faults are often expressed as monoclines. The Barwon Downs Graben contains major aquifers.
Major aquifers occur in basal Tertiary units including Pebble Point, Dilwyn and Mepunga Formations. Pebble Point Fm is confined between the Otway Grp and Pember Mudstone.
Dilwyn and Mepunga Formations considered to be in direct connection and referred to as one aquifer. Vary between confined to semi-confined aquifer. Unconfined where it outcrops at Barongarook High.
Drill findings indicated presence of valley like features either side of the Yeo Dome. Valleys have been infilled by Tertiary aged sediments. On the western side of the Yeo Dome, the valley runs approximately south-north from Kawarren to Barongarook (identified as Kawarren recharge avenue). Considered to provide important recharge pathways from outcropping of aquifer on Barongarook High to the confined aquifer system.
Potentiometric surface for the TA showed the outcrops of Dilwyn Fm acted as a recharge area. Groundwater flows to the south west from the Barongarook High towards Gellibrand River.
Estimations indicated ~14,800 ML/annum flow off the Barongarook High into the TA in Barwon Downs Graben, split Kawarren recharge avenue ~8,500 ML and Yeodene recharge avenue (6,300 ML). Combined the recharge avenues provide ~12,000 ML/annum of recharge to Gellibrand River Catchment.
Effective infiltration rate of 27.4 cm/annum on the Barongarook High was considered too high a rate. Works indicated a structural or stratigraphic barrier within Barwon Downs graben between the borefield and Kawarren which reduced the south-westerly flow from the Yeodene recharge area.
Elastic storage calculated to be ~15,000 ML.
Unconfined storage calculated to be ~5,920,000 ML.
Additional sources of recharge (outside of Barongarook High) to borefield after development included:

Enhanced natural recharge as a result of lowered water levels;
Induced stream bed infiltration as water levels fall below stream level;
Leakage form overlying marl members;
Leakage from clay and silt layers within the TA;
Leakage from Otway Group rocks underlying and flanking grabens; and
Natural recharge from possible (not delineated) recharge zones along Bambra Fault and other structures.

Pumping of borefield projected to start February 1983. Consisted of three bores, combined daily extraction of 35 ML. with a maximum of 12,500 ML in any one year and up to 80,000 ML over a 10 year period.
A second borefield proposed/under consideration pending further pumping test results.
If recharge calculations were correct the annual extraction allowance would exceed the recharge from Yeodene recharge avenue.
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<tr><td colspan="2">Lakey 1983, GSV Gellibrand Groundwater Investigation – Kawarren Pumping Test Report</td></tr>
<tr><td>Scope</td><td>Pumping test on Yaugher 51 bore to determine hydraulic characteristics of Dilwyn Formation and Mepunga Formation to inform possible construction of borefield in Kawarren area.</td></tr>
<tr><td>Key Findings</td><td>Yaugher 51 bore not installed within the Pebble Point Formation.</td></tr>
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Both Dilwyn and Mepunga Formations were found to not comprise a homogeneous aquifer. Slow and incomplete recovery considered due to ‘partial and permanent collapse of aquifer skeleton resulting from depressurising the system from its pristine and possibly slightly over-pressured system’. Similar residual drawdowns observed in Barwon Downs borefield – potentially due to same issue.
An area of concern in relation to the development of a borefield in the Kawarren area was the impact of reduced water levels on stream flow in Ten Mile Creek and Yahoo Creek, and discharge on the natural springs in the area. Many springs in Kawarren area are fed by the Clifton Formation.
Pumping test indicated that drawdowns will initially stabilise upon recharge from the Gellibrand River and reduction in unconfined storage on the Barongarook high. If pumping exceeds the mean annual recharge of the aquifer then substantial of the unconfined aquifer and further reduction of the confined aquifer storage was considered likely to occur. Although this could be offset by increased streambed infiltration from Gellibrand River.
Recommended installation of stream gauges on Yahoo and Ten Mile Creeks, comprehensive survey of springs in the area and completion of additional pumping tests.
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<tr><th colspan="2">Gellibrand Groundwater Investigation – Stage II Report – August 1983, R Lakey & J Leonard (PDF pg 35 of (Lakey R. , 1984)</th></tr>
<tr><td>Scope</td><td>Draws together all geological and hydrogeological information form investigations completed along western flanks of the Otway Ranges.

Investigations completed included geological mapping, geophysical surveys, borehole drilling, wireline logging, aquifer tests, water level monitoring and water quality analysis.</td></tr>
<tr><td>Key Findings</td><td>
Determined that there is a faulted contact between the Tertiary sediments and the basement rock (Otway Group).
The Barwon Downs graben pinches out to the south west around Bunker Hill. The graben deepens in the Gellibrand-Kawarren East area due to half grabens associated with Loves Creek and Kawarren Faults (referred to as Gellibrand Depression). Gellibrand Depression forms a corridor which provides interconnection between the Tertiary sediments in the Barwon Downs and Gellibrand areas.
Pebble Point Formation is divided into a lower shaley unit and an upper sandy unit based on gamma ray log interpretation.
Pember Mudstone overlies the Pebble Point Fm. Dominant carbonaceous muds are considered a sub-unit of Dilwyn Fm.
Considered to be vertical leakage given hydraulic head of Pebble Point Fm higher than the Dilwyn-Mepunga Fms.
Basal Tertiary Aquifer (Pebble Point, Dilwyn and Mepunga Fms) thickest along toe of Barwon and Loves Creek faults. Thickest (324m) of the Tertiary aquifer at bore Yeo 5 (south west of Yeodene).
Main sources of recharge to the aquifer in the Barwon Downs graben are from the Barongarook High via Yeodene to the north east and Yeodene to the south west, via Karwarren. Recharge to the aquifer occurs along all outcrop except the component to the north east which is expected to discharge to the Gellibrand River.
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<tr><th colspan="2">HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area, Kawarren Groundwater Resource Evaluation, May 1994.</th></tr>
<tr><td>Key Findings</td><td>
Investigation into the Kawarren Groundwater sub-basin of Barwon Downs graben considered as an area to construct a borefield.
12 km^2 of the outcropping aquifer material on the Barongarook High acts as a recharge area (out of 28 km^2 outcropping area total).
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<tr><td></td><td>Groundwater primarily moves through a narrow paleo-valley extending northwards from the extracting site at Kawarren towards Barongarook. Approximately 1.5 km wide and 5 km in length, with a thickness of over 100 m of basal Tertiary Eastern View Formation Sediments.
Prominent groundwater divide controls groundwater flow from Barongarook High into the Barwon Downs graben. Local discharge occurs to streams draining the high including Boundary and Ten Mile Creeks.
Considered that sustained pumping would result in reduction of water levels across the high, the groundwater divide would shift and the amount of rejected recharge to the surface water systems, streams and springs would decrease.
Further investigation into the environmental significance of the wetlands and stream was recommended to be completed to establish baseline conditions.
Both Boundary Creek and Ten Mile creek identified as gaining streams.</td></tr>
<tr><td colspan="2">Dalhaus Environmental Geology Pty Ltd, 2002, Groundwater Flow Systems of the Corangamite Catchment Management Authority Region, May 2002 (Report No. CCMA 02/02).</td></tr>
<tr><td>Scope</td><td>Corangamite Catchment Management Authority Region identified as a high risk salinity area.
Purpose to the report was to consolidate information based on data and advice from a workshop.</td></tr>
<tr><td>Key Findings</td><td>Wiridjil Gravels considered an intermediate flow system; Dilwyn Fm considered a regional flow system.</td></tr>
<tr><td colspan="2">Petrides, B., Cartwright, I., 2006, The hydrogeology and hydrogeochemistry of the Barwon Downs Graben aquifer, southwestern Victoria, Australia</td></tr>
<tr><td>Key Findings</td><td>Recharge rates to the aquifer were low (based on Carbon 14 age dating) and that the aquifer could be impacted by over extraction.
Localised flow system, lack of regular spatial variation in groundwater chemistry.
Stable isotopic data indicated that groundwater was recharged under similar climatic conditions of the day.
Barongarook High recharges/provides base flow to Boundary Creek and other surface water bodies.
The Clifton Fm and Gellibrand Marl are not hydraulically connected to LTA, however, Narrawaturk Marl shows minor response to borefield pumping indicating it acts as a leaky aquitard.
Carbon dating indicates the resource is not finite, with long groundwater residence times.
Heterogeneous hydraulic conductivities are present in Dilwyn Mepunga and Pebble Point Fm due to discontinuous beds of sand, gravel, silt and clay.
Concluded that groundwater was mainly extracted during periods of low rainfall and most likely the changes to surface water bodies was reflective of the lack of recent rains that lower water tables in near surface systems.</td></tr>
<tr><td colspan="2">SKM, 2012, Newlingrook Groundwater Investigation, Gellibrand River Streambed and Baseflow Assessment, 21 December 2012.</td></tr>
<tr><td>Scope</td><td>Groundwater level data collection;
River elevation and EC collection;
Spring discharge estimates and water quality sampling; and
Surface water and groundwater sampling.</td></tr>
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<tr><td>Key Findings</td><td>

In 2007 Barwon Water was investigating an additional water supply option during a long drought period. One of these was a borefield installed in the Newlingrook Aquifer.
Investigation found that Gellibrand River was highly connected to the groundwater system and was found to be both currently and historically gaining along the reaches studies.
Pumping may induce greater leakage from the Clifton Fm (aquitard) which had potential to impact springs fed from the formation (presumed the report meant Clifton Fm). Springs derived from shallow groundwater and contribute to generation of tributaries to Love Creek (Porcupine Creek, Yahoo Creek, Serpentine Creek, Ten Mile Creek, and others). Other springs derived from the bedrock or LTA (Eastern View Fm in this report) around margins of the basin.
Consideration of other natural influences such as periods of drought and other climatic factors also have the potential to impact groundwater baseflow to the Gellibrand River and other streams.
Recommended a Permissible Consumptive Volume (PCV) be developed for the Gellibrand GMA that takes into account the likely strong connection between groundwater pumping and stream flow.

</td></tr>
<tr><td colspan="2">Aquade, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area (Completed for LAWROC)</td></tr>
<tr><td>Scope</td><td>

Review of previous reports and publicly available information to consider if groundwater extraction at Barwon Downs was affecting groundwater recharge and groundwater flow rates including to creeks in the Kawarren/Gellibrand System.
Consideration if the groundwater divide had moved as a result of the Barwon Downs borefield operation.

</td></tr>
<tr><td>Key Findings</td><td>

The changes in groundwater levels and gradients in the Kawarren sub-basin indicate changes in groundwater flow and resulting changes in flux between streams and groundwater.
The reduction in groundwater discharge rate to Gellibrand River as a result of drawdowns in Kawarren is not considered to be significant. It wasn’t thought to follow that the reduction in groundwater levels in the Kawarren systems has or will have a measurable effect on streamflow in Love Creek catchment. This was due to the very low permeability confining layers that separate the LTA from the surface water system.
In areas where the creeks directly interact with the aquifer and groundwater levels were lowered there was likely to be a reduction in net flux from groundwater to surface water. The Love Creek catchment area was considered to have the greatest potential for significant impact on stream baseflow.
Ten Mile Creek was considered by previous reports to be sourced from springs discharging from the EVF aquifer (LTA).

</td></tr>
<tr><td colspan="2">Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/16 – Recharge Rate Assessment, 16 September 2016.</td></tr>
<tr><td>Scope</td><td>

Objective was to provide estimated recharge rates of LTA in Barwon Downs region.
Adopted tritium method – using natural levels of tritium in water to calculate age of groundwater. Three approaches used: independent estimates at each site; differential estimates between bores; and interface method to identify spike present in natural tritium levels in the 1960s.
Adopted chloride mass balance method.

</td></tr>
<tr><td>Key Findings</td><td>

Results found that the ‘best representation of current/modern recharge to the LTA on the Barongarook High are derived from the application of independent and interface methods’. Modern recharge rates are most likely around 9 – 11% of average annual rainfall in the area of aquifer outcrop.

</td></tr>
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Item	Details
	• Recharge over a longer term was considered to be about half of modern day estimates. • Recommended an updated numerical model use the recharges rates as a starting point for calibration.
Aquade, 2017, Impacts of Barwon Downs Extraction on Groundwater and Surface Water in the Kawarren Area, 27 January 2017 (prepared for LAWROC).	
Scope	• Updated previous report (Aquade, 2014) incorporating additional groundwater data. • Estimated the baseline flux through Kawarren sub-basin and into Gellibrand River. • Assessment of whether there is evidence from creek flows of a reduction in baseflow in Love Creek. • Consideration of whether there is potential for increased impacts including cease to flow of Love Creek due to future extraction from the borefield.
Key Findings	• The Barwon Downs graben has two sub-basins – Barwon Downs and Kawarren sub-basins aligned approximately NE-SW. Groundwater flow from Barwon Downs to Kawarren sub-basin is restricted by a low transmissivity area. • Love Creek is dominated by groundwater discharge to upper reach tributaries of Ten Mile Creek. • Groundwater extraction in the area has resulted in drawdown of the LTA in the Kawarren area, reducing by 4 m below their baseline levels after the last period of extended pumping in 2010. • A significant reduction in baseflow of Love Creek has been observed. Between 1979 and 1997 the lowest minimum daily flow rate was 1.0 ML/day. Post 1997 there have been a number of years where minimum average daily flow rate was <1.0 ML/day. The minimum flow in Love Creek has reduced by approximately 50%. • An assessment of the aquatic ecosystem in Love Creek was recommended to appreciate the effect of reduced baseflows on the ecosystem.
Jacobs, 2018, Barwon Downs Technical Works Program: Potential impacts and risks from future operation of the Barwon Downs Borefield. 7 December 2018.	
Scope	• Inform Barwon Water licence application via groundwater model to predict potential impacts of pumping to environmental indicators in Gerangamete region. • Assess level of risk of pumping.
Key Findings	• In 2012 Barwon Water commenced a staged technical works program to inform the licence renewal process. Stage 1 involved a review of the existing monitoring program; Stage 2 involved a refinement to the technical works monitoring program, which was designed to improve the monitoring to differentiate between groundwater extraction and climate effects on the groundwater system. It was also developed to predict water table and stream flow changes and increase understanding of potential ecological impacts. Stage 3 involved the construction of additional monitoring assets during 2014/2015; and Stage 4 involved ongoing monitoring. Stage 5 was the development of a licence renewal application to SRW. • Numerical groundwater model was used to run predictive scenarios under varying climate scenarios and under varying pumping scenarios. • LTA estimated volume is 3,000,000 ML. Under constant rate pumping scenario the maximum annual volume extracted was 4,000 ML or 0.1% of total aquifer volume. Under intermittent pumping scenario the maximum annual volume extracted was 12,000 ML or 0.4% of total aquifer volume. • Average recharge to the LTA over past 30 years was estimated to be 5,900 ML/year and was predominantly where the aquifer outcrops. • Proposed groundwater extraction rates were not considered to exceed recharge.

Item	Details
	• When pumping ceases groundwater levels were predicted to recover in the future, with the aquifer returning to pre-development condition when pumping ceases. • Groundwater extraction was not considered to impact on the aquifer matrix subsidence. • Groundwater extraction was not considered to have an adverse impact on the groundwater quality (salinity). Salinity has been monitored annually in three bores since 2004 (102686, 107720, 109114). • Vegetation monitoring indicated that vegetation was buffered from drawdown impacts due to local alluvial aquifers. 14 sites are within the monitoring network (T1-T14) located in topographic depressions associated with drainage lines and creeks. • Risks to receptors indicated that several areas in the catchment (Boundary Creek and Big Swamp) had a high risk to vegetation in areas where the regional aquifer outcrops and there are no alluvial aquifers. • Potential acid sulfate soils: high risks in Reach 2 of Boundary Creek and Barwon River East Branch. Naturally occurring PASS sites were identified in these areas and the LTA outcrops at these locations. • Boundary Creek Reach 1 was considered to be low risk as the drawdown had not extended to this part of the LTA. • Boundary Creek Reach 2 was considered to be a high risk of potential impact. This reach of Boundary Creek flows over the LTA between McDonalds Dam and Yeodene Swamp. It was predicted that the reduction of groundwater contribution to the creek was ~2 ML/day which was more than 100% of low flows. If remediation works were not undertaken at Boundary Creek then it was predicted groundwater levels in Reach 2 would take 20-30 years to recover from historic pumping. • Boundary Creek Reach 3 was considered to be a medium risk as it does not flow directly over the LTA. • Barwon River East Branch was considered to be a medium risk where it flow over the LTA to the south east of the borefield. It was noted that the model over predicted drawdown in this area due to the fault, the aquitard and local alluvial aquifers. The greatest risk of impact to the Barwon River Each Brach was south of the intersection between the river and Birregurra-Forrest Road. Maximum predicted impacts of ~1 ML/day were predicted for the Barwon River East Branch. • Barwon River West Branch is considered low due to its separation from the LTA by local alluvial aquifers. • Barwon River Confluence is considered low due to local alluvial aquifers being present. • Dividing Creek is considered to be a losing creek and is separated from the LTA, however, was considered to be a medium risk because more than 2 m of drawdown is predicted in the LTA in this region. • Barongarook Creek was considered to be a medium risk in the upper reaches of the creek. • The risk to Gellibrand River (key discharge area for regional aquifer) was considered to be medium. The alluvial aquifer was considered to be buffered from drawdowns predicted in the regional aquifer. Small areas of high risk where the LTA outcrops at the surface. • Ten Mile Creek considered to be medium risk. Creek is considered to be a gaining creek. • Yahoo Creek considered to be a medium risk in small areas where there is an absence of alluvial aquifer. • Loves Creek considered to flow over aquitard, however, there are small outcrops of the LTA near the confluence of Gellibrand River. Risk considered to be low. • Several trigger levels set including for each of the identified creeks. • Model predicted that drawdown would be more than 15 m where the LTA is unconfined. This impact could be offset by supplementary flows to Boundary Creek.

Item	Details
Aquade, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment	
Scope	• Assess apparent connection between Barwon Downs pumping and drawdown in the Barongarook Creek Catchment.
Key Findings	• It was understood (based on previous reports) that; – In the 1980s 22.7 GL was extracted; – Between 1997 and 2001 36.8 GL – Between 2006 and 2010 52.7 GL; and – Between 2015 and 2017 3.5 GL. • The drawdown induced by the groundwater extracted extends at least as far as 15 km in the LTA. • Drawdown in an observation bore along Ten Mile Creek has been in the order of 1.2 m. The groundwater level has not recovered to original level
Jacobs, 2019, Technical support for Section 78 Scope of Works: Historical Pumping Risk Assessment Method and Results, 24 September 2019	
Scope	• Renew and update existing numerical model to assess historic impacts associated with groundwater extraction.
Key Findings	• The 2016 model indicated groundwater levels had recovered significantly and approximately 10 m residual drawdown was predicted in the LTA across the majority of the catchment. In Boundary Creek Reach 2 the 2016 model predicted drawdown to be ~5-10 m, while in 2010 the model predicted ~10-20 m of drawdown. Climate influences within the model timeframe resulted in lower groundwater levels across the catchment (2016 drawdown ranging between 0 and 4 m). • Barwon Downs located in Barwon River catchment. The majority of tributaries of Barwon River originate from the Otway Ranges to the south east and flow north towards Birregurra. The remainder originate to the west and flow across the Barongarook High and join Barwon River at Gerangamete Flats. • Changes around the Boundary Creek catchment include land clearing and construction of drainage lines for agriculture in the early 1900s; construction of McDonalds Dam in 1979 which has a licence to extract 160 ML/year; private diverters and farm dams; groundwater extraction from the borefield; drying of Big Swamp; release of supplementary flow to Boundary Creek (currently (as at 2019) 2 ML/day). • Reduction in baseflow of Gellibrand River since mid-1990s. Considered that the change in total baseflow was ~6% reduction. Shallow sediments were considered to collect local recharge and hold local groundwater flow cells that contribute to local discharge to the river. • Estimated maximum impact associated with historical pumping on Barwon River East Branch was ~3.3 ML/day (~33% of low flow) where the river flows over the LTA. • Estimated maximum impact associated with historical pumping on Barwon River West Branch was considered negligible where it flows over the LTA ~<1% of low flow. • Estimated maximum impact associated with historical pumping on the Barwon River downstream of the confluence of the east and west branches was considered to be ~14% of the low flow. • In Boundary Creek the estimated impact associated with historical pumping Reach 1 was considered to be <0.1 ML/day or <1% of low flow, Reach 2 was estimated to be 2.9 ML/day or >100% of low flow, while Reach 3 was estimated to be ~0.3 ML/day or 30% of low flow. • Dividing Creek has no gauge and is considered to be an ephemeral creek that flows after rainfall. It is also considered to be disconnected from the LTA.

Item	Details
	• Estimated maximum impact associated with historical pumping on Gellibrand River baseflow was ~0.3 ML/day (~2% of low flow) • Maximum impact associated with historical pumping on Ten Mile Creek was 0.2 ML/day (~15% low flow). • Estimated maximum impact associated with historical pumping on Yahoo Creek was 0.08 ML/day (~8% of low flow) • Estimated maximum impact associated with historical pumping on Loves Creek was 0.02 ML/day (~1% low flow) • Vegetation studies in the 1980s indicated vegetation was not well understood in the area. Principal types of trees were Peppermints, Messmate Stringybark and Manna Gum (Farmer-Bowers, 1986). In open forest areas Swamp Gum was widespread and was found in areas that were waterlogged and sometimes acidic soils. • Vegetation surveys completed in the early stages of the Millenium Drought identified the health of vegetation had declined at several swamp sites. It was concluded that the decline in vegetation health was likely due to a combination of below average rainfall and declining groundwater levels from pumping. • Vegetation areas identified as potential high risk due to drawdown included west of the graben to the north of Yeodene, east of the graben extending from the area around Barwon Downs to Deans Marsh and south of the graben along Gellibrand River.
Otway Water Book 21: An aquifer divide shift and Study of the EVF aquifers in the Gerangamete and Gellibrand Groundwater Management Areas, 2013	
Key Findings	• Timeline of extractions from Barwon Downs Borefield. • Three Groundwater Management Areas – Newlingrook, Gellibrand and Gerangamete. Newlingrook separated from Gellibrand by Gellibrand Saddle, while Yeo Dome separates Gellibrand and Gerangamete. • Aquifer divide between Barwon Downs sub-basin and Kawarren sub-basin due to Yeo Dome. • Yeo 40 (obs bore 109131 – new/replacement bore installed around 2001/2002) – important bore with a trigger level of 158.5 m AHD whereby supplementary flows released into Boundary Creek • Hydrographs for Kawarren/Gellibrand region indicate no response to three relatively wet winters, while there is a recovery in bores in the Barwon Downs area.
Otway Water Book 28: The Western Front, Ten Mile and Loves Creek Catchment 2015	
Scope	• Draws together various studies to clarify potential impacts of groundwater extraction on the upper reaches of the Gellibrand River Catchment.
Key Findings	• ‘Big picture’ should include observation bore info, data, hydrographs and behaviour; observable data of groundwater receptors; rainfall history and patterns; infiltration rates; stream flow gauging station records; land use change. • The groundwater flow path to the west and south west of the Barongarook High (Kawarren sub-basin) has not been studied. • Over several decades locals have noticed dramatic decline in surface water flows in Loves Creek and upper Gellibrand River catchments. • Jacobs (2015) investigated noticeable groundwater extraction taking place in the Kawarren sub-basin. Extremely small pumped from private bore used for stock and domestic purposes. Jacobs recommended further investigation into the causes of drawdown in the region including estimating likely magnitude of groundwater pumping in the area. • Hydrographs indicate decreases of water level of between 4 – 5 m with no noticeable recovery.

Item	Details
	• Healey rainfall gauge sits within the Barongarook High recharge area. Hopkins rainfall gauge lies to the south. • During periods of drought annual rainfall decreased by more than 200 m. It was thought that this would not have affected the recharge to the aquifer or have a mild impact. Based on precipitation, recharge to the aquifer in the observation bores should '*reflect a reasonably full aquifer system if it had not been for a significant groundwater extraction*.' • Ten Mile Creek Stream Gauge (1985 – 1995, reinstated in 2008 - 2009). Decline in base flows during period of 25,000 ML extraction at Barwon Downs between 1986 and 1990. • Loves Creek Stream Gauge (1979 – at least 2013) • Between 1947 – 1977 there were a number of areas where trees had been cleared. Reduced clearing occurred between 1977 and 2007. Some areas have had pine and blue gum plantations.
Austral Research and Consulting, 2022, Upper Barwon River Macroinvertebrate Sampling Report 2019-2022. 24 June 2022.	
Scope	• Undertaken an investigation into the sediment and water quality and macroinvertebrate condition of upper Barwon River. • Survey of 12 Sites along East Barwon, West Barwon and Barwon Rivers as well as Boundary Creek between Spring 2019 and Autumn 2022. • Collection of macroinvertebrates and in situ water quality, vegetation, site descriptions and photos
Findings	• Metal and acidity originating from Big Swamp and Boundary Creek were found to be highly variable, likely linked to flows through Big Swamp. • pH in the Barwon River downstream of the confluence with Boundary Creek appeared unaffected by low pH in Boundary Creek and were within the ecological optimum range of 6.5 – 8.5. • Concentrations of aluminium, arsenic, copper and iron concentrations generally exceeded the ANZECC guideline levels at Big Swamp and/or Boundary Creek. Zinc concentrations exceeded ANZECC guideline levels in the Barwon River West Branch and along most of the main branch of the river. • Biological objectives for macroinvertebrate sampling were met at four sites once out of six sampling events, while one site met the objectives twice out of six events. • Risks to Barwon River are highest in May and June when discharge from Boundary Creek contains higher concentrations of parameters and flows from the creek increase. • Stream health was considered good downstream of the confluence based on macroinvertebrate community composition. • Boundary Creek was considered to be in very good condition upstream of Big Swamp while the health of Boundary Creek downstream of Big Swamp was improving steadily. There is evidence of regional pH changes.
EAL Consulting Service, 2011, Preliminary Inland Acid Sulfate Soil Assessment Report, Investigation of Wetland Habitats (Barongarook Creek Catchment, Boundary Creek Catchment, Loves Creek Catchment)	
Scope	• Identify the presence of potential and/or actual acid sulfate soils within wetlands within the Barongarook, Boundary, Porcupine, Spiny Horn and Yahoo Catchments. • Completion of site specific soil sampling. • YH1 – along Yahoo Creek; PC4 along Porcupine Creek; SH1 along Spiny Horn Creek
Findings	• The area is described as undulating plains with deeply weathered soils (Tertiary clays) and minor outcrops of sands (associated with Yeodene land system). Steep to middle slope

Item	Details
	consist of yellow gradational sandy loams, while drainage lines and lower lying regions consists of mottled yellow gradational clays. • Peat forests are present within valley infills and low lying drainage lines • The Porcupine Creek sample indicated levels of actual and potential acidity. • The Yahoo Creek sample indicate high levels of actual and very low levels of potential acidity. Soils in the region were considered to be transferral and were not considered indicative of acid sulfate conditions. Although TAA values indicate an acid soil profile not necessarily indicative of sulfidic acidity. • The Spiny Creek sample indicate minute levels of actual and high levels of potential acidity. The site has an extremely high acid neutralising capacity indicating potential to neutralise any sulfur from oxidation. • Excluding Grays land Shorts Road and Yahoo Creek regions all regions in study area show Inland ASS characteristics. • Big Swamp Boundary creek and Parkers old Friend Road regions considered IASS. In regions of depressed groundwater heights and limited recharge, oxidation of soils has resulted in formation of highly acidic conditions. • Areas with sustained groundwater (permanent or semi-permanent) inundation also display IASS characteristics with significant potential for acid generation.
ELA, 2022, Barwon Downs Groundwater Dependent Ecosystems Monitoring Report – November 2020 (V4)	
Scope	• Development of Groundwater Dependent Ecosystems (GDEs) monitoring sites to assess presence of potential GDEs in locations identified by Jacobs as having a high or moderate risk of impact from aquifer drawdown. • Sampling of vegetation from a single 50 m long vegetation transect.
Key Findings	• The identification of GDEs based solely on risk-based modelling was difficult. • Uncertainty whether vegetation that was surveyed was relaying on existing groundwater or using available surface water. Sites were not located close to the Barwon Downs borefield. • Continuation of monitoring the sites for long term effects of pumping will unlikely yield results of value. • Further works required to identify GDEs. Should specifically target where the LTA outcrops.
ELA 2022, Groundwater Dependent Ecosystem Survey of the Barwon Downs Region	
Key Findings	• Investigation areas identified as follows: – 1. Yeodene – 2. Barwon River confluence – 3. Deans Marsh – 4. Barwon River East Branch – 5. Barwon River West Branch – 6. Ten Mile Creek – 7. Yahoo Creek – 8. Gellibrand River – 9. Big Swamp • Investigation areas 6, 7, 8 in the Loves Creek investigation area. • Investigation areas 1 and 2 (Yeodene and Barwon River confluence, respectively) had no patches of GDE vegetation.

<table>
<tr><th>Item</th><th>Details</th></tr>
<tr><td></td><td>Water tables varied between 5 and 20 m in investigation areas 6 and 7 depending on topography of water course and adjacent banks. Water levels in investigation areas 3, 4, 5 and 8 had an average depth of 5 m to water level.
Mapping of water courses indicating probability of groundwater interaction. Major watercourses in investigation 8 had a high probability while in investigation areas 6 and 7 there was a moderate probability.
Vegetation in Investigation areas 6 – 8 was considered to be of high quality remnant vegetation. Classified as herb-rich foothill forest.
Potential for GDEs were Investigation area 3 – moderate; investigation area 4, 6, 7 and 8 – high; and investigation area 9 – low.</td></tr>
<tr><td colspan="2">Preliminary Draft Regional Landcare Action Plan for the Corangamite Region, 1993</td></tr>
<tr><td>Scope</td><td>Develop a Corangamite Regional Landcare Action Plan, defining where the Landcare Group was at the time, where they want to get to and how to get there.</td></tr>
<tr><td>Key Findings</td><td>Major issues identified in the plan included salinity of groundwater in the Barwon Downs area.
Minor issues included landslips</td></tr>
<tr><td colspan="2">Jacobs, 2022, Surrounding Environment Bore Completion Report, Boundary Creek, Big Swamp and surrounding environment Remediation and Environmental Protection Plan. 25 October 2022</td></tr>
<tr><td>Scope</td><td>Installation of 21 wells across 10 nested sites in the surrounding environment areas requiring further investigation.
Redevelopment of four DELWP monitoring wells.
Sampling and analysis of acid sulfate soils (ASS).
Deployment of four loggers for ongoing monitoring.</td></tr>
<tr><td>Key Findings</td><td>Two bores (EBBH01 and BRBH01) were found to be artesian.
At Big Swamp silty clays with sands to depths of 5 m were consistent with alluvial sediments. Between 5 and 15 m depth high plasticity brown-grey clays were consistent with the Narrawaturk Marl, while at depths greater than 16 m the sands were consistent with Dilwyn Formation. Previous investigations had not identified Narrawaturk Marl at this location and it had been thought that there was direct connection between the alluvial sediments and the LTA.
At Barwon River East Branch alluvial sediments were found to depths of 6 m consisting of interbedded sands. Narrawaturk Marl (high plasticity brown clays) was identified between 6 and 13.6 m, while Dilwyn Formation (fine to medium grained well rounded sands and gravelly clays) were identified between 13.6 and 22 m depths.
High plasticity soft brown clays to depths of 6 m that were interpreted to be consistent with alluvial sediments were identified at Barwon River West Branch. Gellibrand Marl was interpreted to be at depths of between 6 and 11 m (grey silty clays) while Narrawaturk Marl was encountered between 11 and 15 m depths (brown high plasticity clays). Dilwyn Formation (sands) were encountered between 15 and 20 m. High plasticity clays from 20 to 36 m may represent weathered basement. There are some discrepancies with historical investigations around the depths to basement, which have previously been reported at depths >50 m.
Barwon River confluence bores encountered alluvial deposits to 6 m depth before Gellibrand Marl between 6 and 10 m. Narrawaturk Marl was encountered to 10 m depths.
At Barongarook Creek East Branch Narrawaturk Marl was encountered at surface to 25m depths. Underlying the marl were sands consistent with Dilwyn Formation.
North of Yeodene Narrawaturk Marl was encountered from surface to 0 m.</td></tr>
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Item	Details
	• At Deans Marsh Narrawaturk Marl was interpreted to be present from surface to 30 m. • At Pennyroyal Creek (Deans Marsh) alluvial deposits were encountered from surface to 7 m depths, while Narrawaturk Marl was encountered between 7 and 30m. • 34 samples were selected for ASS screen tests. Initial screening identified potential and more detailed analysis was completed on 10 samples.
Glover, 2014, Characterisation of acid sulfate soils in south-west Victoria, Australia. PhD Thesis, December 2014.	
Scope	• Investigation into inland ASS. • Five sites within Otway Ranges, Barwon River areas including Boundary Creek.
Key Findings	• Within the Otway Ranges study area the Dilwyn Flow System (LTA) is identified as the predominant aquifer. The potentiometric surface of the LTA is near surface which influences the overlying Gerangamete Marl Local Flow System (Gellibrand Marl, minor Narrawaturk Marl). • Headwaters of the Barwon River often steep and stepped over prominent scarps of resistant sandstone beds. Permanent water storage of the West Barwon Reservoir is also located near the headwaters in the Otway Ranges. • Numerous tea-tree swamps that potentially contain ASS occur in areas with sustained waterlogging across the Otway Ranges, particularly to the north of the foothills. • Study areas included Boundary Creek, Porcupine Creek, Pennyroyal Creek and Bambra Wetlands. • Boundary Creek has a strong seasonal flow due largely to evaporation exceeding rainfall between October and April, with the highest evaporation occurring in January and February. Minimum flows generally occur in January to April while maximum flows occur between August and September. • For Boundary Creek and Barwon River a baseflow of 1ML/d is recommended to maintain semi-permanent aquatic habitat. McDonalds Dam has altered the flow of Boundary Creek and environmental releases are recommended. ~522 ML was discharged into Boundary Creek from the dam during 2012-2013. • The swamp along Boundary Creek (Big Swamp) was partially drained ~1946 for agriculture and the drainage channels are present today. Sub-surface fire in the peat swamp smouldered between 1998 and 2010 while the swamp remained dry. A trench was dug in March/April 2010 along the southern and eastern sides of the swamp to contain the smouldering. • The Otway Group was interpreted to be encountered at a depth of approximately 6.1 m on the southern side of the swamp and ~3.5 m on the northern side of the swamp. • Samples collected from Big Swamp indicated sediment has not completely oxidised and there is no buffering capacity in the sediments. • Porcupine Creek contains a large wetland. Flows are highest from June to November. Porcupine Creek flows across Gellibrand Marl. Small amount of acidity present in sediment sampled and not completely oxidised. No carbonate minerals observed in Porcupine Creek so neutralisation would not occur if oxidisation was to occur. • Pennyroyal Creek and Bambra Wetlands are tributaries of Upper Barwon Catchment. Many swamps and wetlands along tributaries have been drained by artificial deepening of channels and land use change. Sample results indicate oxidation of the sediments have already occurred. There were no carbonate minerals present.
GHD 2021, Big Swamp Integrated Groundwater-Surface Water Modelling for Detailed Design, Technical Modelling Report. Prepared for Barwon Water, April 2021	
Scope	• Develop an integrated surface water – groundwater model to inform detailed design of the preferred remediation strategy of the Boundary Creek and Big Swamp system.

Item	Details
Key Findings	• Big Swamp sits within a narrow alluvial aquifer system and generally aligns with a topographic valley that has been incised into the older underlying material (i.e., Gellibrand Marl and LTA). • The Quaternary Aquifer underlies the swamp to a depth of at least 6 m (although it is not known if that thickness extends across the entire swamp). The Gellibrand Marl extends to a thickness of approximately 20 m before the LTA is encountered at ~26 m bgl. The LTA becomes confined by the Gellibrand Marl in approximately the middle of Big Swamp • In the upstream sections of Boundary Creek, near McDonalds Dam the Quaternary Aquifer is considered to be <8 m thick and increases in thickness downstream to up to 14 m in the downstream end of the swamp. • Slug tests were completed on bores screened in the Quaternary Aquifer. Hydraulic conductivity ranged between 0.02 to 1.4 m/day. There appeared to be no correlation between the hydraulic conductivity and the presence of silts, sands or clays. • The hydraulic conductivity of the Gellibrand Marl in bores downstream of Big Swamp was low and ranged between 1.8 x 10^{-5} and 8 x 10^{-3} m/d. • Slug tests were completed on bores screened in the LTA located west of Boundary Creek with the hydraulic conductivity ranging between 9.2 x 10^{-5} and 0.11 m/d. The hydraulic conductivity is generally higher where the bores are shallow and the sand/gravel is abundant. • The water table responds to changes in surface water, i.e. inundation events with minimal lag time - <4 days. • Boundary Creek acts as a losing stream. There are spatial differences in the timing and amount of response to the water table from seasonal flow events. • Under non-pumping conditions it was considered likely that groundwater in the Quaternary Aquifer would have been recharged from a combination of rainfall and surface water inundation and through-flow and baseflow from the LTA. During pumping water levels declined to be around 15 m bgl along the upper reaches of Boundary Creek. Based on this it was considered that the water table of the unconfined portion of the LTA would have become disconnected from the base of the Quaternary Aquifer. • Water levels have gradually recovered to approximately 8 m bgl, however are still lower than near surface levels measured in 1997. There is currently a net downward hydraulic gradient from the Quaternary Aquifer to the LTA, thereby limiting the amount of through-flow into the Quaternary Aquifer underlying the Big Swamp. • There is seasonal variation in the vertical hydraulic gradient between the Quaternary Aquifer and the LMTD. There is limited upward vertical leakage from the LTA to the LMTD and the Quaternary Aquifer. • There is considered to be a component of downward leakage from the Quaternary Aquifer to the LTA during periods of inundation. • The model identified a hydraulic barrier configuration of 7 barriers that were considered to be effective in managing water levels in the Big Swamp. • A minimum flow of 0.5 ML/d was required downstream of Big Swamp. A supplementary flow of 2 ML/d during dry periods was considered sufficient to maintain inundation and ponding, however, wasn't considered sufficient to maintain minimum downstream flow.
CDM Smith 2022, PRB Assessment. Prepared for Barwon Water, 13 September 2022.	
Scope	• Review and update the conceptual understating of hydrogeology in the Big Swamp and Boundary Creek systems in relation to water level recovery. • Review of current and relevant hydrogeological factors in Big Swamp and consideration of low and high flow inundations potentially relevant to PRB locations. • Consideration of PRB as an option for mitigation of acidity and metals precipitation into Boundary Creek and Barwon River.

Item	Details
Key Findings	• Boundary Creek divided into three reaches: Reach 1 is upper reach with McDonalds Dam (160 ML capacity). Upstream of McDonalds Dam quaternary sediments are underlain by Otway Group and the creek is weakly gaining. ~500 m stretch from upstream of McDonalds Dam to the dam the quaternary sediments are underlain by LTA and is losing. • Surface water impacts in Boundary Creek primarily associated with downstream of Big Swamp. Acidification was more pronounced in western portion than eastern portion largely due to groundwater levels being closer to surface in eastern portion. • Groundwater level have recovered since pumping ceased in 2010 by 3 – 10 m. • Streamflow through Big Swamp is the predominant driver of groundwater levels in the upper groundwater flow system of the swamp. • Majority of the eastern bores are artesian, while only one bore in the west is artesian occasionally. • Potential contributions of alluvial groundwater discharge was assessed using a mass balance approach. The data indicated that groundwater contributes between 2 and 45% of total discharge to the swamp. Generally the discharge is lower during elevated streamflow periods and elevated during lower stream flow periods. This equates to 0.05 – 0.91 ML/day. The calculations indicated a potential increase in groundwater discharge over time. • PRB was not considered a feasible option for risk mitigation at the site.

Appendix C

Hydrographs

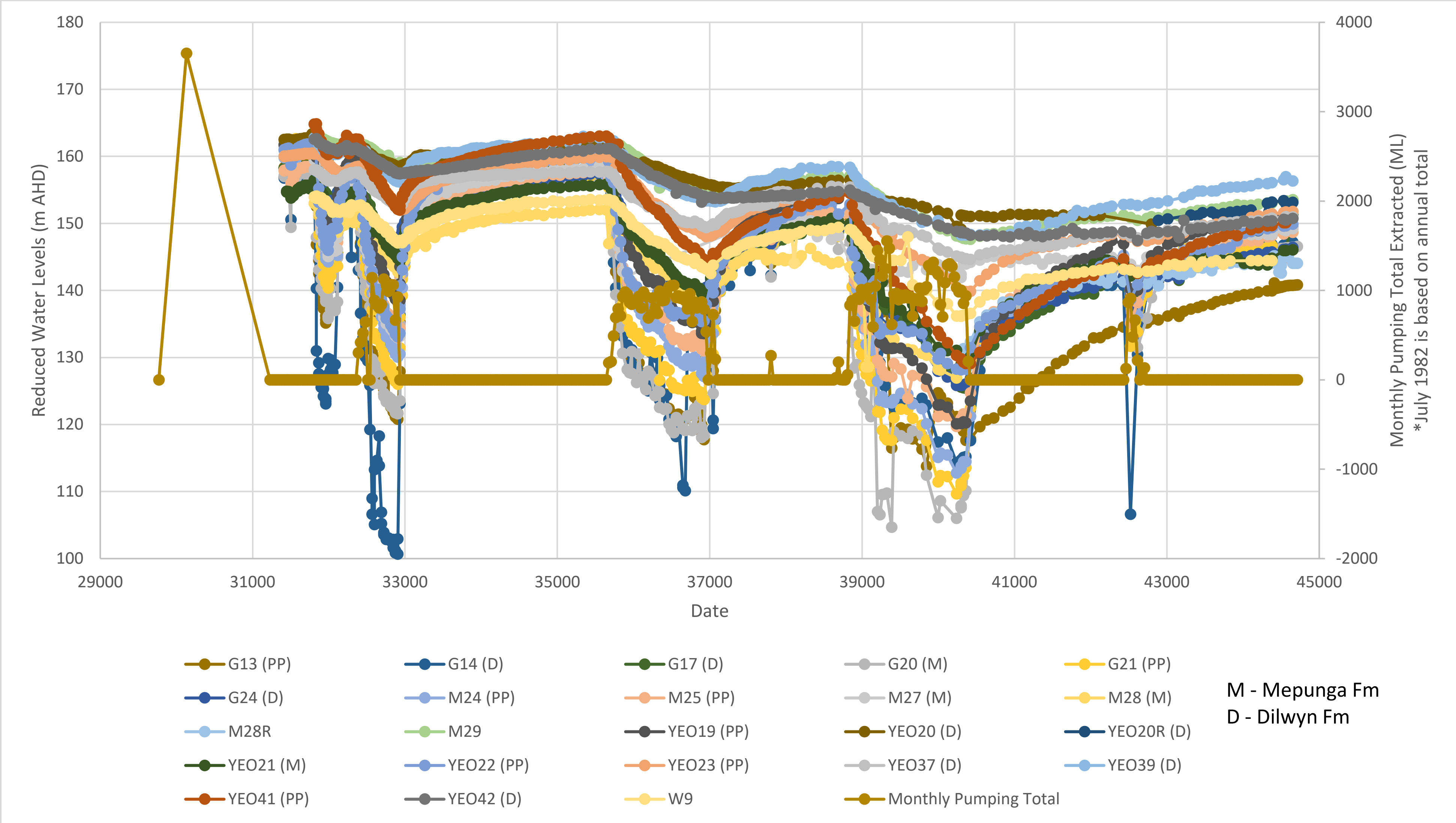

Figure C1 - Groundwater Bore Hydrographs - Substantial Response

Hydrogeological Investigation of the Barwon Downs sub-basin Investigation Area

Surrounding Environment Investigation

Barwon Water

Date: Jun 23	Drawn: RC
Scale: nts	Chk'd: RC
Original:	Rev: 0
File Reference:	

BlueSphere ENVIRONMENTAL

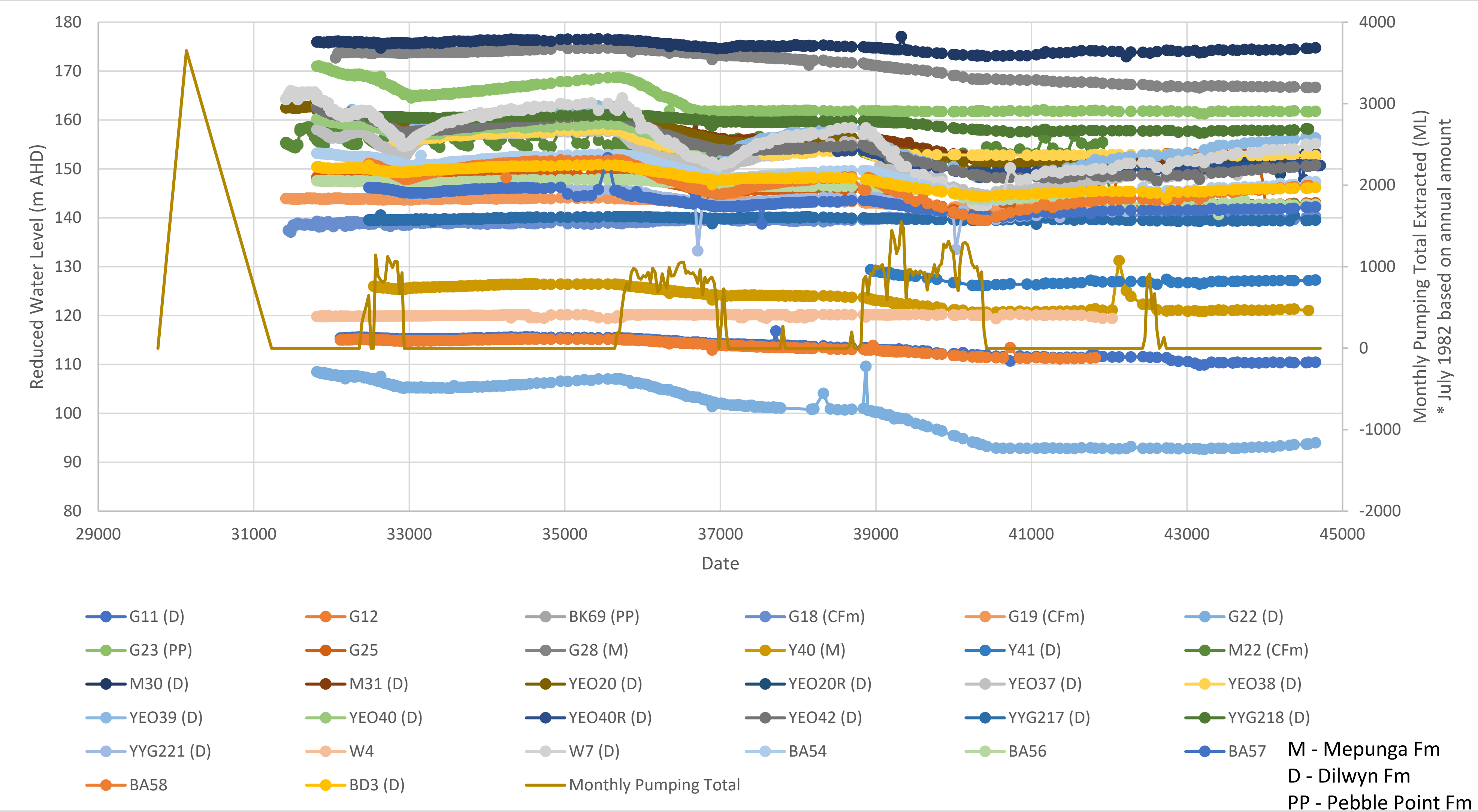

Figure C2 - Groundwater Bore Hydrographs - Subdued Response

Hydrogeological Investigation of the Barwon Downs sub-basin Investigation Area

Surrounding Environment Investigation

Barwon Water

Date: Jun 23	**Drawn:** RC
Scale: nts	**Chk'd:** RC
Original:	**Rev:** 0
File Reference:	

BlueSphere ENVIRONMENTAL

Appendix D

Acid Sulfate Soil Tables

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
DMBH01V/DMBH02V	BH18/19_0-1	Jacobs (2022)	7.5	6.2	1.3	3	-	-	-	Possible ASS
	BH18/19_1-2	Jacobs (2022)	5.3	3.9	1.4	1	-	-	-	
	BH18/19_2-3	Jacobs (2022)	4.8	3.9	0.9	1	-	-	-	
BSBH13LTA	BH01_1.0	Jacobs (2022)	4.2	1.8	2.4	4	103	69	247	Actual and Potential ASS
	BH01_1.0	Jacobs (2022)	4.8	1.6	3.2	4	-	-	-	
	BH01_2.0	Jacobs (2022)	3.6	1.3	2.3	4	-	-	-	
	BH01_3.0	Jacobs (2022)	3.7	1.4	2.3	4	-	-	-	
	BH01-4.0	Jacobs (2022)	4	1.6	2.4	4	-	-	-	
	BH01_6.0	Jacobs (2022)	4.3	1.9	2.4	2	-	-	-	
	BH01_7.0	Jacobs (2022)	4.4	1.8	2.6	3	-	-	-	
	BH01-8.0	Jacobs (2022)	4.2	1.8	2.4	2	-	-	-	
	BH01-11	Jacobs (2022)	4.2	1.6	2.6	4	46	625	671	
	BH01-12	Jacobs (2022)	4.7	2	2.7	4	-	-	-	
	BH01_15.0	Jacobs (2022)	4.5	1.6	2.9	4	23	440	463	
	BH01_16.0	Jacobs (2022)	4.9	2.1	2.8	4	-	-	-	
	BH01_17.0	Jacobs (2022)	5	1.5	3.5	3	-	-	-	
	BH01-21	Jacobs (2022)	6.8	2.5	4.3	2	<2	31	31	
	BH01-23	Jacobs (2022)	6.1	1.9	4.2	2	-	-	-	
	BH01-24	Jacobs (2022)	6.6	2.2	4.4	2	2	26	28	
WBBH01/WBBH02	BH04_BH05-1.0	Jacobs (2022)	6.8	2.6	4.2	3	-	-	-	Potential ASS
	BH04_BH05-2.0	Jacobs (2022)	6.7	3.5	3.2	3	7	16	23	
	BH04_BH05-3.0	Jacobs (2022)	6.4	4	2.4	4	-	-	-	
GRBH01/GRBH02	BH08_09_1.0	Jacobs (2022)	6.8	3.4	3.4	2	-	-	-	Not Identified
	BH08_09_2.0	Jacobs (2022)	7.4	5.1	2.3	2	<2	<10	<10	
	BH08_09_3.0	Jacobs (2022)	6	3.4	2.6	2	11	<10	14	
BCBH01/BCBH02	BH14_15-1	Jacobs (2022)	5.9	4.2	1.7	1	-	-	-	Potential ASS
	BH14_15-2	Jacobs (2022)	6	3.7	2.3	1	13	11	24	
	BH14_15-3	Jacobs (2022)	5.6	3.8	1.8	1	-	-	-	
	BH14_15-22	Jacobs (2022)	5.9	2.4	3.5	4	-	-	-	
NYBH01/NYBH02	BH16_BH17-3.0	Jacobs (2022)	5.3	3.6	1.7	1	-	-	-	Not Identified
PCBH01V/PCBH02V	BH20-21-1.0	Jacobs (2022)	5.8	3.1	2.7	1	4	<10	11	Not Identified
	BH20-21_2.0	Jacobs (2022)	4.9	3.4	1.5	2	-	-	-	
	BH20_21_3.0	Jacobs (2022)	4.9	3	1.9	1	-	-	-	
	BH20_21_4.0	Jacobs (2022)	5.2	3.5	1.7	2	-	-	-	
McD1	N/A	EAL Consulting	-	-	-	-	-	-	-	Possible ASS
PC4	N/A	EAL Consulting	-	-	-	-	-	-	-	Actual and Potential ASS
SB1	^ SB1_0.9-1.0	EAL Consulting	-	-	-	-	80	237	317	Actual and Potential ASS
SB2	^ SB2_0.3-0.5	EAL Consulting	-	-	-	-	128	187	315	Actual and Potential ASS
SB3	^ SB3_1.0	EAL Consulting	-	-	-	-	38	0	38	Actual ASS
SB4	^ SB4_0.0-0.1	EAL Consulting	-	-	-	-	80	87	167	Actual and Potential ASS
SB5	^ SB5_0.1-0.2	EAL Consulting	-	-	-	-	207	2270	2478	Actual and Potential ASS
SB6	^ SB6_0.8-1.0	EAL Consulting	-	-	-	-	255	1628	1883	Actual and Potential ASS
SB7	^ SB7_0.2-0.4	EAL Consulting	-	-	-	-	186	256	442	Actual and Potential ASS
SB8	^ SB8_0.1	EAL Consulting	-	-	-	-	174	6	217	Actual ASS
SB9	^ SB9_0.1	EAL Consulting	-	-	-	-	263	12	291	Actual ASS
SB10	^ SB10_0.1	EAL Consulting	-	-	-	-	698	25	1926	Actual and Potential ASS
SB11	^ SB11_0.1	EAL Consulting	-	-	-	-	543	31	1508	Actual and Potential ASS
SB12	^ SB12_0.5	EAL Consulting	-	-	-	-	1319	443	1770	Actual and Potential ASS
SB13	^ SB13_0.1	EAL Consulting	-	-	-	-	416	6	1159	Actual ASS
SB14	^ SB14_0.8	EAL Consulting	-	-	-	-	1174	9998	11942	Actual and Potential ASS
SB15	^ SB15_0.8	EAL Consulting	-	-	-	-	237	1060	1298	Actual and Potential ASS
SB16	^ SB16_0.1	EAL Consulting	-	-	-	-	499	56	1423	Actual and Potential ASS

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
SB17	^ SB17_0.3	EAL Consulting	-	-	-	-	51	399	450	Actual and Potential ASS
SH1	N/A	EAL Consulting	-	-	-	-	-	-	-	Actual ASS
YH1	N/A	EAL Consulting	-	-	-	-	-	-	-	Not Identified
BC1	0.5	Glover (2014)	4.08	-	-	-	122	363	-	Actual and Potential ASS
	1	Glover (2014)	3.83	-	-	-	131	243	-	
	1.5	Glover (2014)	3.91	-	-	-	213	409	-	
	2	Glover (2014)	4.42	-	-	-	259	1262	-	
	2.5	Glover (2014)	3.52	-	-	-	209	1344	-	
BC2	1.5	Glover (2014)	4.63	-	-	-	81.2	639	-	Actual and Potential ASS
BC3	2	Glover (2014)	4.57	-	-	-	51.2	252	-	Actual and Potential ASS
PR	0.0-0.2	Glover (2014)	7.31	-	-	-	0	449	-	Potential ASS
	0.2-0.4	Glover (2014)	6.86	-	-	-	0	155	-	
BW	0.0-0.1	Glover (2014)	4.81	-	-	-	8.46	123	-	Potential ASS
	0.1-0.3	Glover (2014)	4.46	-	-	-	6.8	533	-	
	0.3-0.6	Glover (2014)	4.67	-	-	-	4.3	48.1	-	
Site 2	2-1(0-32)	Jacobs, SKM (2015)	6.1	2.3	3.8	-	13	<10	16	Actual and Potential ASS
	2-1(194-256)	Jacobs, SKM (2015)	6.7	5.6	1.1	-	31	<10	40	
	2-1(256-300)	Jacobs, SKM (2015)	7.3	5.4	1.9	-	6	<10	<10	
	2-2(150-225)	Jacobs, SKM (2015)	7.4	6.8	0.6	-	4	<10	<10	
	2-4(0-26)	Jacobs, SKM (2015)	6.3	2.7	3.6	-	16	<10	22	
	2-4(26-60)	Jacobs, SKM (2015)	5.8	3.7	2.1	-	12	<10	14	
	2-4(177-232)	Jacobs, SKM (2015)	7.2	5.5	1.7	-	33	<10	34	
Site 4	4-1(19-41)	Jacobs, SKM (2015)	7.5	2.9	4.6	-	<2	82	82	Actual and Potential ASS
	4-1(41-79)	Jacobs, SKM (2015)	7.5	3.5	4	-	<2	<10	<10	
	4-1(219-242)	Jacobs, SKM (2015)	8.7	7	1.7	-	<2	20	<10	
	4-1(0-69)	Jacobs, SKM (2015)	7.2	3.8	3.4	-	<2	<10	<10	
	4-3(0-15)	Jacobs, SKM (2015)	7.6	4.2	3.4	-	<2	<10	<10	
	4-3(41-150)	Jacobs, SKM (2015)	8.3	4.4	3.9	-	<2	28	25	
	4-3(173-242)	Jacobs, SKM (2015)	8.3	7	1.3	-	<2	<10	<10	
Site 7	7-1(209-300)	Jacobs, SKM (2015)	6.2	1.7	4.5	-	5	5	5	Actual and Potential ASS
	7-2(160-230)	Jacobs, SKM (2015)	5.7	1.7	4	-	206	494	706	
	7-3(15-31)	Jacobs, SKM (2015)	6.9	4.1	2.8	-	6	50	56	
	7-3(138-166)	Jacobs, SKM (2015)	5.8	1.4	4.4	-	83	565	648	
	7-3(177-300)	Jacobs, SKM (2015)	5.6	1.5	4.1	-	92	168	261	
	7-4(80-150)	Jacobs, SKM (2015)	5.8	1.8	4	-	38	68	106	
	7-4(220-300)	Jacobs, SKM (2015)	5.8	1.3	4.5	-	105	398	503	
Site 9	9-1(30-60)	Jacobs, SKM (2015)	4.8	2.4	2.4	-	99	<10	113	Actual and Potential ASS
	9-2(0-30)	Jacobs, SKM (2015)	5	2.3	2.7	-	91	18	118	
	9-2(30-60)	Jacobs, SKM (2015)	5.2	3.8	1.4	-	68	<10	76	
	9-3(0-30)	Jacobs, SKM (2015)	6	3.4	2.6	-	29	<10	33	
	9-3(60-90)	Jacobs, SKM (2015)	5.7	2.8	2.9	-	70	<10	74	
	9-3(120-150)	Jacobs, SKM (2015)	5.4	2.6	2.8	-	65	<10	69	
	9-4(0-30)	Jacobs, SKM (2015)	5.4	2.8	2.6	-	48	<10	53	
	9-4(60-90)	Jacobs, SKM (2015)	5.8	2.8	3	-	46	<10	50	

Prepared by: BS
Checked by: BS

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
Site 13	13-1(0-47)	Jacobs, SKM (2015)	5.5	2.4	3.1	-	34	<10	46	Actual and Potential ASS
	13-2(26-59)	Jacobs, SKM (2015)	4.9	2.8	2.1	-	20	<10	25	
	13-2(59-150)	Jacobs, SKM (2015)	5.6	3.8	1.8	-	48	<10	51	
	13-2(183-219)	Jacobs, SKM (2015)	4.8	3.7	1.1	-	2	<10	<10	
	13-4(0-250)	Jacobs, SKM (2015)	5.8	1.9	3.9	-	40	<10	54	
	13-4(73-113)	Jacobs, SKM (2015)	4.4	2.8	1.6	-	44	<10	48	
	13-4(113-230)	Jacobs, SKM (2015)	5.7	3.6	2.1	-	30	<10	32	
	13-4(230-300)	Jacobs, SKM (2015)	4.4	3	1.4	-	64	<10	66	
Site 14	14-1(0-37)	Jacobs, SKM (2015)	2.3	1.4	0.9	-	496	10	1050	Actual and Potential ASS
	14-1(37-98)	Jacobs, SKM (2015)	2.6	0.8	1.8	-	767	6840	7640	
	14-1(106-150)	Jacobs, SKM (2015)	6	1.6	4.4	-	144	2030	2190	
	14-1(240-300)	Jacobs, SKM (2015)	6.5	1.6	4.9	-	196	2450	2650	
	14-2(0-37)	Jacobs, SKM (2015)	2.4	1.3	1.1	-	578	90	1310	
	14-2(23-56)	Jacobs, SKM (2015)	6.3	1.5	4.8	-	399	4340	4750	
	14-3(0-23)	Jacobs, SKM (2015)	6.4	3.3	3.1	-	7	33	40	
	14-3(23-56)	Jacobs, SKM (2015)	6.9	5.2	1.7	-	8	42	50	
	14-3(175-238)	Jacobs, SKM (2015)	3.3	2	1.3	-	294	<10	418	
	14-3(238-300)	Jacobs, SKM (2015)	6	1.5	4.5	-	223	1050	1280	
	14-4(0-11)	Jacobs, SKM (2015)	6	2.3	3.7	-	27	<10	42	
YS06	1	Barwon Water	5.8	3.2	2.6	4	81	10*	91	Actual and Potential ASS
	1.5	Barwon Water	5	2	3	3	44	22*	65	
	2.5	Barwon Water	5.3	3.5	1.8	1	3.7	<3*	<10	
	0.5	Barwon Water	5.6	2.1	3.5	3	21	4*	25	
	3	Barwon Water	5.2	3.8	1.4	2	5.5	<3*	<10	
BSBH14	0-0.15	Barwon Water	-	-	-	-	429	68	667	Actual and Potential ASS
	0.15-0.7	Barwon Water	-	-	-	-	1243	1313	3214	
	0.7-1	Barwon Water	-	-	-	-	1891	237	3253	
	1-1.5	Barwon Water	-	-	-	-	627	7336	8327	
	1.5-2	Barwon Water	-	-	-	-	165	437	602	
	2.5-3	Barwon Water	-	-	-	-	1093	68	1294	
	3-3.5	Barwon Water	-	-	-	-	49	31	92	
	3.5-4	Barwon Water	-	-	-	-	34	13	47	
	4-4.5	Barwon Water	-	-	-	-	24	14	38	
	4.5-6	Barwon Water	-	-	-	-	42	37	79	
BSBH15	0-0.2	Barwon Water	-	-	-	-	307	52	425	Actual and Potential ASS
	0.2-0.5	Barwon Water	-	-	-	-	578	919	1590	
	0.5-1	Barwon Water	-	-	-	-	692	2150	2912	
	1-1.5	Barwon Water	-	-	-	-	682	8301	9092	
	1.5-2	Barwon Water	-	-	-	-	569	12954	13769	
	2-2.5	Barwon Water	-	-	-	-	747	5644	6520	
	2.5-3	Barwon Water	-	-	-	-	298	1032	1330	
	3-3.5	Barwon Water	-	-	-	-	386	873	1309	
	3.5-4	Barwon Water	-	-	-	-	401	1237	1694	
	4-4.5	Barwon Water	-	-	-	-	87	368	476	
	4.5-6	Barwon Water	-	-	-	-	76	81	197	
BSBH16	0-0.1	Barwon Water	-	-	-	-	200	38	279	Actual and Potential ASS
	0.1-0.5	Barwon Water	-	-	-	-	185	24	318	
	0.5-1	Barwon Water	-	-	-	-	57	5	72	
	1-1.5	Barwon Water	-	-	-	-	77	0	83	
	1.5-2	Barwon Water	-	-	-	-	24	0	24	
	2-2.5	Barwon Water	-	-	-	-	43	2	47	
	2.5-3.2	Barwon Water	-	-	-	-	72	14	86	
	3.2-4	Barwon Water	-	-	-	-	35	9	44	
	4-4.5	Barwon Water	-	-	-	-	61	3	64	
	4.5-6	Barwon Water	-	-	-	-	31	0	31	
BSBH17	0-0.1	Barwon Water	-	-	-	-	103	16	300	Actual and Potential ASS
	0.1-0.7	Barwon Water	-	-	-	-	83	6	121	
	0.7-1.35	Barwon Water	-	-	-	-	56	0	56	
	1.35-1.6	Barwon Water	-	-	-	-	46	0	52	
	1.6-2	Barwon Water	-	-	-	-	42	4	46	
	2-2.5	Barwon Water	-	-	-	-	32	5	37	
	2.5-3	Barwon Water	-	-	-	-	37	8	45	
	3-3.5	Barwon Water	-	-	-	-	35	5	40	
	3.5-4	Barwon Water	-	-	-	-	40	0	40	
	4-4.5	Barwon Water	-	-	-	-	16	0	16	
	4.5-6	Barwon Water	-	-	-	-	15	72	87	
	1	Barwon Water	2.8	1.6	1.2	4	580	-	9600	

Prepared by: BS
Checked by: BS

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
BSBH18	0-0.2	Barwon Water	-	-	-	-	389	51	586	Actual and Potential ASS
	0.2-0.8	Barwon Water	-	-	-	-	694	6481	7667	
	0.8-1.2	Barwon Water	-	-	-	-	610	7478	8396	
	1.2-1.6	Barwon Water	-	-	-	-	723	12426	13858	
	1.6-2	Barwon Water	-	-	-	-	235	510	745	
	2-2.4	Barwon Water	-	-	-	-	147	117	264	
	2.4-2.8	Barwon Water	-	-	-	-	352	3734	4086	
	2.8-3.2	Barwon Water	-	-	-	-	99	75	174	
YS04	0.5	Barwon Water	4.3	2.6	1.7	3	49	4*	54	Actual ASS
	2	Barwon Water	4.3	3.6	0.7	1	13	<3*	13	
	3	Barwon Water	4.2	3.4	0.8	1	7.3	<3*	<10	
	1	Barwon Water	4.3	3.4	0.9	1	59	<3*	68	
YS05	0.5	Barwon Water	3.6	1.6	2	4	570	31*	640	Actual and Potential ASS
	2	Barwon Water	4.1	2.3	1.8	4	110	120*	230	
	3	Barwon Water	4.2	2.3	1.9	4	48	44*	93	
BSBH11		Barwon Water	-	-	-	-	225	8	916	Actual and Potential ASS
	0.3-1	Barwon Water	-	-	-	-	199	4	337	
	1-1.5	Barwon Water	-	-	-	-	507	53	1510	
	1.5-1.8	Barwon Water	-	-	-	-	61	157	218	
	1.8-2	Barwon Water	-	-	-	-	41	136	178	
	2-2.5	Barwon Water	-	-	-	-	99	207	306	
	2.5-3	Barwon Water	-	-	-	-	168	8	176	
	3-3.5	Barwon Water	-	-	-	-	198	4	202	
	3.5-4	Barwon Water	-	-	-	-	157	0	157	
	4-4.5	Barwon Water	-	-	-	-	195	0	195	
	4.5-6	Barwon Water	-	-	-	-	72	21	96	
BSBH12	0-0.5	Barwon Water	-	-	-	-	74	9	111	Actual and Potential ASS
	0.5-1.2	Barwon Water	-	-	-	-	323	63	453	
	1.2-1.6	Barwon Water	-	-	-	-	568	700	2140	
	1.6-2	Barwon Water	-	-	-	-	807	832	2503	
	2-2.2	Barwon Water	-	-	-	-	520	3897	4565	
	2.2-2.4	Barwon Water	-	-	-	-	220	65	352	
BSBH08	0-0.15	Barwon Water	-	-	-	-	114	10	124	Actual and Potential ASS
	0.15-0.35	Barwon Water	-	-	-	-	917	57	1523	
	0.35-1	Barwon Water	-	-	-	-	1342	1896	4202	
	1-1.5	Barwon Water	-	-	-	-	709	10946	12152	
	1.5-2	Barwon Water	-	-	-	-	72	108	180	
	2-2.5	Barwon Water	-	-	-	-	143	107	254	
	2.5-3	Barwon Water	-	-	-	-	103	7	110	
	3-3.5	Barwon Water	-	-	-	-	118	5	123	
	3.5-4	Barwon Water	-	-	-	-	87	5	92	
	4-4.5	Barwon Water	-	-	-	-	60	24	84	
	4.5-6	Barwon Water	-	-	-	-	68	20	88	

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
BSBH09	0-0.75	Barwon Water	-	-	-	-	140	104	244	Actual and Potential ASS
	0.75-1.2	Barwon Water	-	-	-	-	327	25	361	
	1.2-1.5	Barwon Water	-	-	-	-	413	22	477	
	1.5-1.8	Barwon Water	-	-	-	-	348	487	917	
	1.8-2.2	Barwon Water	-	-	-	-	239	3570	3809	
	2.2-2.5	Barwon Water	-	-	-	-	197	3277	3474	
	2.5-3	Barwon Water	-	-	-	-	278	3736	4014	
	3-3.5	Barwon Water	-	-	-	-	574	11339	12319	
	3.5-4	Barwon Water	-	-	-	-	226	470	696	
	4-4.5	Barwon Water	-	-	-	-	121	15	136	
	4.5-6	Barwon Water	-	-	-	-	70	22	92	
BSBH10	0-0.2	Barwon Water	-	-	-	-	330	11	365	Actual and Potential ASS
	0.2-0.6	Barwon Water	-	-	-	-	443	22	503	
	0.6-1.5	Barwon Water	-	-	-	-	459	60	605	
	1.5-2	Barwon Water	-	-	-	-	438	100	562	
	2-2.5	Barwon Water	-	-	-	-	195	3465	3660	
	2.5-3	Barwon Water	-	-	-	-	222	1492	1714	
	3-3.5	Barwon Water	-	-	-	-	250	6771	7021	
	3.5-4	Barwon Water	-	-	-	-	116	433	549	
	4-4.5	Barwon Water	-	-	-	-	189	2771	2960	
	4.5-6	Barwon Water	-	-	-	-	113	3797	3910	
BSBH04	0-0.6	Barwon Water	-	-	-	-	160	11	375	Actual and Potential ASS
	0.6-0.8	Barwon Water	-	-	-	-	846	326	2033	
	0.8-1.5	Barwon Water	-	-	-	-	739	4233	5560	
	1.5-2	Barwon Water	-	-	-	-	250	9800	10088	
	2-2.5	Barwon Water	-	-	-	-	160	305	465	
	2.5-3	Barwon Water	-	-	-	-	49	346	395	
	3-3.5	Barwon Water	-	-	-	-	127	166	307	
	3.5-4	Barwon Water	-	-	-	-	245	16	261	
	4-4.5	Barwon Water	-	-	-	-	87	7	94	
	4.5-6	Barwon Water	-	-	-	-	64	72	136	
BSBH05	0-0.2	Barwon Water	-	-	-	-	127	57	184	Actual and Potential ASS
	0.2-0.4	Barwon Water	-	-	-	-	360	26	403	
	0.4-0.6	Barwon Water	-	-	-	-	381	40	444	
	0.6-1	Barwon Water	-	-	-	-	392	188	596	
	1-1.5	Barwon Water	-	-	-	-	362	187	567	
	1.5-2	Barwon Water	-	-	-	-	322	1798	2120	
	2-2.5	Barwon Water	-	-	-	-	95	476	571	
	2.5-3	Barwon Water	-	-	-	-	106	2523	2629	
	3-3.5	Barwon Water	-	-	-	-	177	4761	4938	
	3.5-4	Barwon Water	-	-	-	-	138	6377	6515	
	4-4.5	Barwon Water	-	-	-	-	59	311	370	
	4.5-6	Barwon Water	-	-	-	-	83	229	312	
BSBH06	0-0.2	Barwon Water	-	-	-	-	196	75	271	Actual and Potential ASS
	0.2-0.4	Barwon Water	-	-	-	-	299	85	414	
	0.4-0.5	Barwon Water	-	-	-	-	357	45	430	
	0.5-1	Barwon Water	-	-	-	-	359	63	432	
	1-1.5	Barwon Water	-	-	-	-	500	500	1022	
	1.5-2	Barwon Water	-	-	-	-	427	1775	2202	
	2-2.5	Barwon Water	-	-	-	-	117	639	756	
	2.5-3	Barwon Water	-	-	-	-	160	4790	4950	
	3-3.5	Barwon Water	-	-	-	-	92	384	476	
	3.5-4	Barwon Water	-	-	-	-	152	2085	2237	
	4-4.5	Barwon Water	-	-	-	-	139	8042	8181	
	4.5-6	Barwon Water	-	-	-	-	55	260	315	
BSBH07	0-0.4	Barwon Water	-	-	-	-	301	42	366	Actual and Potential ASS
	0.4-0.8	Barwon Water	-	-	-	-	345	392	740	
	0.8-1.5	Barwon Water	-	-	-	-	305	1979	2284	
	1.5-2	Barwon Water	-	-	-	-	170	2479	2649	
	2-2.5	Barwon Water	-	-	-	-	162	1789	1951	
	2.5-3	Barwon Water	-	-	-	-	149	2113	2262	
	3-3.5	Barwon Water	-	-	-	-	160	3085	3245	
	3.5-4	Barwon Water	-	-	-	-	199	5415	5614	
	4-4.5	Barwon Water	-	-	-	-	203	5965	6168	
	4.5-6	Barwon Water	-	-	-	-	192	3593	3785	
YS01	1	Barwon Water	3.9	3.1	0.8	4	39	<3*	39	Actual ASS
	0.5	Barwon Water	4.6	2.9	1.7	4	270	5*	280	

Table D1 - Summary of Previous Acid Sulfate Soil Results

Location	Sample ID	Source	pH (F)	pH (Fox)	ΔpH	Reaction Rate	TAA	Potential Acidity	Net Acidity	ASS Type
			units	units	units	-	(mol H+)	(mol H+)	(mol H+)	
YS01	1.5	Barwon Water	3.9	2.6	1.3	2	89	<3*	89	Actual ASS
	3	Barwon Water	4.1	3.2	0.9	2	28	<3*	28	
YS02	1	Barwon Water	3.4	1.6	1.8	3	910	550*	1500	Actual and Potential ASS
	2	Barwon Water	4.5	1.5	3	4	470	2900*	3400	
	3	Barwon Water	5.9	1.8	4.1	4	81	1200*	1200	
YS03	0.5	Barwon Water	4.8	3.6	1.2	4	110	3*	130	Actual and Potential ASS
	1	Barwon Water	3.9	2.7	1.2	4	240	23*	310	
	2	Barwon Water	5.9	1.9	4	4	72	230*	300	
	3	Barwon Water	5.9	2.2	3.7	4	78	150*	230	
BSBH01	0-0.15	Barwon Water	-	-	-	-	549	19	996	Actual and Potential ASS
	0.15-0.4	Barwon Water	-	-	-	-	387	15	413	
	0.4-0.7	Barwon Water	-	-	-	-	340	12	361	
	0.7-1	Barwon Water	-	-	-	-	352	274	626	
	1-1.5	Barwon Water	-	-	-	-	293	1690	1983	
	1.5-2	Barwon Water	-	-	-	-	102	295	397	
	2-2.5	Barwon Water	-	-	-	-	71	748	819	
	2.5-3	Barwon Water	-	-	-	-	142	3722	3864	
	4.5-6	Barwon Water	-	-	-	-	34	226	260	
	0-0.4	Barwon Water	-	-	-	-	486	21	662	
	0.4-0.8	Barwon Water	-	-	-	-	451	16	540	
	0.8-1.2	Barwon Water	-	-	-	-	403	19	517	
	1.2-1.6	Barwon Water	-	-	-	-	337	2572	2967	
	1.6-2	Barwon Water	-	-	-	-	430	174	622	
	2-2.4	Barwon Water	-	-	-	-	148	829	977	
	2.4-2.8	Barwon Water	-	-	-	-	85	1528	1613	
	2.8-3.2	Barwon Water	-	-	-	-	84	419	503	
	3.6-4	Barwon Water	-	-	-	-	198	2763	2961	
	4-4.4	Barwon Water	-	-	-	-	163	3818	3981	
	4.4-4.8	Barwon Water	-	-	-	-	139	3036	3175	
BSBH02	0-0.4	Barwon Water	-	-	-	-	540	15	950	Actual and Potential ASS
	0.4-0.8	Barwon Water	-	-	-	-	442	16	527	
	0.8-1.2	Barwon Water	-	-	-	-	528	68	640	
	1.2-1.6	Barwon Water	-	-	-	-	403	556	1091	
	1.6-2	Barwon Water	-	-	-	-	96	600	696	
	2-2.4	Barwon Water	-	-	-	-	80	198	278	
	2.4-2.8	Barwon Water	-	-	-	-	97	643	740	
	2.8-3.2	Barwon Water	-	-	-	-	85	978	1063	
	3.2-3.6	Barwon Water	-	-	-	-	84	1816	1900	
BSBH03	0-0.4	Barwon Water	-	-	-	-	320	12	533	Actual and Potential ASS
	0.4-0.8	Barwon Water	-	-	-	-	339	10	404	
	0.8-1.2	Barwon Water	-	-	-	-	346	18	383	
	1.2-1.6	Barwon Water	-	-	-	-	349	18	393	
	1.6-2	Barwon Water	-	-	-	-	296	286	582	
	2-2.4	Barwon Water	-	-	-	-	276	615	891	
	2.4-2.8	Barwon Water	-	-	-	-	237	366	610	
	2.8-3.2	Barwon Water	-	-	-	-	143	159	307	
	3.2-3.6	Barwon Water	-	-	-	-	138	535	673	
LBC01	3	Barwon Water	6	2.8	3.2	4	120	190*	320	Actual and Potential ASS
	0.5	Barwon Water	4.7	3.4	1.3	4	250	8*	270	
	1.5	Barwon Water	4.6	2.4	2.2	4	260	14*	280	
LBC02	0.5	Barwon Water	5.1	4	1.1	4	150	4*	170	Actual ASS
	1	Barwon Water	4.5	3	1.5	4	200	6*	210	
	3	Barwon Water	6.3	3.6	2.7	4	28	5*	33	

Notes: * denotes adopted Chromium reducible sulfur value (acidity units) in place of potential acidity (acidity units)
^ Sample with highest reported net acidity value adopted for interpretation