



BlueSphere
ENVIRONMENTAL

Hydrogeological Investigation of the Kwararren Sub-basin

Surrounding Environment Investigation

Prepared for:

Barwon Water

**55-67 Ryrie Street
Geelong VIC 3220**

16 December 2024

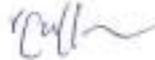
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Table of Contents

Acknowledgments	3
List of Abbreviations	i
Executive Summary	i
1 Introduction	1
1.1 Background	1
1.1.1 Stakeholders	2
1.2 Objectives	3
1.3 Scope of Work and Methodology	3
2 Key Documents and Information Sources	5
2.1 Introduction	5
2.2 Key Documents	5
2.2.1 Section 78 Notice	5
2.2.2 Remediation Environmental Protection Plan	6
2.3 List of Reports Considered	7
2.4 Information Sources	8
3 Kawarren Investigation Area (KIA) Overview	10
3.1 Introduction	10
3.2 KIA Definition	10
3.3 KIA History	10
3.4 Previous Investigations	11
4 Conceptual Site Model	13
4.1 Introduction	13
4.2 Climate	13
4.2.1 Regional Conditions	13
4.2.2 Recognised Drought Periods	13
4.2.3 Local Rainfall Conditions	14
4.2.3.1 Available Data	14
4.2.3.2 Average Annual Rainfall	15
4.2.3.3 Long-Term Rainfall Trends	16
4.2.4 Evaporation	19
4.2.5 Climate Change	19
4.3 Topography	20
4.4 Drainage	20
4.5 Vegetation	21
4.6 Site Inspection	22
4.7 Land Use Review	22
4.8 Geology	23
4.8.1 Structural Setting	23
4.8.1.1 Grabens	23

	4.8.1.2	Yeo Dome Basement High	25
	4.8.1.3	Basement Topography	25
	4.8.2	Regional Surface Geology	25
	4.8.3	Geology of the KIA	29
4.9		Hydrogeology	32
	4.9.1	Hydrostratigraphy	32
	4.9.2	Quaternary Aquifer (QA)	35
	4.9.3	Lower-Mid Tertiary Aquifer (LMTA)	35
	4.9.4	Lower Mid Tertiary Aquitard (LMTD)	36
	4.9.5	Lower Tertiary Aquifer (LTA)	39
	4.9.5.1	Aquifer Distribution	39
	4.9.5.2	Groundwater Flow Systems	39
	4.9.5.3	LTA Hydraulic Parameters	41
	4.9.5.4	Hydraulic Gradients	44
	4.9.5.5	Flow Rates and Residence Times	44
	4.9.5.6	Aquifer Recharge and Discharge Estimates	45
	4.9.6	Otway Group Aquifer	48
4.10		Groundwater Resource Utilisation	48
	4.10.1	Registered Extractive Use Bores	48
	4.10.2	Barwon Downs Borefield	48
	4.10.2.1	Licence	49
	4.10.2.2	Operational History	50
4.11		PCV Amendment Rationale	51
4.12		Groundwater Quality	52
4.13		Surface Water	53
	4.13.1	Regional Setting	53
	4.13.2	Local Surface Water Systems	53
	4.13.3	Springs / Soaks	56
	4.13.4	Hydrological Characteristics	56
	4.13.5	Surface Water Quality	57
	4.13.6	Surface Water Utilisation	57
4.14		GDEs	60
4.15		Acid Sulfate Soils	60
5		Impact Assessment	63
	5.1	Groundwater Potentiometric Surface Trends	63
	5.2	Identification of Susceptible Water Features	64
	5.3	Observed Surface Water Flow Trends	65
	5.3.1	Loves Creek and Tributaries	69
	5.3.2	Gellibrand River	73
	5.4	Apportionment of Likely Influences on Observed Flow Trends	76
	5.4.1	Long-term Rainfall Deficit on Recharge to LTA	76
	5.4.1.1	Ten Mile Creek and Yahoo Creek	77
	5.4.1.2	Loves Creek	77
	5.4.1.3	Gellibrand River	77
	5.4.1.4	Summary	78
	5.4.2	Influence from Upstream Tributaries	78

5.4.3	Surface Water Extraction	78
5.4.4	Groundwater Extraction from the LTA	79
5.4.5	Land Use Change	81
5.4.6	Summary	81
5.5	Significance of Observed Hydraulic Influence	84
5.6	Risk Assessment	84
5.7	Overview of Changes Since Worst Case Conditions	87
6	Data Gaps	88
7	Conclusions and Recommendations	89
7.1	Conclusions	89
7.2	Recommendations	90
8	Limitations	91
9	References	92

List of Tables (Body of Report)

Table 1 Stakeholders	2
Table 2 Rainfall Stations	14
Table 3 Average Annual Rainfall by Station	15
Table 4 Cumulative Change in Rainfall (1997 to 2009) by Station	17
Table 5 Detailed Stratigraphy (Top to Bottom of Sequence)	30
Table 6 Summary of Regional Aquifers / Aquitards (Top to Bottom of sequence)	33
Table 7 LTA Hydraulic Properties Summary	42
Table 8 Average Linear Velocity Kawarren Recharge Avenue and Pipeline Restriction	44
Table 9 Previous LTA Recharge and Discharge Estimates (as quoted)	45
Table 10 Production Bore Summary (adapted from GHD, 2023)	49
Table 11 Licence Conditions	49
Table 12 Pumping Summary	50
Table 13 Salinity Range of Aquifer/Aquitard Groupings	52
Table 14 Statistical Analysis of Groundwater Quality Data - Gellibrand Area	52
Table 15 Summary of Surface Water Catchments in KIA	54
Table 16 Surface Water Catchment Hydrological Characteristics (adapted from Hebblethwaite and James 1990) ¹	56
Table 17 Summary of Licenced Surface Water Extraction	59
Table 18 Summary of Acid Sulfate Soil Classification	61
Table 19 Gellibrand River Baseflow Estimates and Streamflow Contribution	67
Table 20 Hydraulic Gradient Estimates	79
Table 21 Summary of Surface Water Impact Assessment	83
Table 22 Risk Assessment for Protection of GDEs	86

List of Figures (Body of Report)

Figure 1 Spatial Trend of Average Annual Rainfall in Victoria (1991 – 2020, 30 year period) (BoM, 2020)	13
Figure 2 Rainfall deciles for the Millennium drought (1997 to 2009) (Bureau of Meteorology, 2020).	14
Figure 3 Average Annual Rainfall from nine rainfall station sites	16
Figure 4 Accumulative Monthly Residual Rainfall (grey shading indicates periods of drought)	18
Figure 5 Pan Evaporation Barwon Downs Area	19
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))	21
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	23
Figure 8 Regional Tectonic Setting, Eastern Otway Basin (after Department of Minerals and Energy (1984)) (approximate KIA Location shown in red)	24
Figure 9 Regional Structural Setting (Leonard, Lakey, & Blake, 1983)	25
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)	27
Figure 11 Regional Geological Cross Sections (Colac 1: 50,000 Geological Map Series)	28
Figure 12 Bore hydrographs in LTA and LMTD	37
Figure 13 Bore Hydrographs in LTA and Clifton Formation (uncertainty regarding M22 water levels pre refurbishment)	38
Figure 14 Recharge Avenues (Modified from (Department of Minerals and Energy, 1984))	40
Figure 15 Cross Section of Kawarren Recharge Avenue after (HydroTechnology, 1994)	40
Figure 16 Monthly Extracted Total	51
Figure 17 Minimum Monthly and Annual Streamflow Observations – Yahoo Creek	69
Figure 18 Minimum Monthly and Annual Streamflow Observations – Ten Mile Creek	70
Figure 19 Minimum Monthly and Annual Streamflow Observations – Porcupine Creek	70
Figure 20 Minimum Monthly and Annual Streamflow Observations – Loves Creek	72
Figure 21 Minimum Monthly and Annual Streamflow Observations (Logarithmic) – Loves Creek	73
Figure 22 Minimum Monthly and Annual Streamflow Observations – Gellibrand River at Bunker Hill	74
Figure 23 Minimum Monthly and Annual Streamflow Observations – Gellibrand River Tributaries (excluding Loves Creek)	75

List of Figures

Figure F1 Regional Setting	95
Figure F2 Kawarren Sub-basin Investigation Area	95
Figure F3 Hydrology and Rainfall Stations	95
Figure F4 Topography	95
Figure F5 Ecological Vegetation Classes	95
Figure F6 Registered Groundwater Wells	95
Figure F7 Extractive Groundwater Users	95
Figure F8 Top of Otway Group	95
Figure F9 Surficial Geology	95
Figure F10 LTA Thickness	95
Figure F11 Clifton Formation Thickness	95
Figure F12 Conceptualised Geological Cross Section A-A'	95
Figure F13 Conceptualised Geological Cross Section B-B'	95
Figure F14 Conceptualised Geological Cross Section C-C'	95
Figure F15 Conceptualised Geological Cross Section D-D'	95
Figure F16 Potentiometric Surface Contours – LTA (after Leonard 1983)	95
Figure F17 Potentiometric Surface Contours – LTA 2010	95
Figure F18 Potentiometric Surface Contours – LTA 2021	95
Figure F19 Mapped Springs (Porcupine Creek Sub-Catchment)	95
Figure F20 Mapped Springs (Ten Mile Creek Sub-Catchment)	95
Figure F21 Mapped Springs (Yahoo Creek Sub-Catchment)	95
Figure F22 Mapped Springs (Loves Creek and Gellibrand River Sub-Catchment)	95
Figure F23 Groundwater Dependent Ecosystems	95
Figure F24 Acid Sulfate Soils	95
Figure F25 Water Level Change in Kawarren Sub-basin Investigation Area: 1997 – 2013	95
Figure F26 Expected Recharge and Discharge Areas – LTA	95

List of Appendices

Appendix A	Section 78 Notice
Appendix B	Previous Investigation Report Summaries
Appendix C	Aerial Photographs (1982 – 2019)
Appendix D	Site Inspection and Interview Summaries
Appendix E	Acid Sulfate Soil Tables
Appendix F	Hydrographs

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	Titrateable 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, as well as associated catchment areas to identify any other areas that could have been potentially affected within the study area.

During the course of the 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. Groundwater was extracted from the borefield under 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;
- Identify potential groundwater dependent ecosystems and their relationship to the LTA; and
- Use the CSM in conjunction with the available data 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 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, the weight of evidence indicates that extraction has not resulted in environmentally significant adverse impacts – i.e., material harm to human health or the environment, within the KIA. It is noted that some concerns and observations raised by knowledgeable community members as part of this work do not appear to be related to extraction from the Barwon Downs borefield. Some of these concerns also related to features that are separated from the LTA and more likely driven by changes within the LMTA, that forms the uppermost aquifer system across a large proportion of the Barwon Downs graben.

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. Groundwater was extracted from the borefield under 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 objectives of the REPP are twofold:

- **The Boundary Creek & Big Swamp Remediation Plan** – that outlines the controls and actions that have and will be implemented to:
 - **Ensure** no further harm from Barwon Water's historic groundwater pumping or remediation actions.

- **Protect** the water quality and ecological values of the Barwon River.
- **Improve** the water quality and streamflows within Boundary Creek.
- **Improve** the ecological values of Big Swamp.
- **The Surrounding Environment Investigation** – To investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction activities at the Barwon Downs borefield.

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,	Independent Technical Expert

Stakeholder Group	Stakeholder	Interest
	School of Environmental Sciences, Charles Sturt University	
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
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 model¹ (CSM) based on the current state of knowledge which describes the physical setting and groundwater system including geological, hydrogeological and hydrological characteristics;
- Identify potential groundwater dependent ecosystems and their relationship to the LTA; and
- Use the CSM in conjunction with the available data 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 a site inspection to ground truth the findings of the desktop review and interviews with knowledgeable landholders;

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)

- Development of a CSM for the KIA;
- Identification of water features (surface water features and/or groundwater dependent ecosystems) that are potentially susceptible to impacts from Barwon Water's historic management of groundwater pumping activities within the LTA;
- Apportionment of likely flow impact from Barwon Water's historic management of groundwater pumping activities within the LTA as opposed to other factors;
- Overview of changes and/or improvements since the cessation of Barwon Water's groundwater pumping activities;
- Consultation with relevant stakeholders including presenting and testing the assumptions in the CSM and inclusion of feedback from independent technical experts; 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.*

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 on 8 October 2024 (Barwon Water, 2024). 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 objectives of the REPP are twofold:

- **The Boundary Creek & Big Swamp Remediation Plan** – that outlines the controls and actions that have and will be implemented to:
 - **Ensure** no further harm from Barwon Water’s historic groundwater pumping or remediation actions.
 - **Protect** the water quality and ecological values of the Barwon River.
 - **Improve** the water quality and streamflows within Boundary Creek.
 - **Improve** the ecological values of Big Swamp.
- **The Surrounding Environment Investigation** – To investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction activities at the Barwon Downs 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 occurrence of cease to flow events in Boundary Creek and the increased severity of wet-dry cycling processes within Big Swamp – a wetland that is primarily fed by inflows from Boundary Creek.

This occurred 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 from being realised.

Remedial actions for Boundary Creek and Big Swamp included:

- Cessation of groundwater pumping activities;
- Decommissioning of the Barwon Downs borefield extraction bores;
- Provision of supplementary flows, where required, to maintain flows of at least 0.2 ML/day at the Boundary Creek at Yeodene stream gauge (site 233228)
- Provide suitable conditions for wetland species to recolonise impacted areas; and
- Development of risk-based contingency measures to be implemented in the unlikely event that they are required.

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 21 groundwater (GW) bores and 5 stream gauges within the areas for further investigation. Further, in 2022, Barwon Water redeveloped and reinstated 3 former state observation bores adjacent to the Gellibrand River and installed loggers to recommence monitoring at these locations.

As part of these works, the vegetation around the new bores (ELA, 2020) and within the broader area was also assessed to determine the GDE potential within the surrounding environment (ELA, 2022).

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. Heislars, 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 Kwararren 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 Kwararren 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
- 44_2022.10.25_Otway Ranges surrounding areas hydrogeological investigation_Final_Appendices_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 Kwararren 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 km², 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). Plantations of pine and gum have been in both the Ten Mile and Yahoo Creeks since c. 1970s (pers. Comms M. Gardiner) with multiple rotations occurring. 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,

2024). 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 km² of outcropping aquifer material which was considered to act as the principal recharge area to the KIA, from a total outcrop area of 28 km². 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 online² 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).

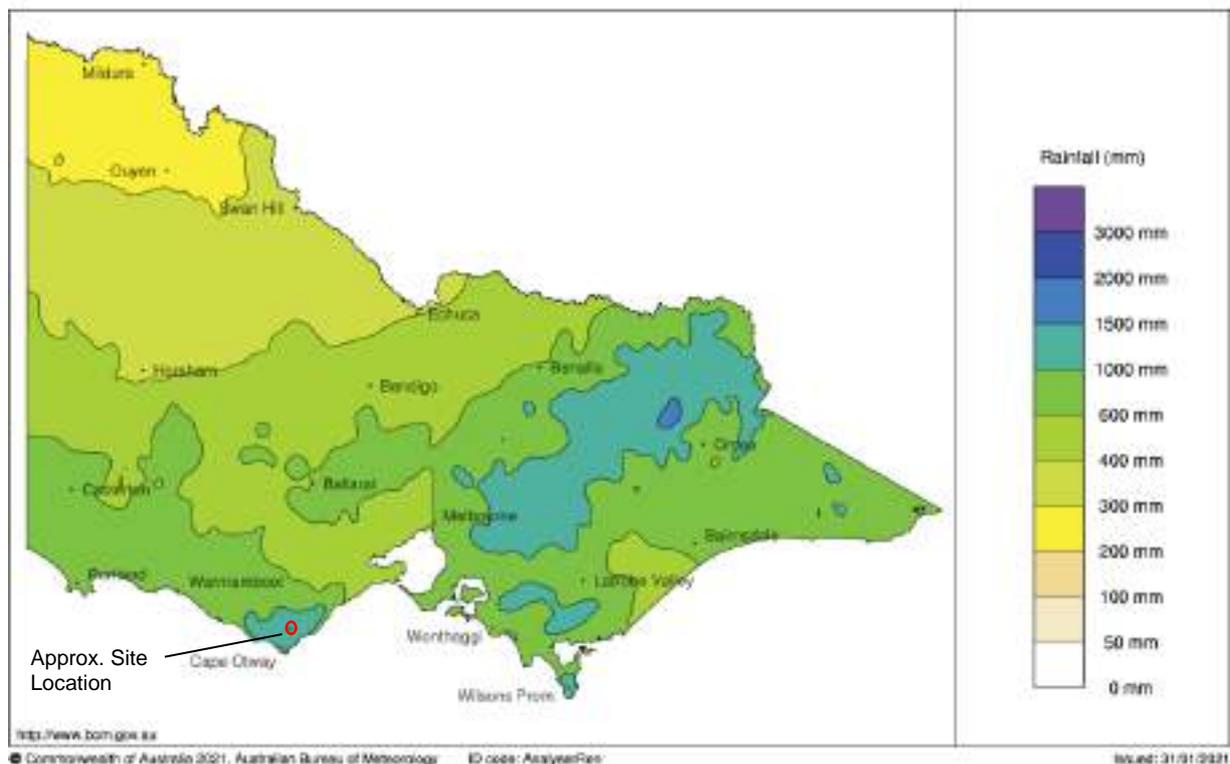


Figure 1 Spatial Trend of Average Annual Rainfall in Victoria (1991 – 2020, 30 year period) (BoM, 2020)

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).

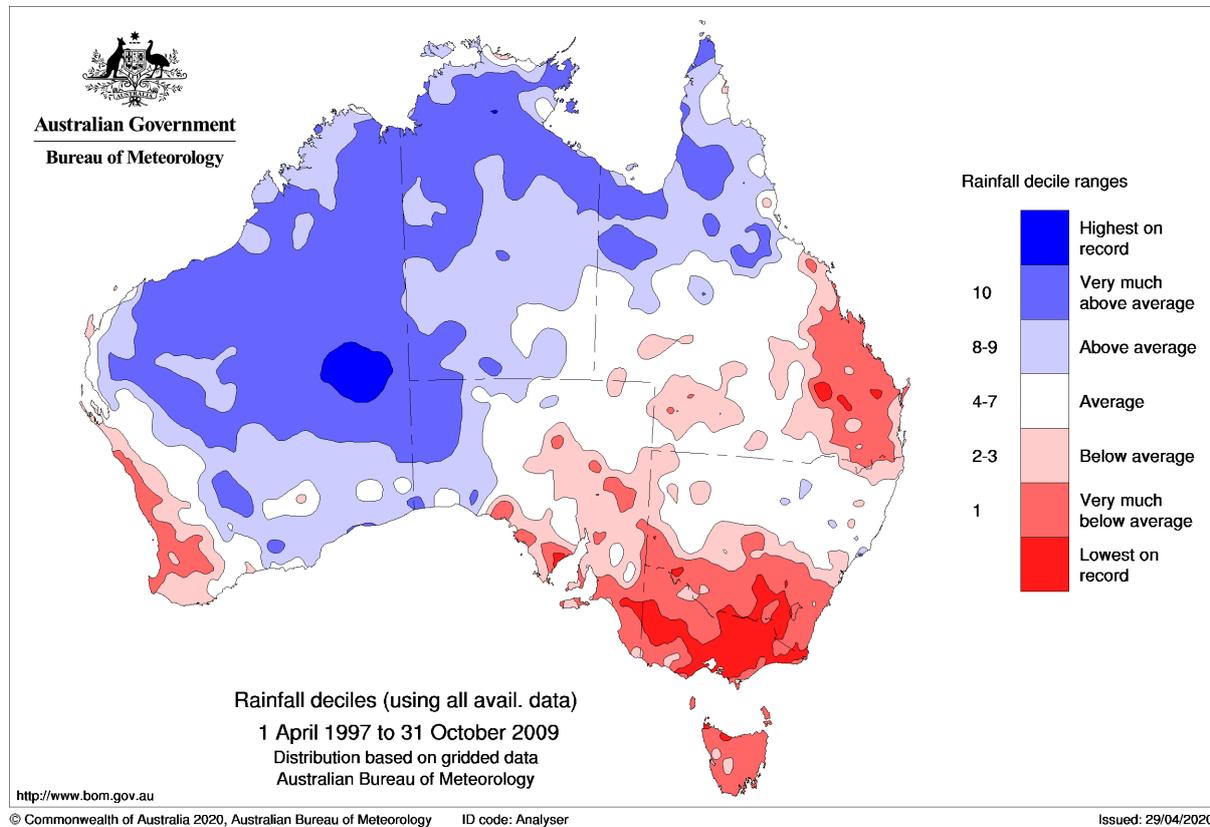


Figure 2 Rainfall deciles for the Millennium drought (1997 to 2009) (Bureau of Meteorology, 2020).

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

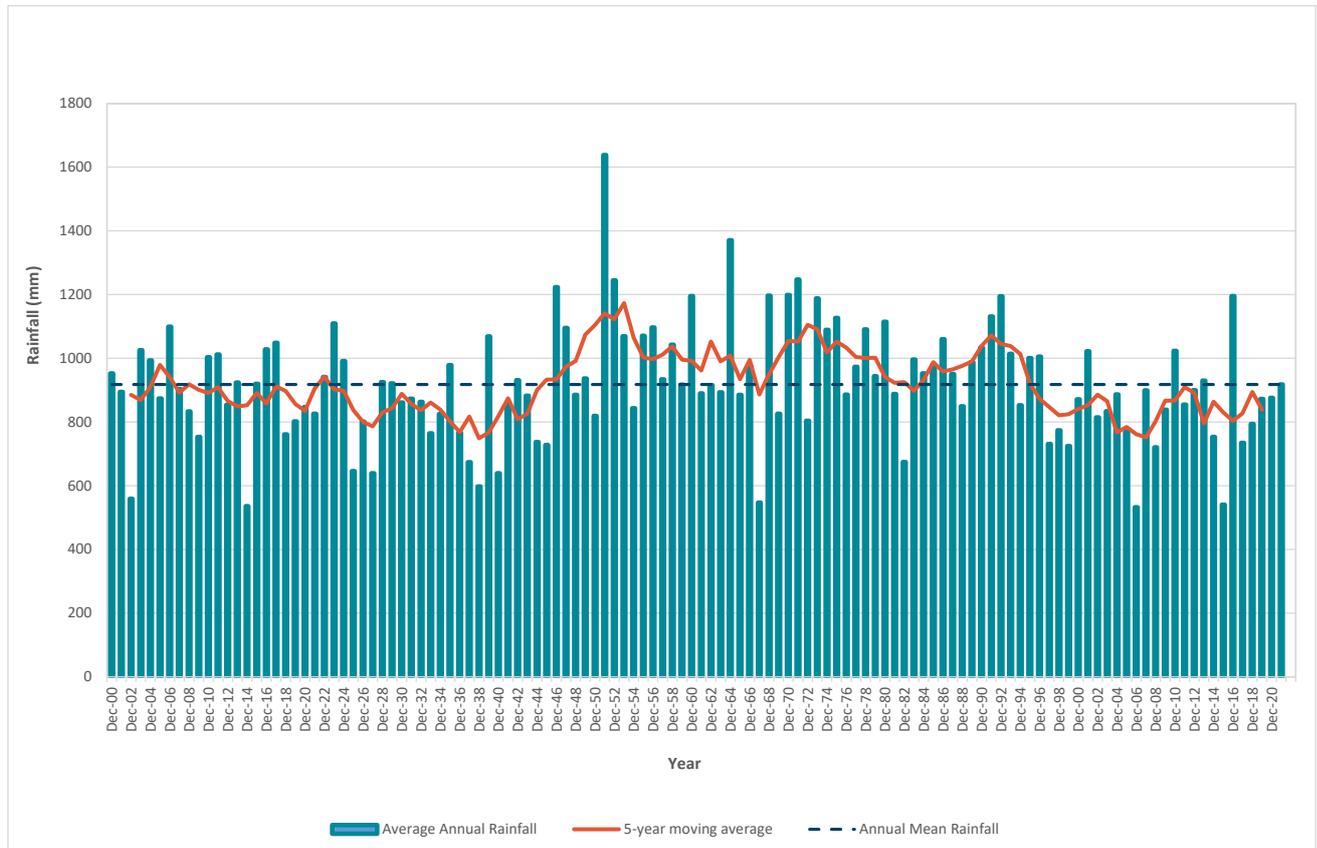


Figure 3 Average Annual Rainfall from nine rainfall station sites

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%

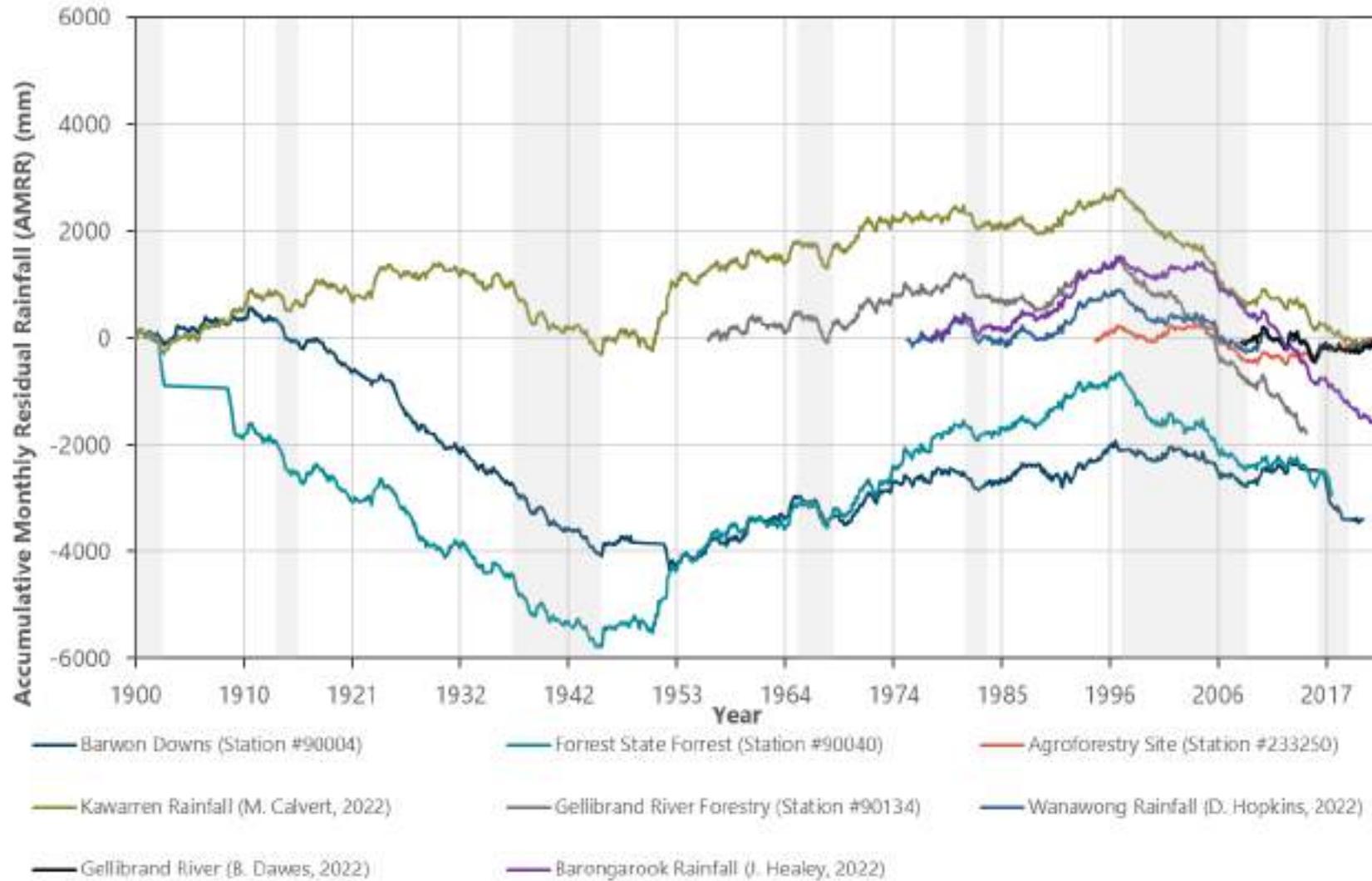


Figure 4 Accumulative Monthly Residual Rainfall (grey shading indicates periods of drought)

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).

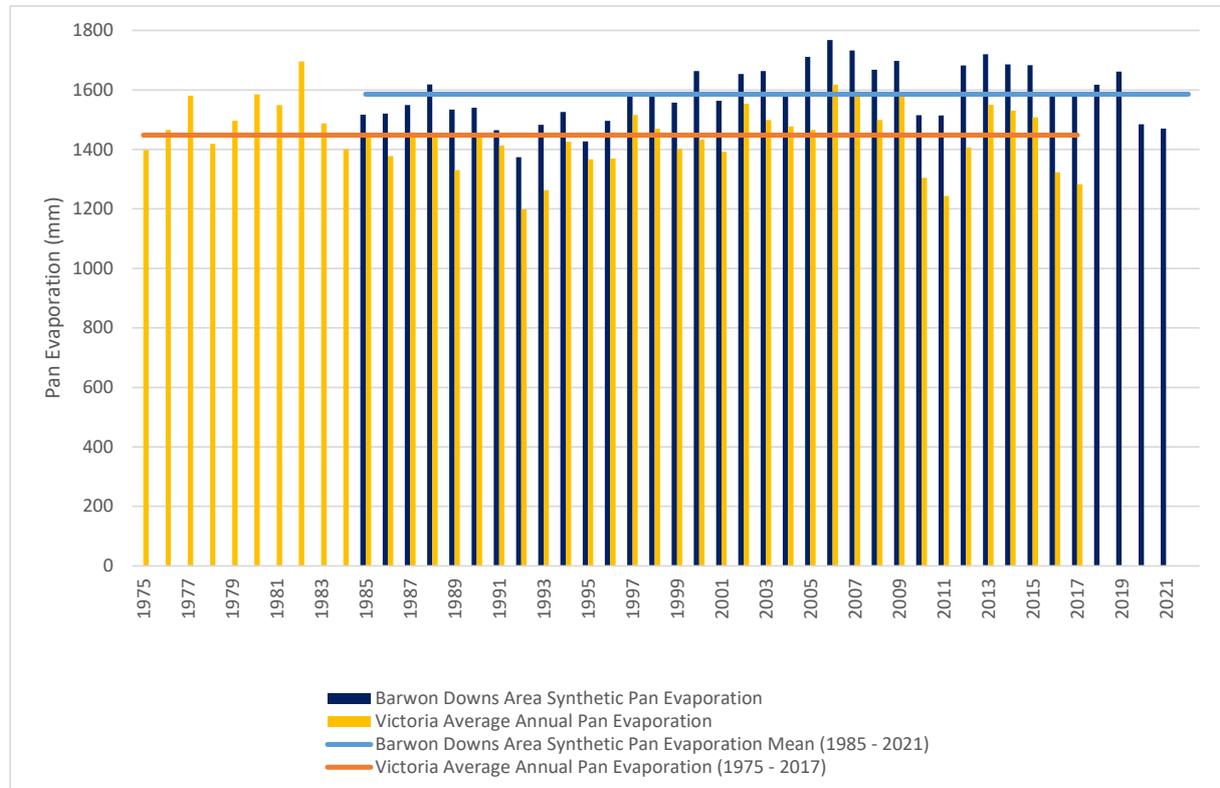


Figure 5 Pan Evaporation Barwon Downs Area

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**.

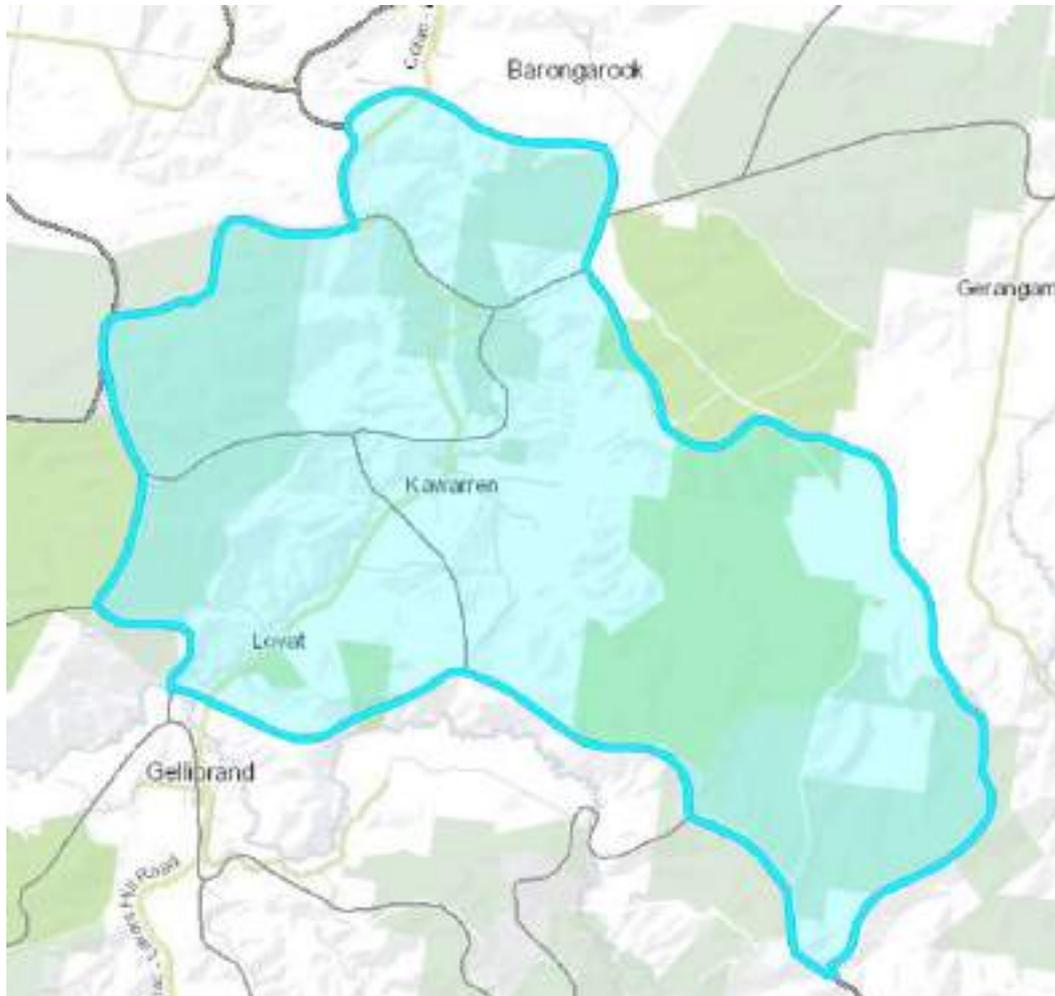


Figure 6 Loves Creek catchment including Ten Mile Creek, Yahoo Creek and Porcupine Creek sub-catchments (MapShare Victoria, Department of Energy, Environment and Climate Action (EECA) formerly Department of Environment, Environment, Land, Water and Planning (DEWLP))

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.

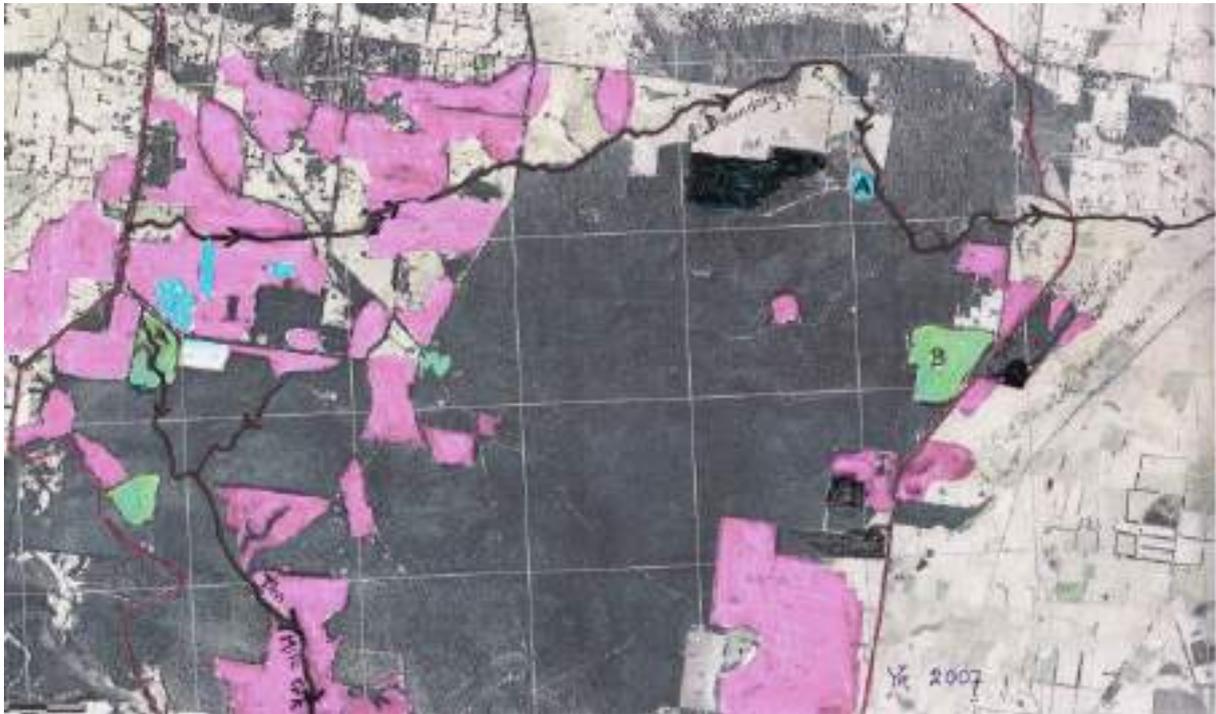


Figure 7 Map 55 from (Gardiner, 2015c) showing areas cleared of trees between 1947 and 1977 (pink shading), between 1977 and 2007 (blue shading). Green shading indicates areas planted out with pine or eucalyptus

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 (Lahey & 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 undisturbed 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).

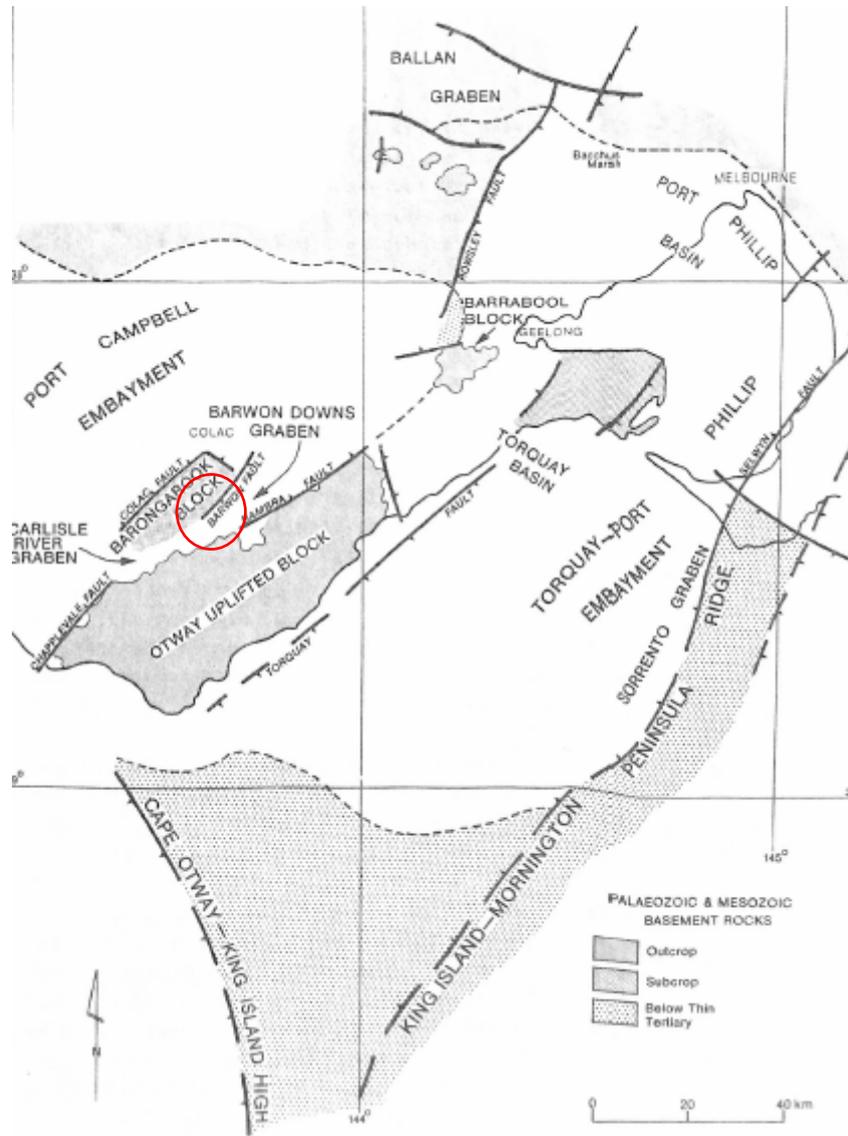


Figure 8 Regional Tectonic Setting, Eastern Otway Basin (after Department of Minerals and Energy (1984)) (approximate KIA Location shown in red)

The Barwon Downs Graben is bordered by the Loves Creek Monocline in the north, separating the graben from the Barangaroo High (**Figure 9**). To the south the Baramba 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 Baramba 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).

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 (Lahey & 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.

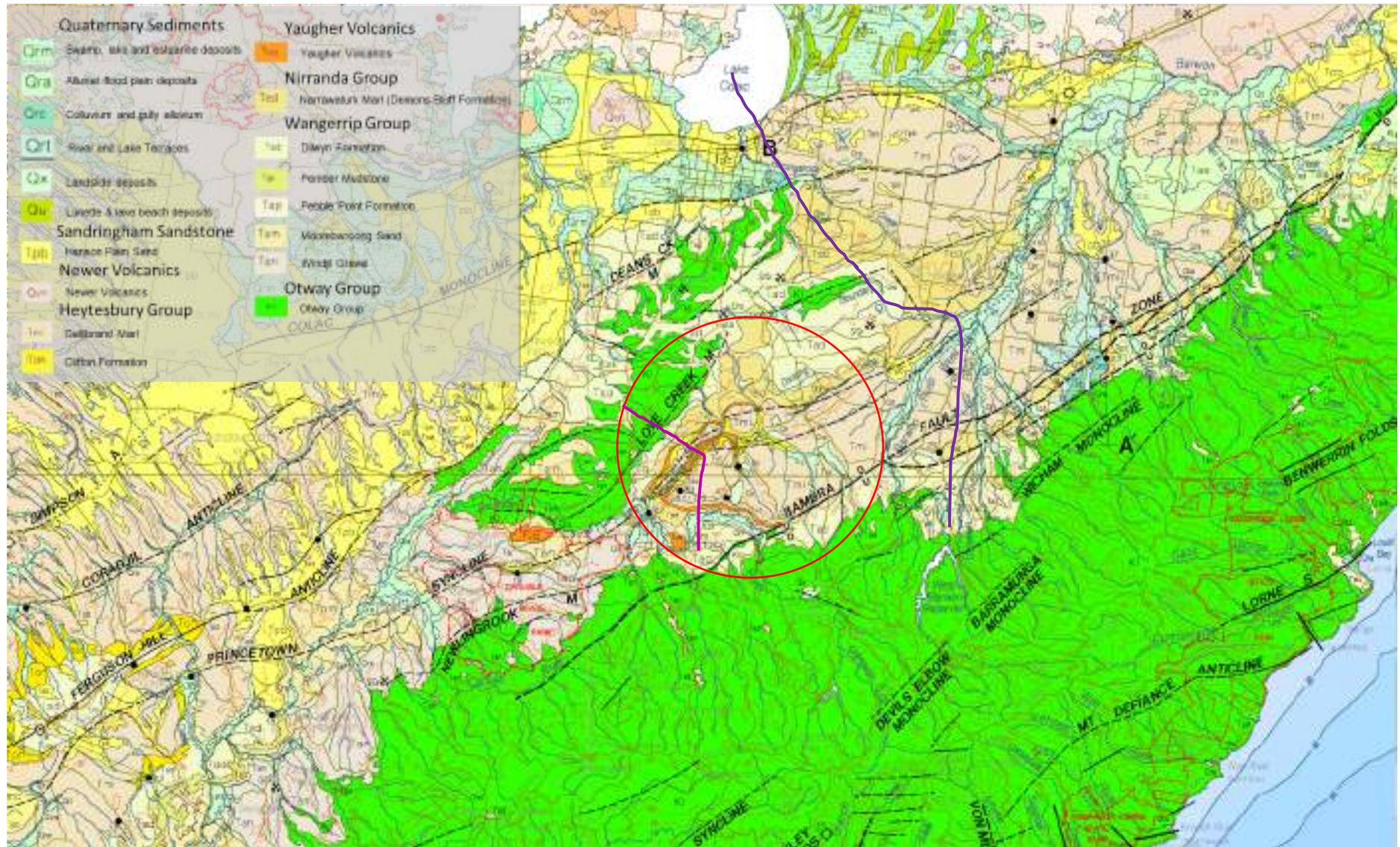


Figure 10 Regional Surficial Geology (Colac 1:250,000 Geological Map Series) (approx. KIA area shown in red, A-A' alignment purple, B-B' alignment pink)

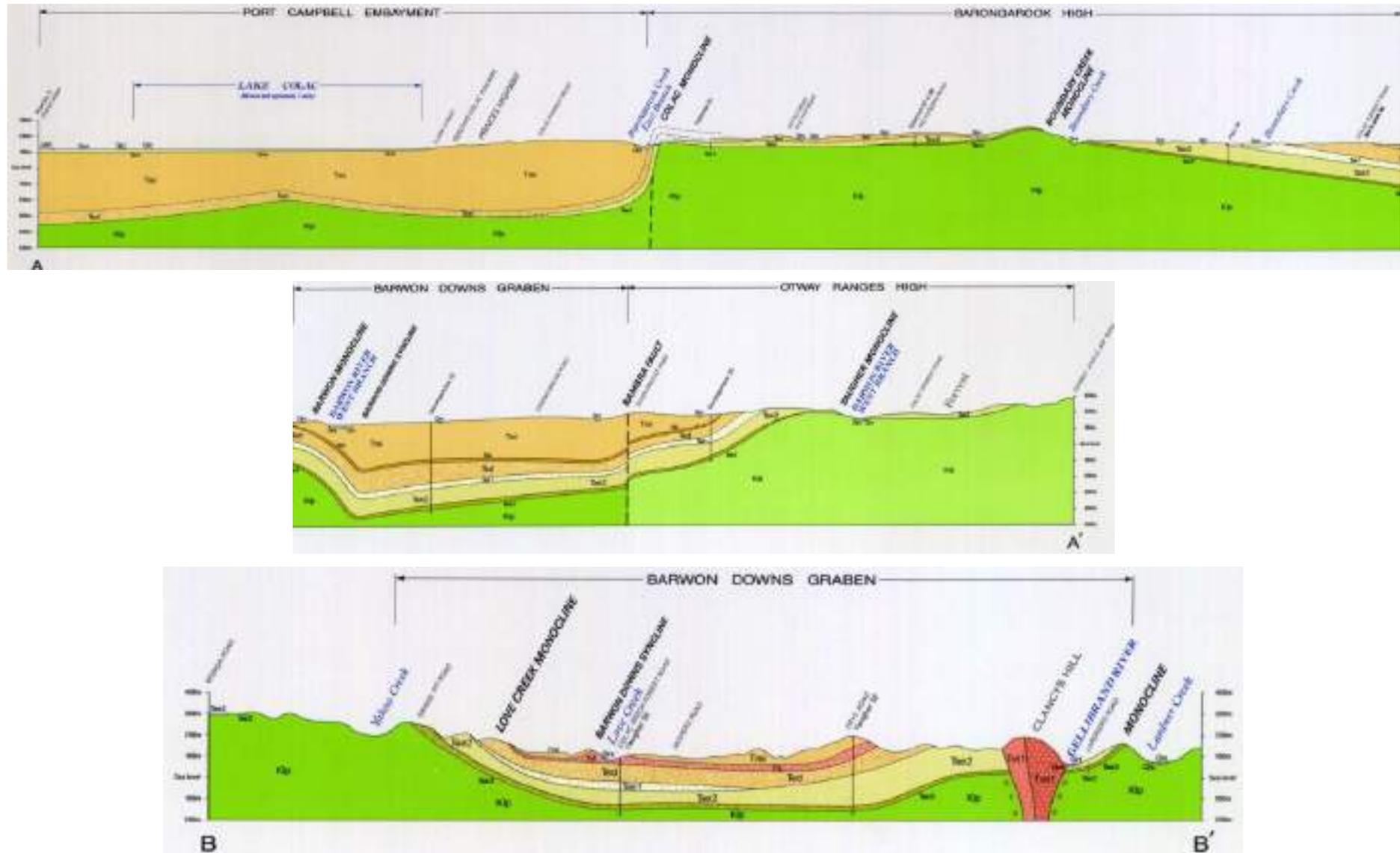


Figure 11 Regional Geological Cross Sections (Colac 1: 50,000 Geological Map Series)

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 interfingering 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. ⁷			
Wangerrip Group						
Mepunga Formation ⁴	Tickell et al., 1991 describe it as originating from a fluvial 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
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.	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
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.	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.
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 Volcanics: 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 Narraturk 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, where 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 Yaughar 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 Yaughar 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 contrast 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 Marl⁷ 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.

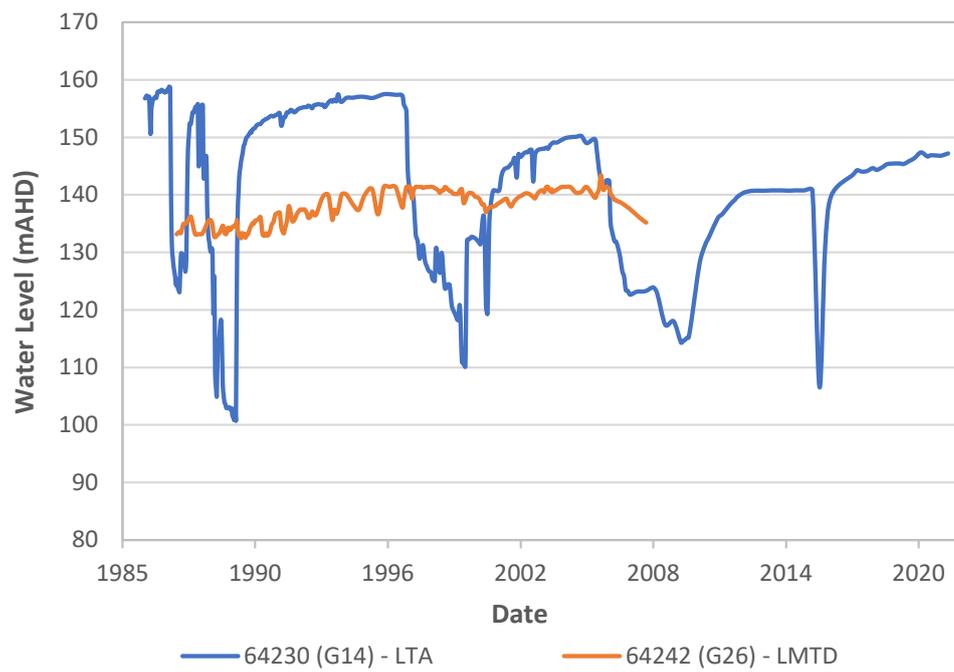
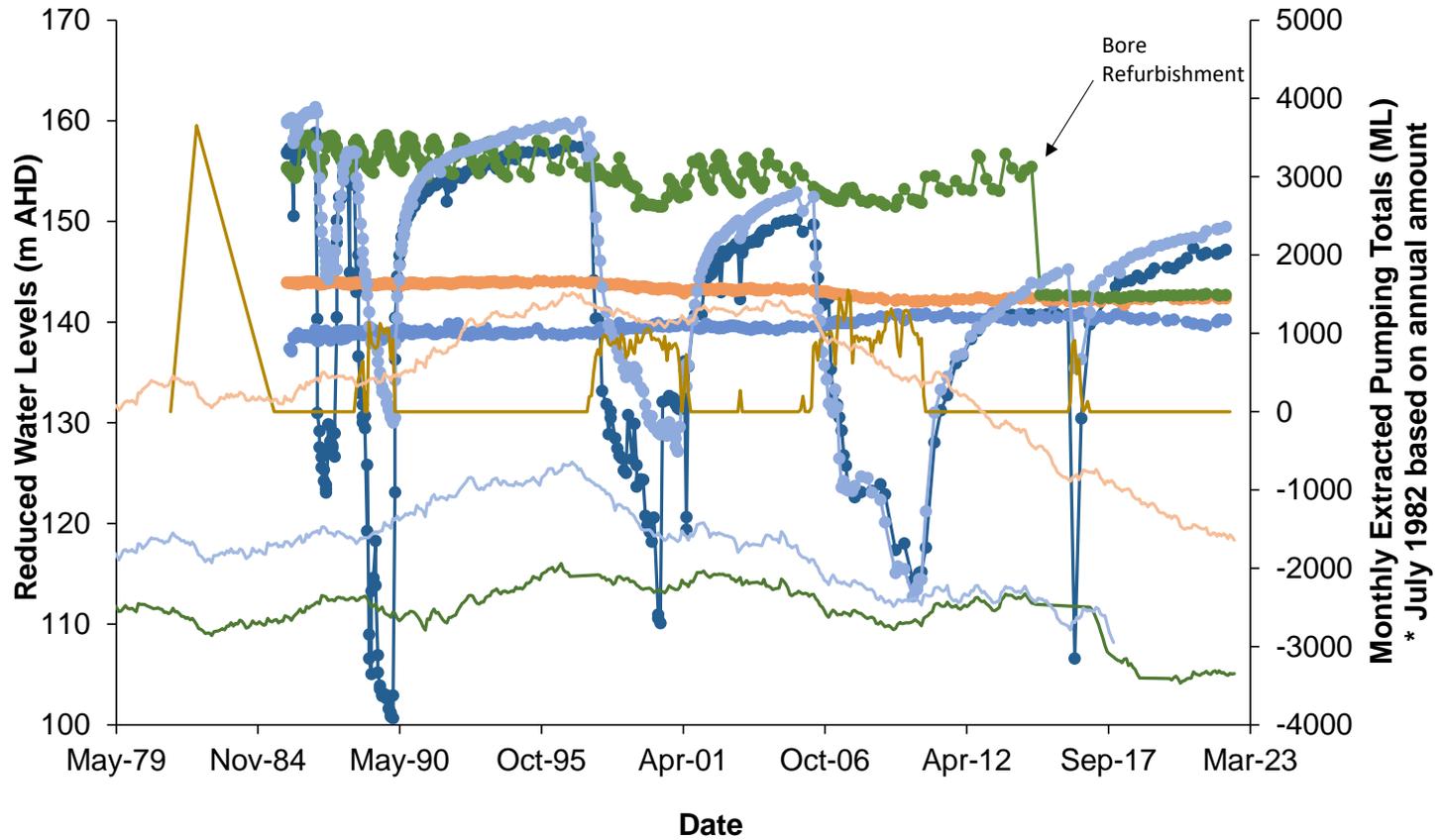


Figure 12 Bore hydrographs in LTA and LMTD



- G14 (D)
 - G19 (CFm)
 - M24 (PP)
- G18 (CFm)
 - M22 (CFm)
 - Monthly Pumping Total
- CFm - Clifton Formation
 - M - Mepunga Fm
 - D - Dilwyn Fm
 - PP - Pebble Point Fm

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 Kwararren 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 Kwararren 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 (Aquadé, 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. Aquadé (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 Aquadé (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 Kwararren 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 'Kwararren 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.

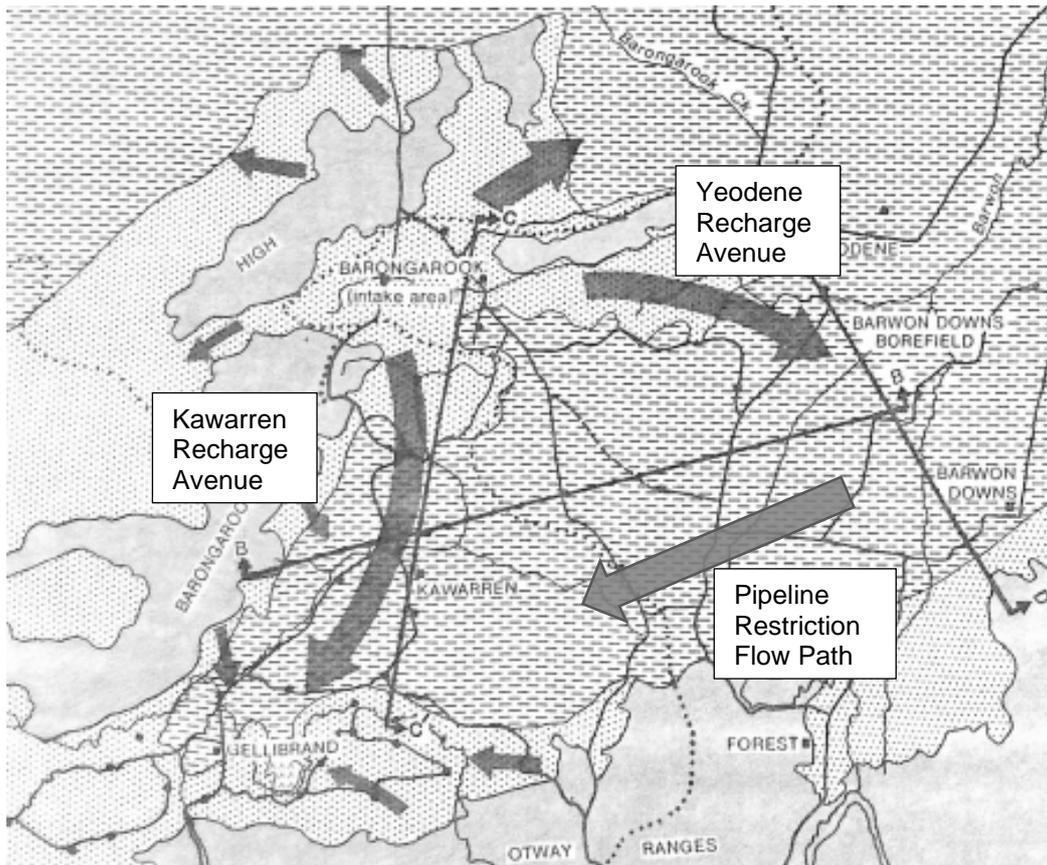


Figure 14 Recharge Avenues (Modified from (Department of Minerals and Energy, 1984))

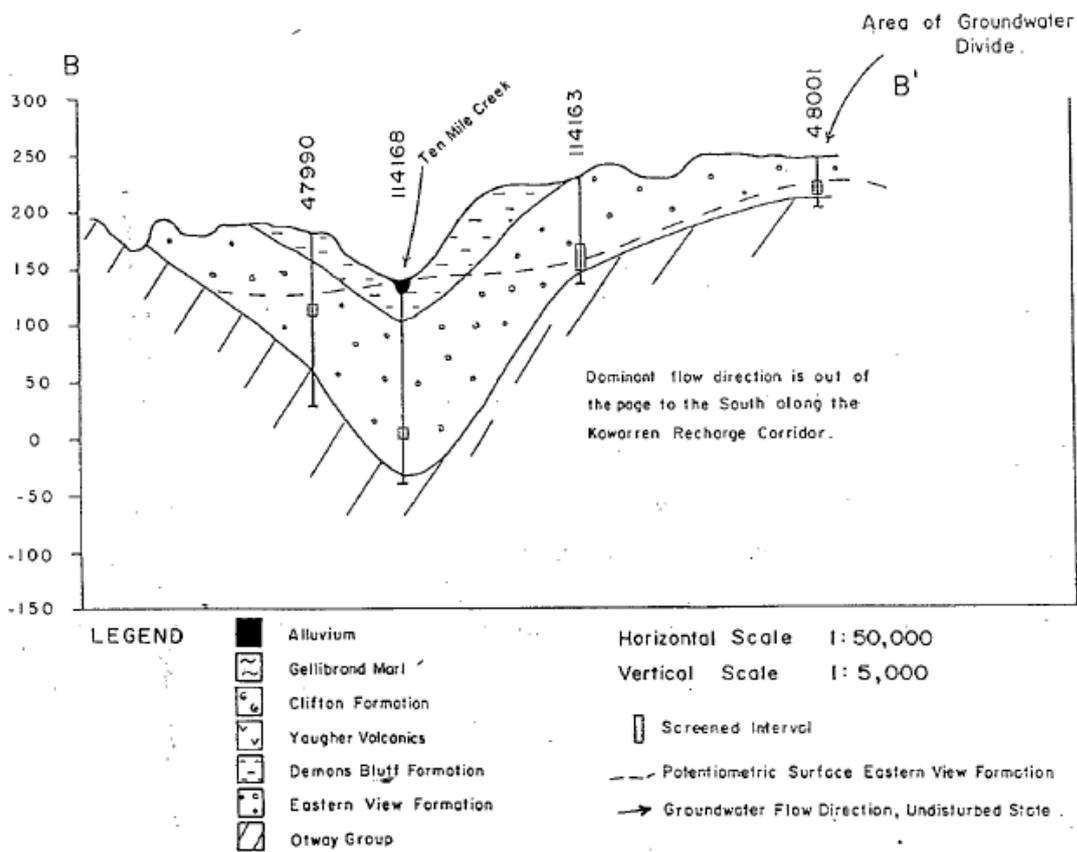


Figure 15 Cross Section of Kowarren Recharge Avenue after (HydroTechnology, 1994)

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 m²/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 m²/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 (m ³ /day)	Test Duration (days)	Drawdown in Production Bore at Test End (m)	Transmissivity of Aquifer Interval test (m ² /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 x 10 ⁻⁴
Gerangamete (Barwon Downs Borefield)	GW2	6	Dilwyn; Pebble Point	75	5564.16	5.0	25.75	512	6.8	3.2 x 10 ⁻⁴
	GW2A	-	Mepunga; Dilwyn; Pebble Point	78	7732.8	0.08	21.45	650	8.3	2.8 x 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 x 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 x 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	Yaughter 27	3	Dilwyn	15	2743.80	10.0	24.88	220	14.7	5×10^{-4}
Mcdonalds Lane	Yaughter 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	Yaughter 37	4+	Dilwyn; Mepunga	72	5413	6.5	-	970	13.5	3.0×10^{-4}
Kawarren	Yaughter 51	Yaughter 50		-	-	-	-	968	-	3.0×10^{-4}
Kawarren	Yaughter 51	Yaughter 35 (108910)		-	-	-	-	1056	-	1.0×10^{-4}
Kawarren	Yaughter 51	Yaughter 34 (108909)	-	-	-	-	-	728	-	1.1×10^{-3}
Kawarren	Yaughter 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 'aquitar' (comprising Narrawaturk Marl, Yaughar 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**), given the limited response in water levels during pumping periods when compared to the LTA water levels.

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 km² 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)	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Intake area ~54 km² 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 indicated that 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	<ul style="list-style-type: none"> Intake area for Barwon downs Graben is ~31 km² 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)	<ul style="list-style-type: none"> Through-flow via the Pipeline Restriction calculated via porioning 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Intake area for Barwon downs Graben is ~31 km² 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)	<ul style="list-style-type: none"> Reported to be via flow-net analysis (Aquadre Groundwater Services, 2019) 	Lakey & Leonard, 1984 ⁷
1,500 – 2,000	-	Barongarook to Kawarren Avenue	<ul style="list-style-type: none"> Based on 10 km² of outcropping LTA Effective infiltration rate of 17% (using mean annual precipitation of 1,000 mm) 	Stanley, 1991
0	-	Kawarren (via pipeline)	<ul style="list-style-type: none"> Considered at the time to no longer exist based on pump test responses noting further investigation was recommended. 	Stanley, 1991
1,600	-	Barongarook to Kawarren Avenue	<ul style="list-style-type: none"> Based on 12 km² of outcropping LTA. Effective infiltration rate of 16% (using mean annual precipitation of 1,000 mm) 	HydroTechnology, 1994
300	-	Kawarren (via pipeline)	<ul style="list-style-type: none"> 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
			<ul style="list-style-type: none"> m/day and so considered more representative) Hydraulic gradient of 0.03 	
-	No more than 2,900 ML/year	Gellibrand River	<ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> 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 km² to 12 km²) 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 & Cartwright, 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 km²), 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).

Lahey & 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 Lahey & 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. The registered extractive use detail has been sourced from the State database and the locations may be inaccurate. Local knowledge indicates that some of the bores identified within the area either do not exist or have not been used for a long time.

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 (Lahey & Leonard, 1983).
- An additional two production bores were installed in 2001.

Table 10 Production Bore Summary (adapted from GHD, 2023)

Production Bore ID	Date Installed	Bore Depth (m)	Screen Interval (m)	LTA ¹ Units
GW2A	20 May 1982 Relined in 1998 and refurbished in 2016	535	401 - 542	Mepunga, Dilwyn, Pebble Point
GW3	25 Sep 1983 Relined in 1997 and refurbished in 2016	538.8	378 - 527	Mepunga, Dilwyn, Pebble Point
GW4	15 February 1982 Relined in 1997 and refurbished in 2016	645	473 - 620	Mepunga, Dilwyn, Pebble Point
GW5	29 November 1981 Re-sleeved in 1987 and refurbished in 2016	511	361.5 – 501.5	Mepunga, Dilwyn, Pebble Point
GW6	12 January 2001 Refurbished in 2016	491.7	355 – 485	Mepunga, Dilwyn, Pebble Point
GW8	31 January 2001 Refurbished in 2016	550.4	396.5 – 544.5	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
1982/1983	3,652 ML	Corresponded to the 1982-83 drought
1987 – 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
2016	3,449.1 ML	The last time the borefield was used to supplement drinking water supplies
Total Volume Extracted	115,949.1 ML	Up to 119,000 ML

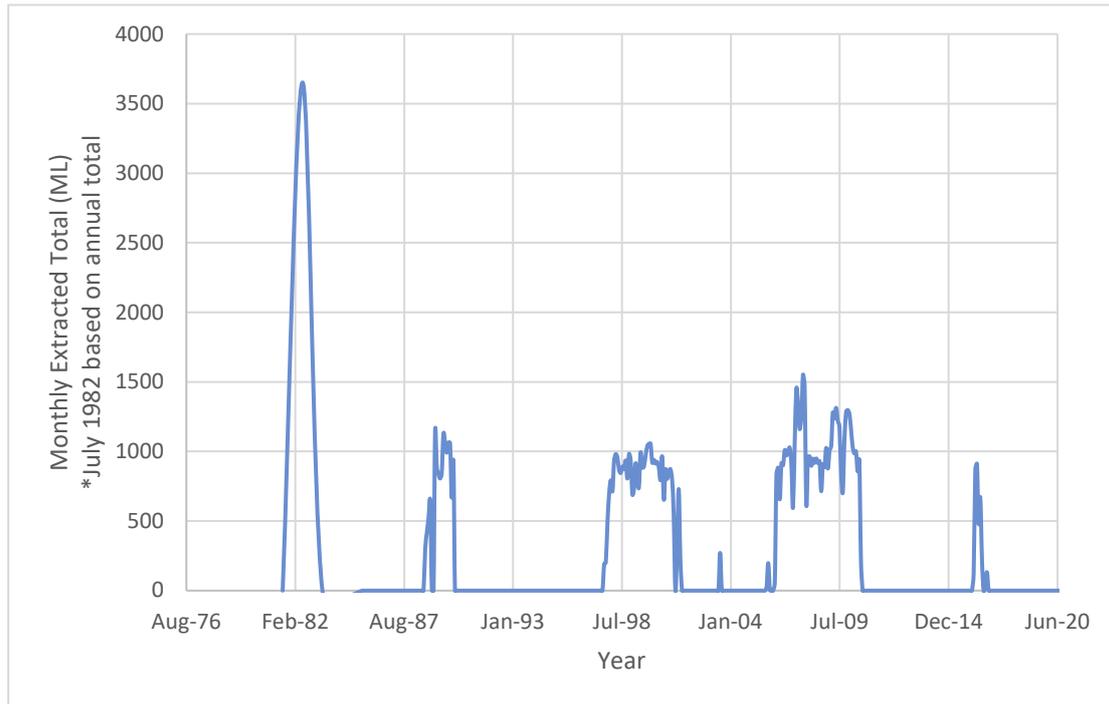


Figure 16 Monthly Extracted Total

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 years⁹. This was equivalent to the Barwon Water licence current at the time.

A PCV for the Gellibrand GMA of 0 ML was established. The Gerangamete PCV was amended in 2019 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 extent to which the PCV amendment would allow recovery to occur is unknown, however, during the review of the PCV it was noted that *"1,100 ML/year could be extracted from the area without causing further declines in water levels. This rate of extraction is expected to stabilise groundwater levels in the aquifer but will not allow for recovery of groundwater levels...Approximately 200-400 ML/year could be extracted from the area without causing adverse impacts to the waterways, once groundwater levels recover..."*¹⁰

DEECA have advised that *"...the review was specifically for the PCV of Gerangamete and is not a sustainable yield. The 200-400 ML/year volume was determined to be the volume that could be extracted while maintaining connection to Boundary Creek."*

The Gerangamete Local Management Plan was last updated in April 2023 and is to be reviewed on an as needs basis ¹¹.

⁹ Victorian Government Gazette, Permissible Consumptive Volume Groundwater Order 2011, No. G28, Thursday 14 July 2011

¹⁰ Otway Water Book 55 Otway Ranges Subterranean National Park, M. Gardiner September 2019.

¹¹ 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 13** below sourced from (Tickell et al., 1991).

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	500
Gellibrand Marl	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	

Parameter	Minimum Concentration	Maximum Concentration	ADWG
	mg/L	mg/L	mg/L
Silicate	1	39	
Total hardness	7	220	
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. (Lahey & 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	<p>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.</p> <p>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.</p>	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	<p>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.</p> <p>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.</p>	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	<p>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.</p> <p>Porcupine Creek originates in the south eastern corner of the KIA and flows north west before joining Ten Mile Creek and forming Loves Creek.</p> <p>It is understood (anecdotally) that both Porcupine Creek and Loves Creek flow throughout the year.</p>	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, Yaagher 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	<p>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.</p> <p>Loves Creek joins Gellibrand River just north of the Gellibrand township.</p> <p>Other contributors to Gellibrand River within or bordering the KIA include Lardners Creek and Charleys Creek.</p>	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 upper reaches of Ten Mile Creek are not expected to be fed by groundwater discharge (see **Figure F26**), and rather may well be fed by rainfall / runoff processes. 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 Kwarren 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	10 th Percentile	ML/day	4.46	4.35	13.38	27.23
	50 th percentile	ML/day	2.02	1.07	1.91	6.12
	90 th percentile	ML/day	1.42	0.84	0.30	2.66

Aspect		Units	Ten Mile Creek (235239)	Yahoo Creek (235240)	Porcupine Creek (235241)	Loves Creek (235234)
	98 th percentile	ML/day	1.27	0.81	0.17	2.29
Total Flow	10 th Percentile	ML/day	7.54	12.87	37.49	60.32
	50 th percentile	ML/day	2.64	1.27	4.06	9.85
	90 th percentile	ML/day	1.49	0.87	0.36	2.90
	98 th 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/daykm² versus 0.112 ML/day/km²). 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 holders – (i.e. those that can access water without a licence

or meter). 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. It is also noted that the surface water extraction amounts per year may not be fully realised and as such it is not known whether surface water extraction is a contributing factor to discrepancies of surface water baseflow observed in the following sections.

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 including mapped areas by ELA (2022a) and ELA (2022b) identified small areas of potential GDEs (**Figure F23**).

The process undertaken to identify GDEs within the KIA included the following:

- Review of publicly available information including the BoM GDE Atlas and incorporation of mapped areas onto figures;
- Review of previous investigations completed in the KIA and BDIA including ELA (2022a) and ELA (2022b) and incorporation of mapped areas onto figures;
- Completion of interviews with knowledgeable landholders in the area;
- Review of water levels of both the LTA and the LMTA within the KIA; and
- Display of this information on a figure (see **Figure F23**).

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. It is noted that the upper reaches of Ten Mile Creek are unlikely to receive groundwater discharge given the groundwater elevations being well below the surface (see **Figure F23** and **Figure F26**). Rather it is likely that the upper reaches of Ten Mile Creek are influenced by rainfall/runoff processes. 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 Groundwater Dependent Ecosystems**

Figure F24.

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 groundwater levels of bores in the LTA adjacent to the Gellibrand River area have shown minimal declines due to Barwon Water's groundwater pumping activities at the Barwon Downs borefield. That combined with the estimated discharge during several of the Millennium Drought years (see **Section 4.9.5.6** above) indicates that whilst discharge of groundwater to the Gellibrand River may have reduced somewhat during the groundwater pumping periods, it would not have ceased altogether.

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 refinement of the susceptible water features included the following process:

- Identification of the water feature and GDE based on mapping, community knowledge and previous assessment report data;
- Review of the geology, topography and potentiometric surface in the identified water feature area and their relationship;
- Assessment of whether the water feature and/or GDE are fed (directly or indirectly) by water from the LTA; and
- Reviewed the potential for pumping activities to have led to changes in these systems.

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**. Additionally, whilst there are several springs located along the upper reaches of both Ten Mile and Yahoo Creeks, along the outcrops of LTA, the upper reaches of Ten Mile Creek are not expected to be fed by groundwater discharge (see **Figure F26**), and rather may well be fed by rainfall / runoff processes. The identified springs/soaks and potential GDEs within the KIA were not located on LTA outcrops, where groundwater discharge is occurring, indicating that they were fed by the LMTD rather than the LTA.

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.

The stream flow gauges record flow rather than baseflow and as such a calculation has been completed to obtain the baseflow. 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 ^a	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.

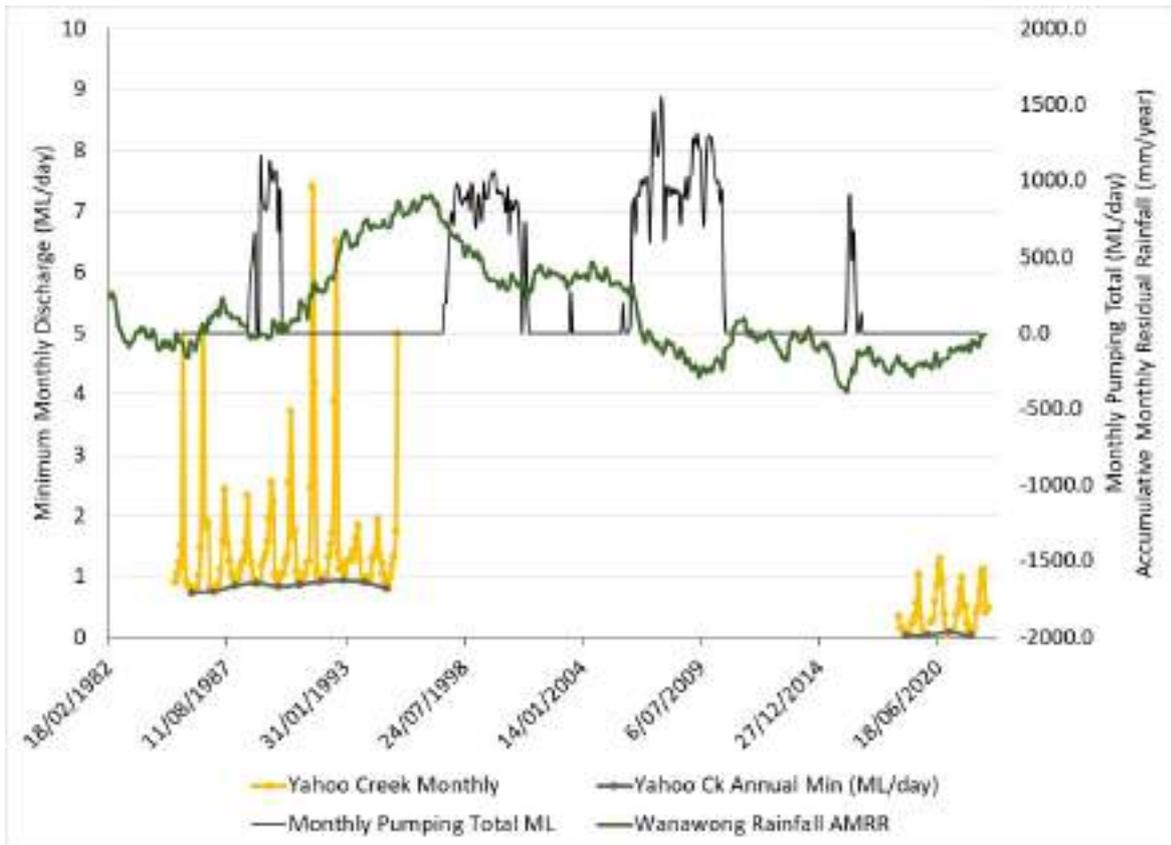


Figure 17 Minimum Monthly and Annual Streamflow Observations – Yahoo Creek

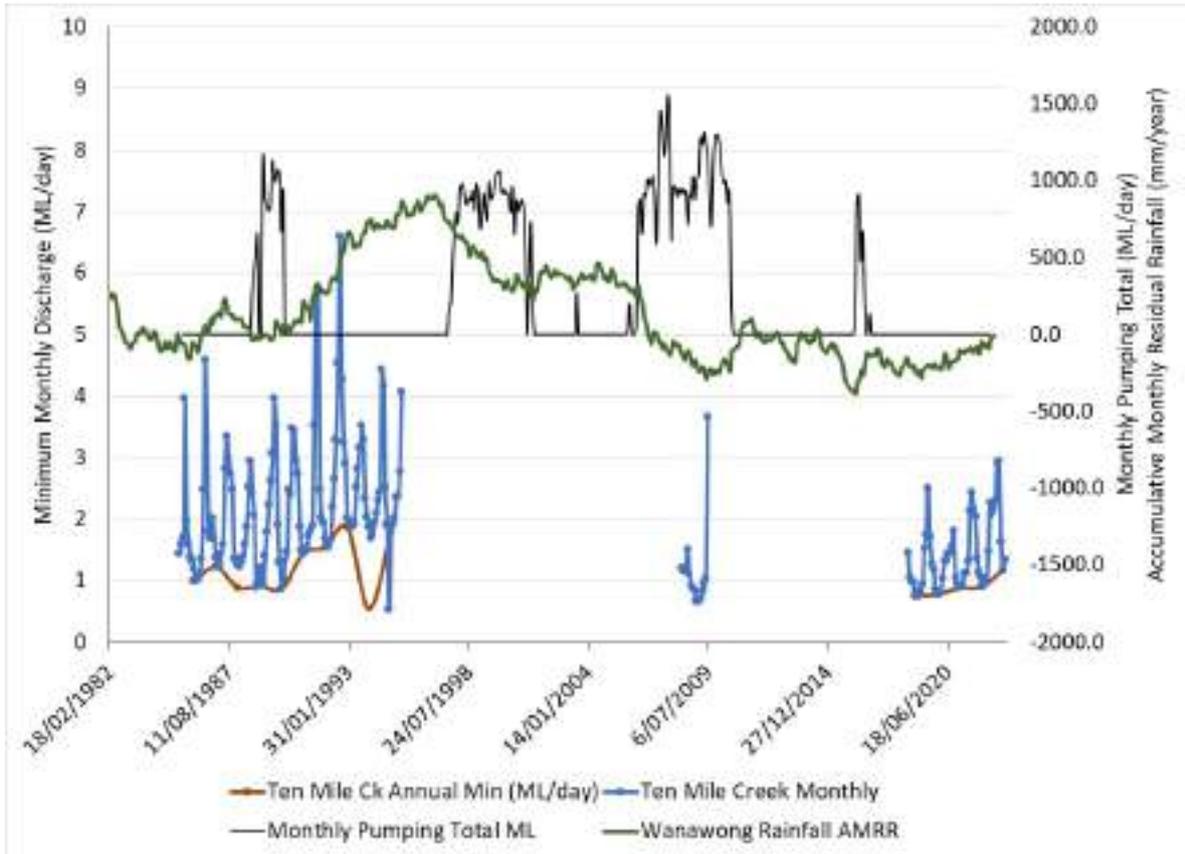


Figure 18 Minimum Monthly and Annual Streamflow Observations – Ten Mile Creek

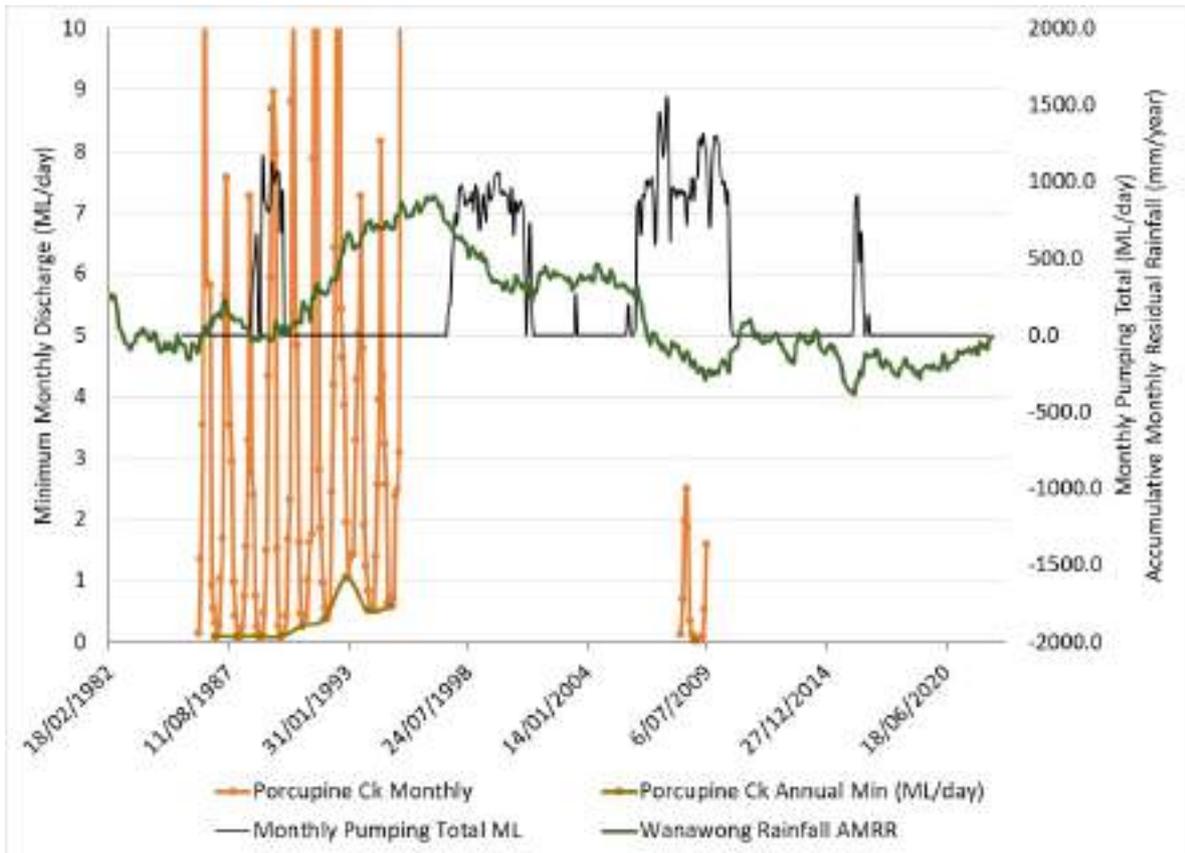


Figure 19 Minimum Monthly and Annual Streamflow Observations – Porcupine Creek

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.

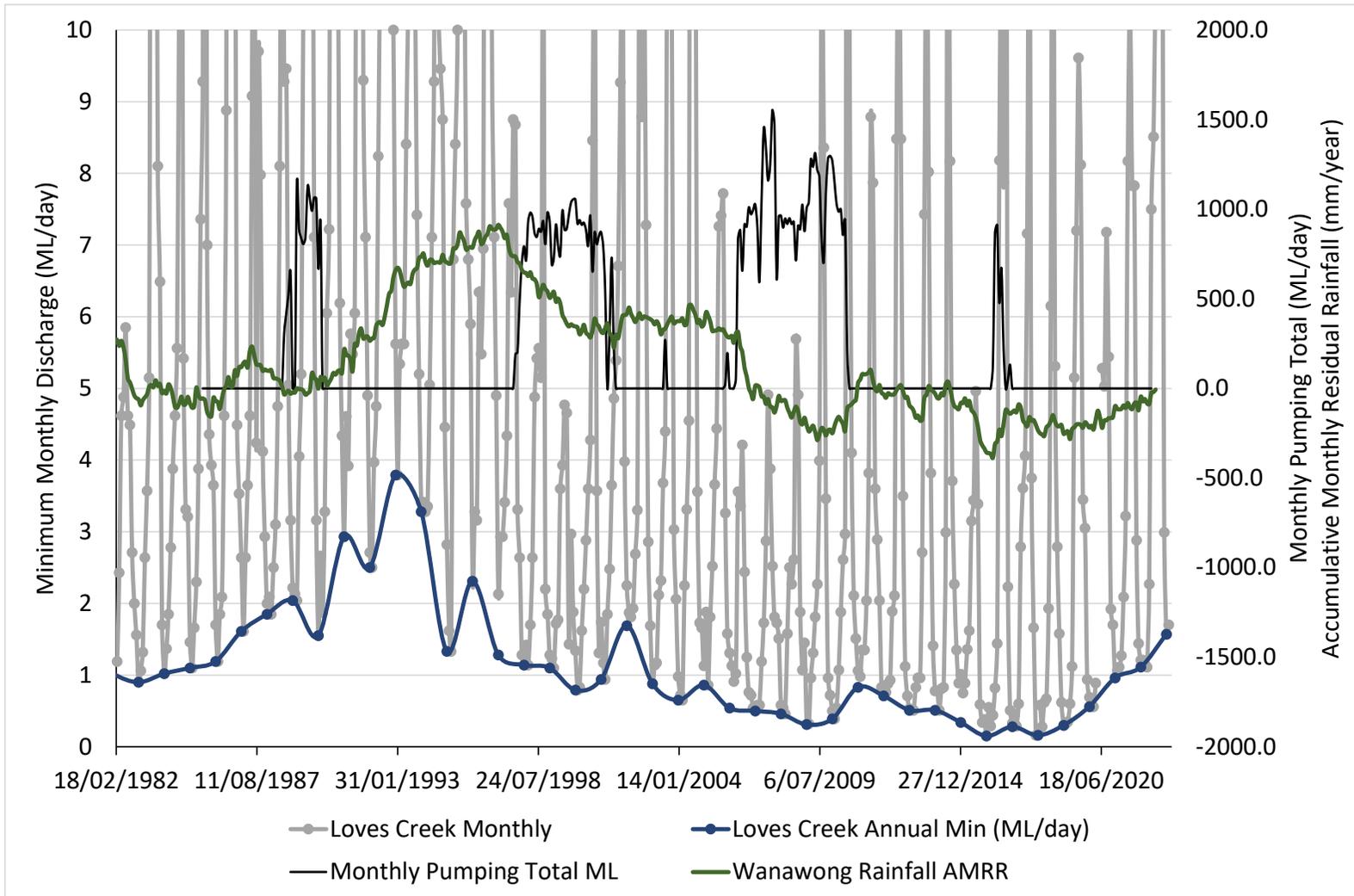


Figure 20 Minimum Monthly and Annual Streamflow Observations – Loves Creek

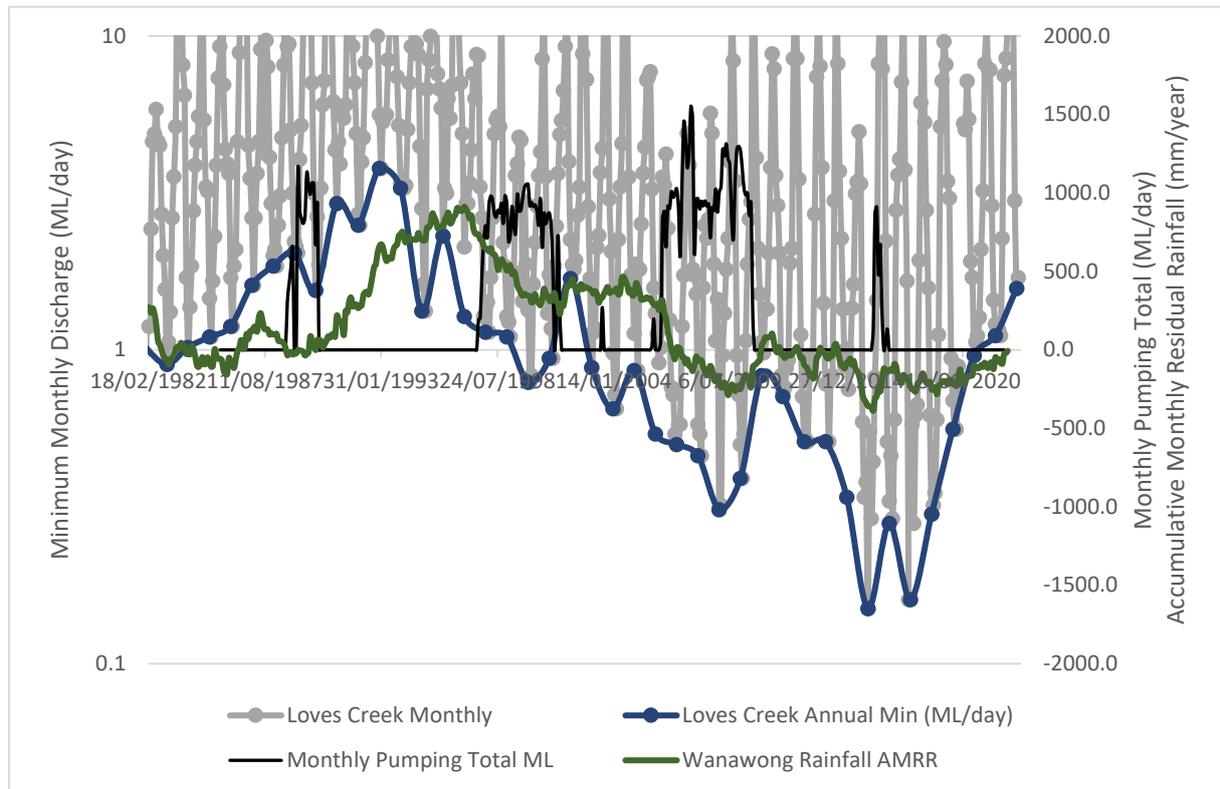


Figure 21 Minimum Monthly and Annual Streamflow Observations (Logarithmic) – Loves Creek

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). It would be expected that the baseflow in Loves Creek is equal to or greater than the sum of the baseflow from its up-stream tributaries as flow from those tributaries ultimately flow toward the Loves Creek gauge. This indicates that there are unaccounted for baseflow losses occurring between the stream gauges under the pre-extraction scenario (i.e. prior to pumping impacts being realised) 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 (i.e. prior to pumping impacts being realised) 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 (discussed in **Section 5.4.3**), however, anecdotal information (pers. Comms M. Gardiner) suggests this is unlikely to be a major contributor based on knowledge of local usage. That being the case, recharge to the Clifton Formation appears to be the most reasonable hypothesis at this time.

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**.

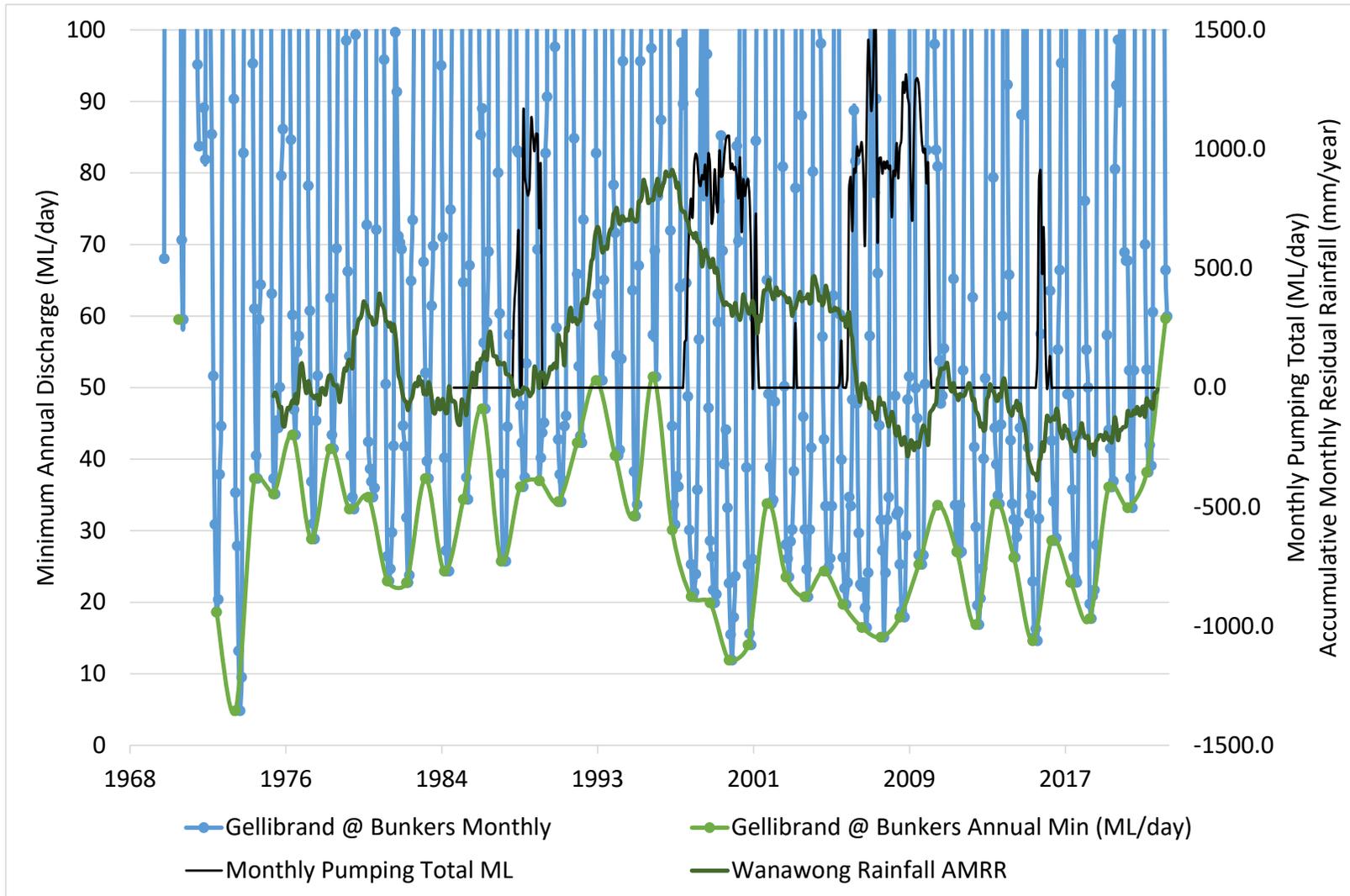


Figure 22 Minimum Monthly and Annual Streamflow Observations – Gellibrand River at Bunker Hill

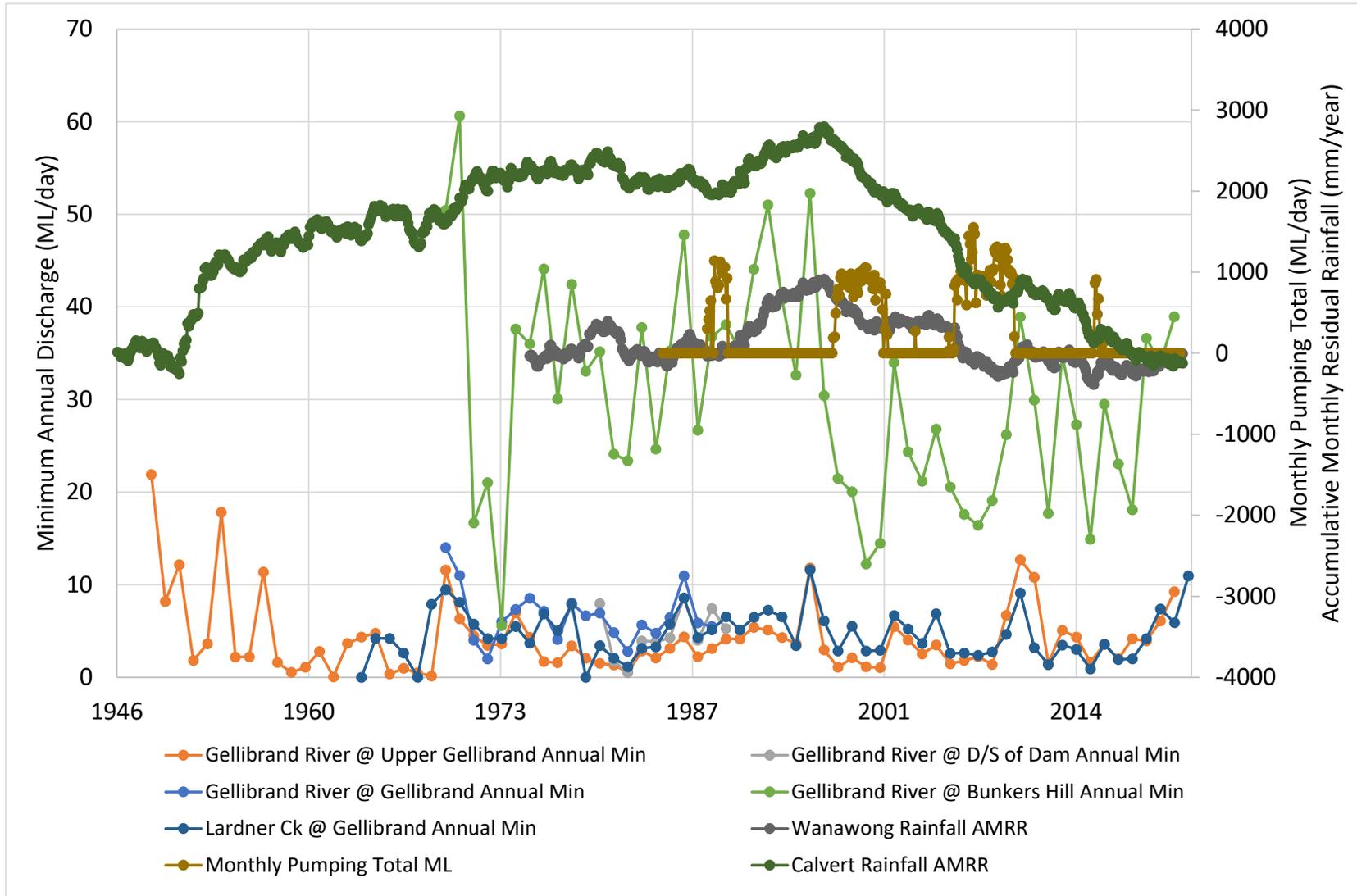


Figure 23 Minimum Monthly and Annual Streamflow Observations – Gellibrand River Tributaries (excluding Loves Creek)

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 Kwarren Sub-Area (**Section 4.2.3.3**). This correlates to rainfall reduction of between 7% and 15% within the Kwarren 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 Kwarren Sub-Area between 1997 to 2009. Based on the maximum rainfall deficit of 148 mm/year, a 12 km² 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 contribute 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 contribute 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 (Aquadre 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 Barangaroo 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. However, anecdotal information (pers. Comms M. Gardiner) suggests this is unlikely to be a major contributor based on knowledge of local usage. That being the case, recharge to the Clifton Formation appears to be the most reasonable hypothesis at this time (refer to Section 5.3.1).

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 Bamba 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)

	Upper Kawarren Avenue	Pipeline Restriction	Gellibrand River East	Gellibrand River West	Source
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 than 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 preceding 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.

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, the weight of evidence indicates that extraction has not resulted in environmentally significant adverse impacts – i.e., material harm to human health or 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. One landholder observation indicated “severe stress” of vegetation in approximately 2010 along the Gellibrand River over areas of Quaternary Sediments and LTA outcrops, however, this does not appear to be related to extraction from the Barwon Downs borefield as the groundwater levels in bores adjacent to the Gellibrand River have shown minimal declines with groundwater levels indicating that groundwater discharge from the LTA to the Gellibrand River has continued.

There were also concerns expressed that the pumping from the Barwon Downs borefield had affected local springs/soaks, or that future extraction could have material impact on their water supply. In a number of cases the springs/soaks of concern were identified as being associated with the LMTA rather than the LTA. As such, the observed changes are more likely related to changes in water levels within the LMTA, that forms the uppermost aquifer system across a large proportion of the Barwon Downs graben. The LMTA is separated from the LTA by the LMTD, whose thickness and low permeability minimises the interaction between these two systems. 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), noting that the large majority of springs in the KIA are fed by the LMTA and not the LTA.

However, 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 be due to 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:**
- Likelihood and consequence definitions adopted in accordance with Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).
 - 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 Worst Case Conditions

Groundwater pressures within the central confined portions of the LTA adjacent to the former extraction bores have reported recoveries of up to 80% since worst case conditions, as at July 2023 (Barwon Water, 2023). 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 Kwarren/Loves Creek areas have stabilised since worst case conditions, however, they have yet to have 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. As discussed in Section 5.1, above, the decline in water levels observed in the KIA was due to watertable decline propagating along the Yeodene recharge avenue, leading to a shift in the groundwater divide in this area, rather than the KIA being within the cone of depression created by the pumping.

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 the KIA Loves Creek and its tributaries since the cessation of pumping have varied with the following improvements summarised below:

- The baseflow in Yahoo Creek has not fully recovered to the baseflow observed between the mid-1980s and early 1990s, however is showing signs of increasing.
- The baseflow in Ten Mile Creek has largely remained consistent with the baseflow levels observed between the mid-1980s and the early 1990s and appears to be increasing overall.
- 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, and continues to increase.
- 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 and continues to increase.

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;
- Identify potential groundwater dependent ecosystems and their relationship to the LTA; and
- Use the CSM in conjunction with the available data 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 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 approximately 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, the weight of evidence indicates that extraction has not resulted in environmentally significant adverse impacts – i.e., material harm to human health or the environment, within the KIA. It is noted that some concerns and observations raised by knowledgeable community members as part of this work do not appear to be related to extraction from the Barwon Downs borefield. Some of these concerns also related to features that are separated from the LTA and more likely driven by changes within the LMTA, that forms the uppermost aquifer system across a large proportion of the Barwon Downs graben.

Improvements in groundwater levels/pressures are evident following the cessation of groundwater extraction from the Barwon Downs borefield in 2016. This recovery has resulted in groundwater flow paths being largely consistent with those recorded in 1983. Whilst groundwater levels/pressures have not yet recovered to pre-pumping levels, this is expected to continue to improve over time. As groundwater levels recover, the identified reductions in baseflow will also reduce.

The findings from this HA should be used to form the basis for the subsequent management decisions in the catchment. Future use of groundwater from 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)).

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 of 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.

9 References

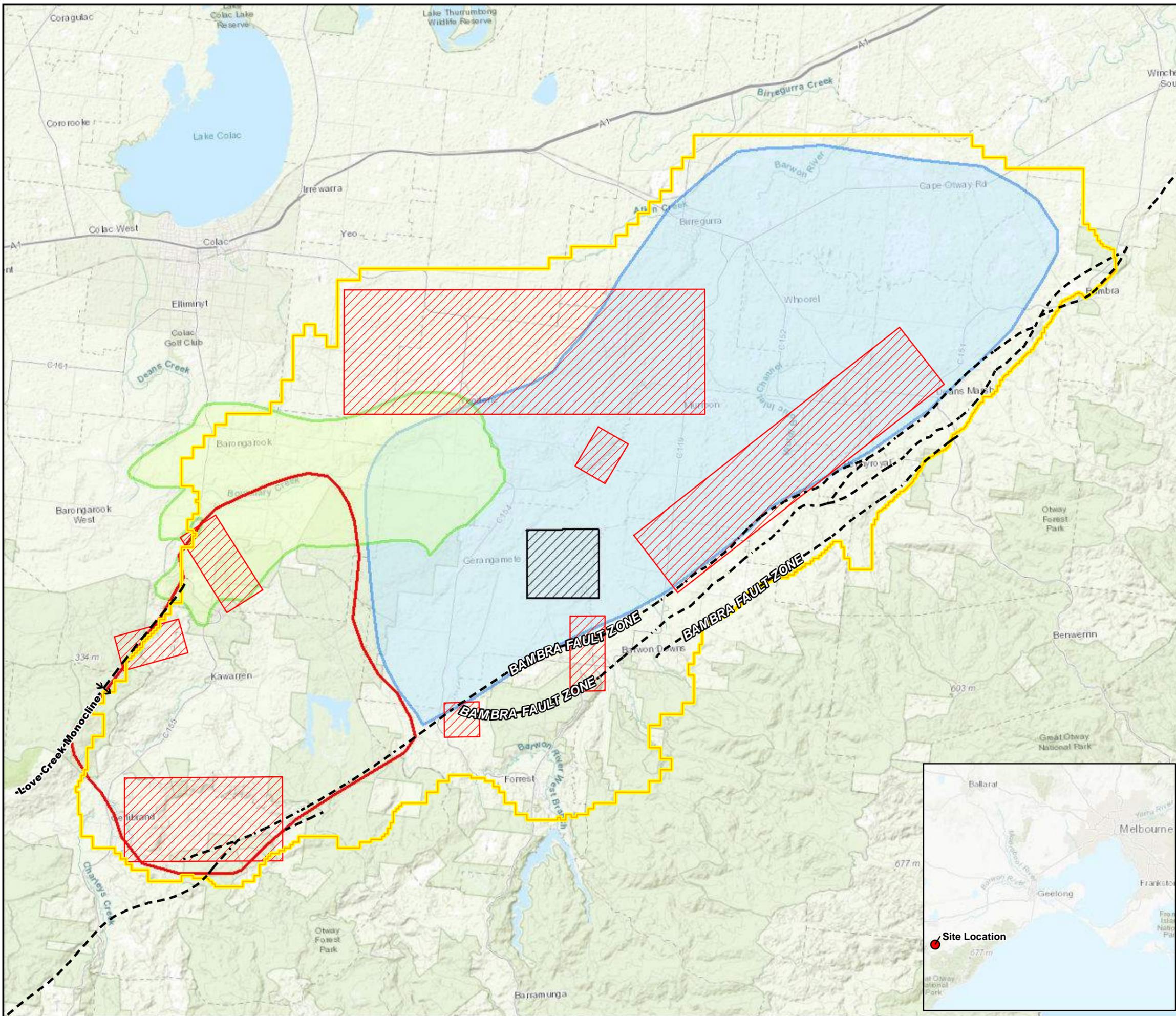
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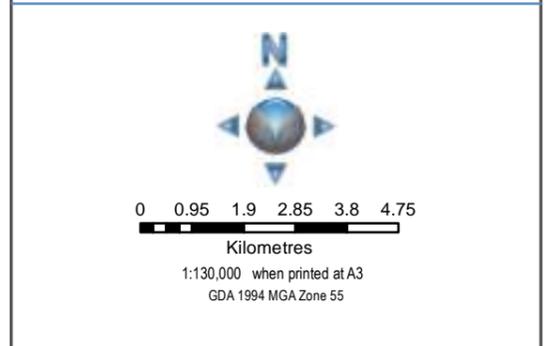
Figures

- Figure F1 Regional Setting
- Figure F2 Kawarren Sub-basin Investigation Area
- Figure F3 Hydrology and Rainfall Stations
- Figure F4 Topography
- Figure F5 Ecological Vegetation Classes
- Figure F6 Registered Groundwater Wells
- Figure F7 Extractive Groundwater Users
- Figure F8 Top of Otway Group
- Figure F9 Surficial Geology
- Figure F10 LTA Thickness
- Figure F11 Clifton Formation Thickness
- Figure F12 Conceptualised Geological Cross Section A-A'
- Figure F13 Conceptualised Geological Cross Section B-B'
- Figure F14 Conceptualised Geological Cross Section C-C'
- Figure F15 Conceptualised Geological Cross Section D-D'
- Figure F16 Potentiometric Surface Contours – LTA (after Leonard 1983)
- Figure F17 Potentiometric Surface Contours – LTA 2010
- Figure F18 Potentiometric Surface Contours – LTA 2021
- Figure F19 Mapped Springs (Porcupine Creek Sub-Catchment)
- Figure F20 Mapped Springs (Ten Mile Creek Sub-Catchment)
- Figure F21 Mapped Springs (Yahoo Creek Sub-Catchment)
- Figure F22 Mapped Springs (Loves Creek and Gellibrand River Sub-Catchment)
- Figure F23 Groundwater Dependent Ecosystems
- Figure F24 Acid Sulfate Soils
- Figure F25 Water Level Change in Kawarren Sub-basin Investigation Area: 1997 – 2013
- Figure F26 Expected Recharge and Discharge Areas – LTA



- Legend**
- Kwarren 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

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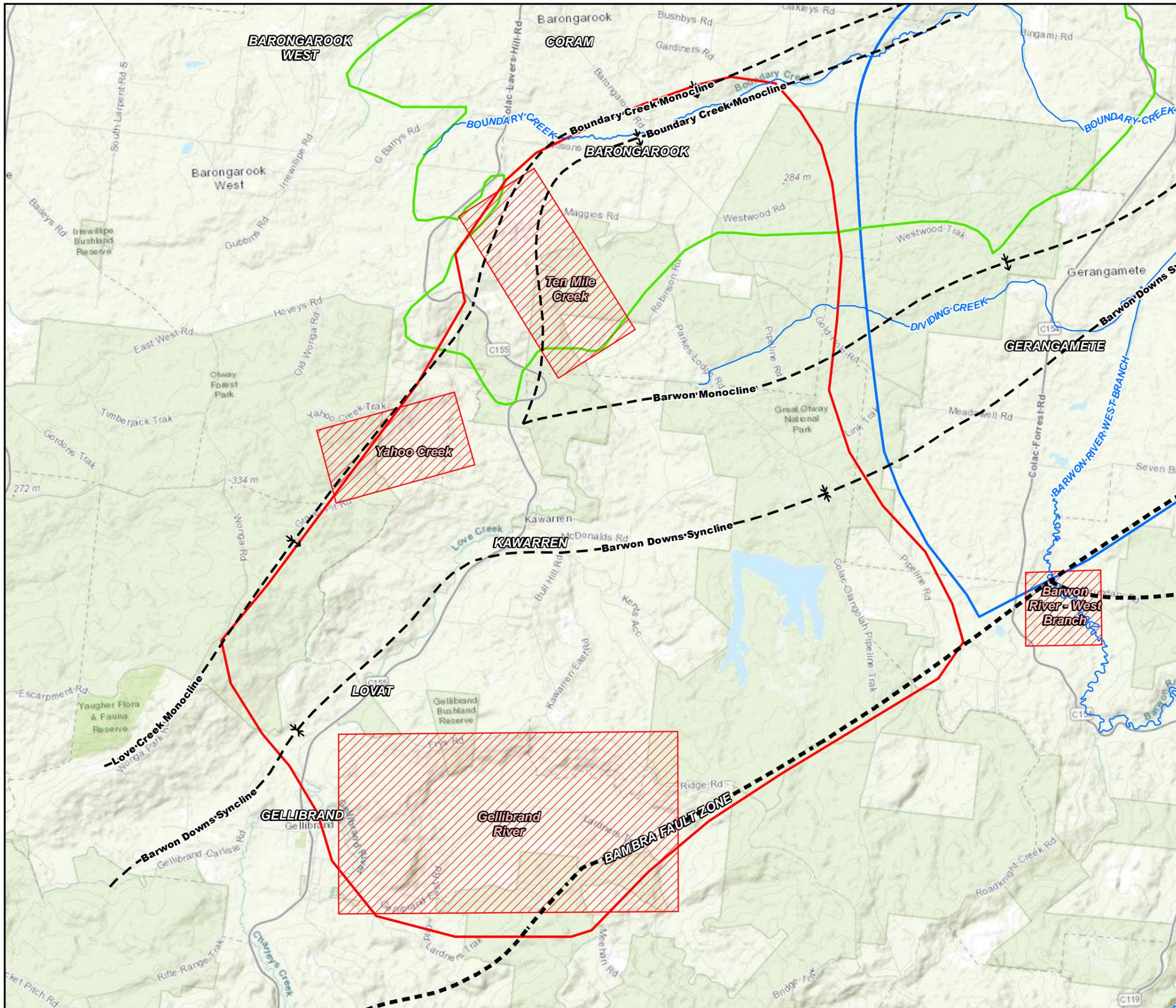
REGIONAL SETTING

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
Barwon Water

Figure
F1



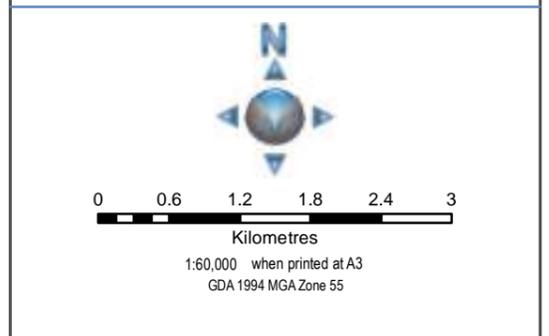


Legend

- Kwarren 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

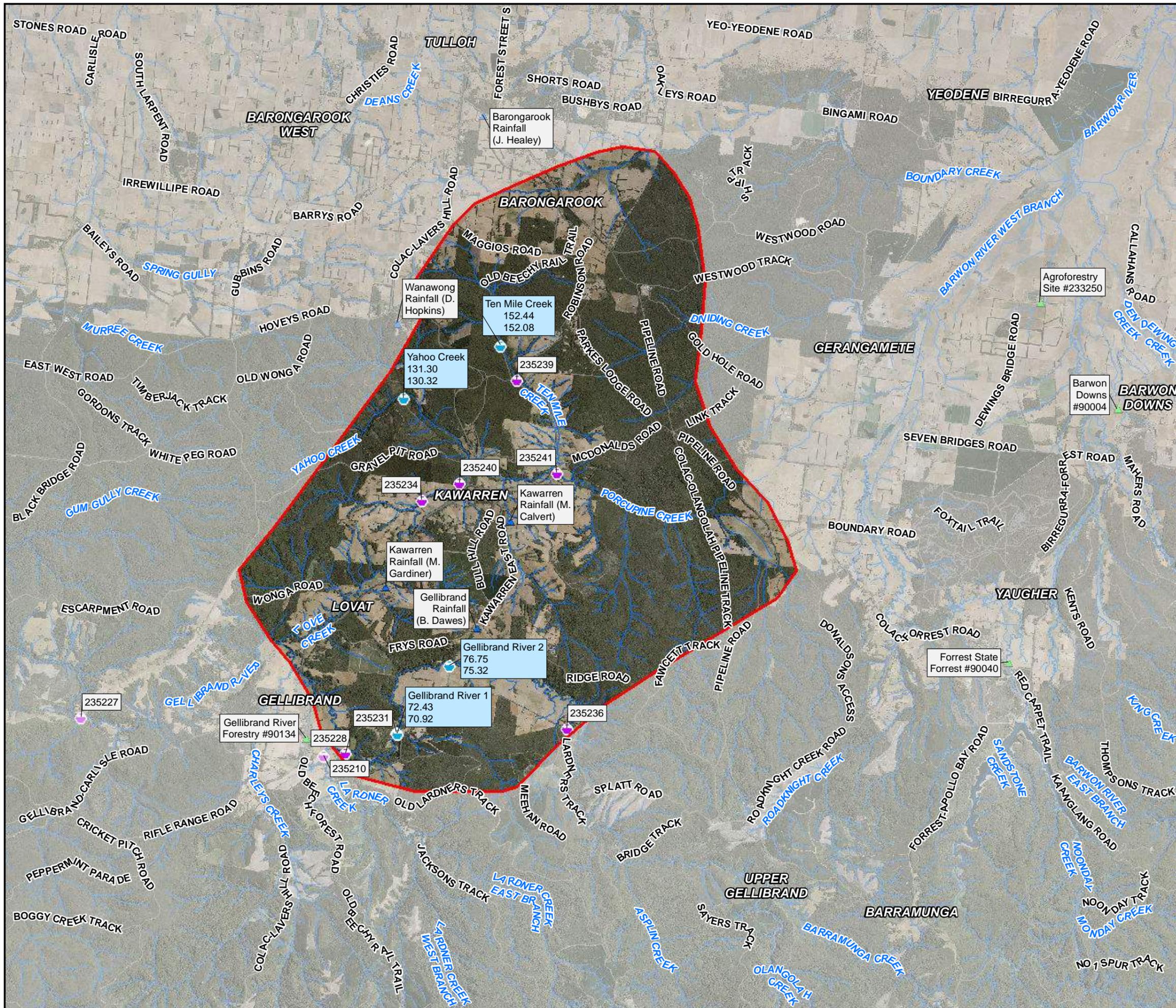


KWARREN SUB-BASIN INVESTIGATION AREA

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin Area
 Barwon Water

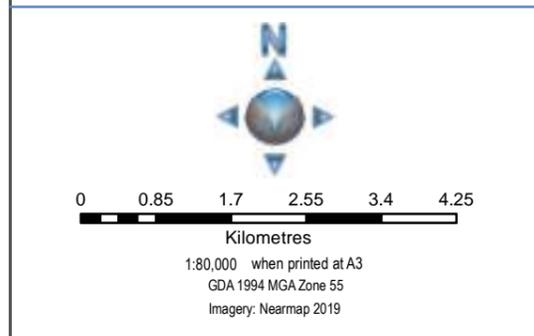
Figure
F2



- 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

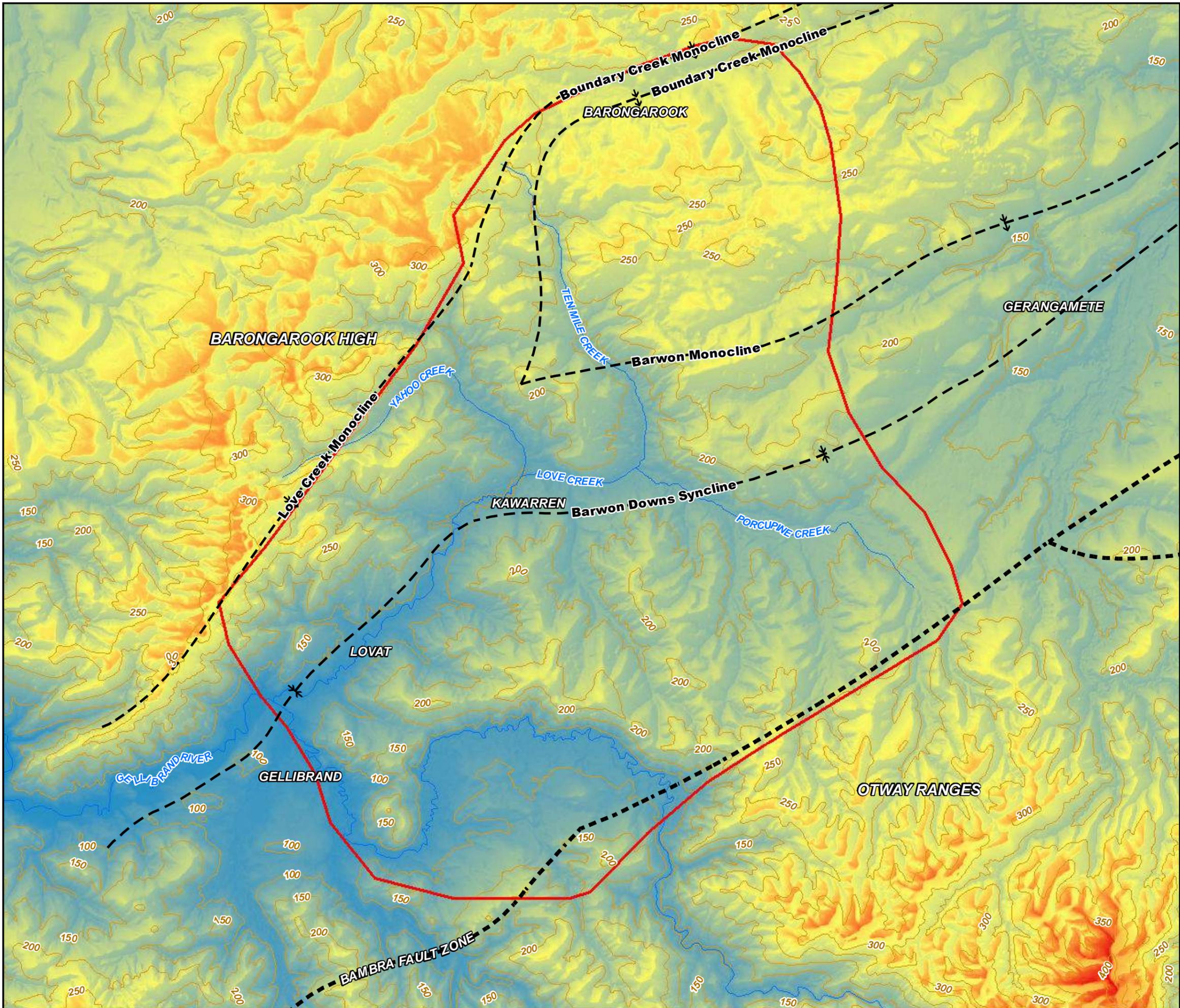


HYDROLOGY AND RAINFALL STATIONS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F3



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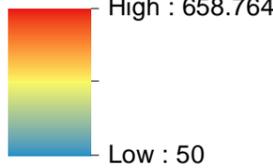
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- Kawarren Sub-basin Investigation Area (approx. extent)
- Regional Elevation Contours (mAHD)
- Watercourse

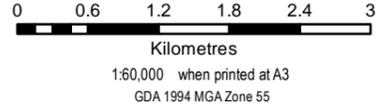
Structural Features

- Monocline
- Syncline
- Geological Faults

Elevation (mAHD)



Note: Digital Elevation Model provided by Barwon Water

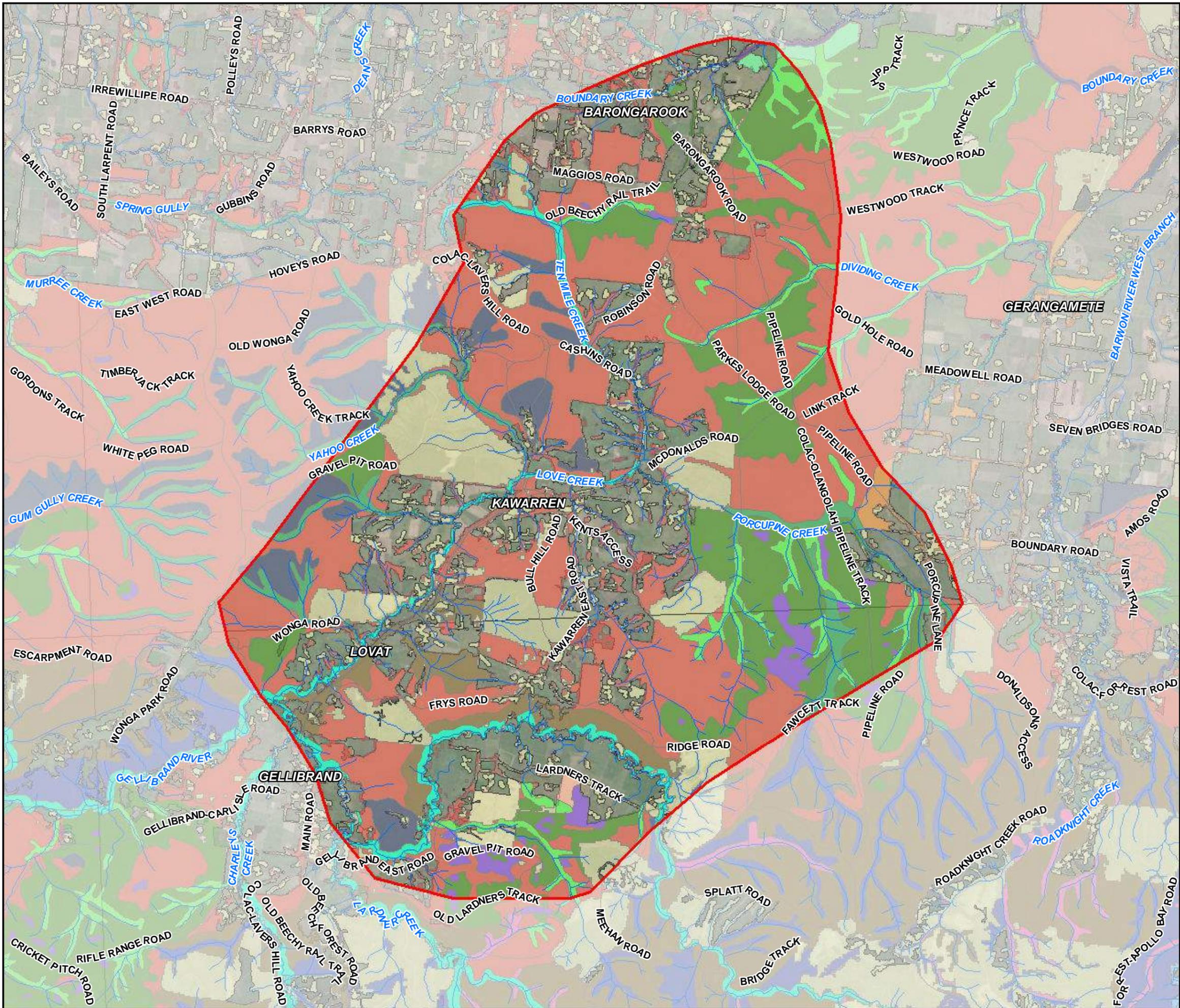


TOPOGRAPHY

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F4



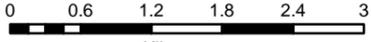
Legend

- 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

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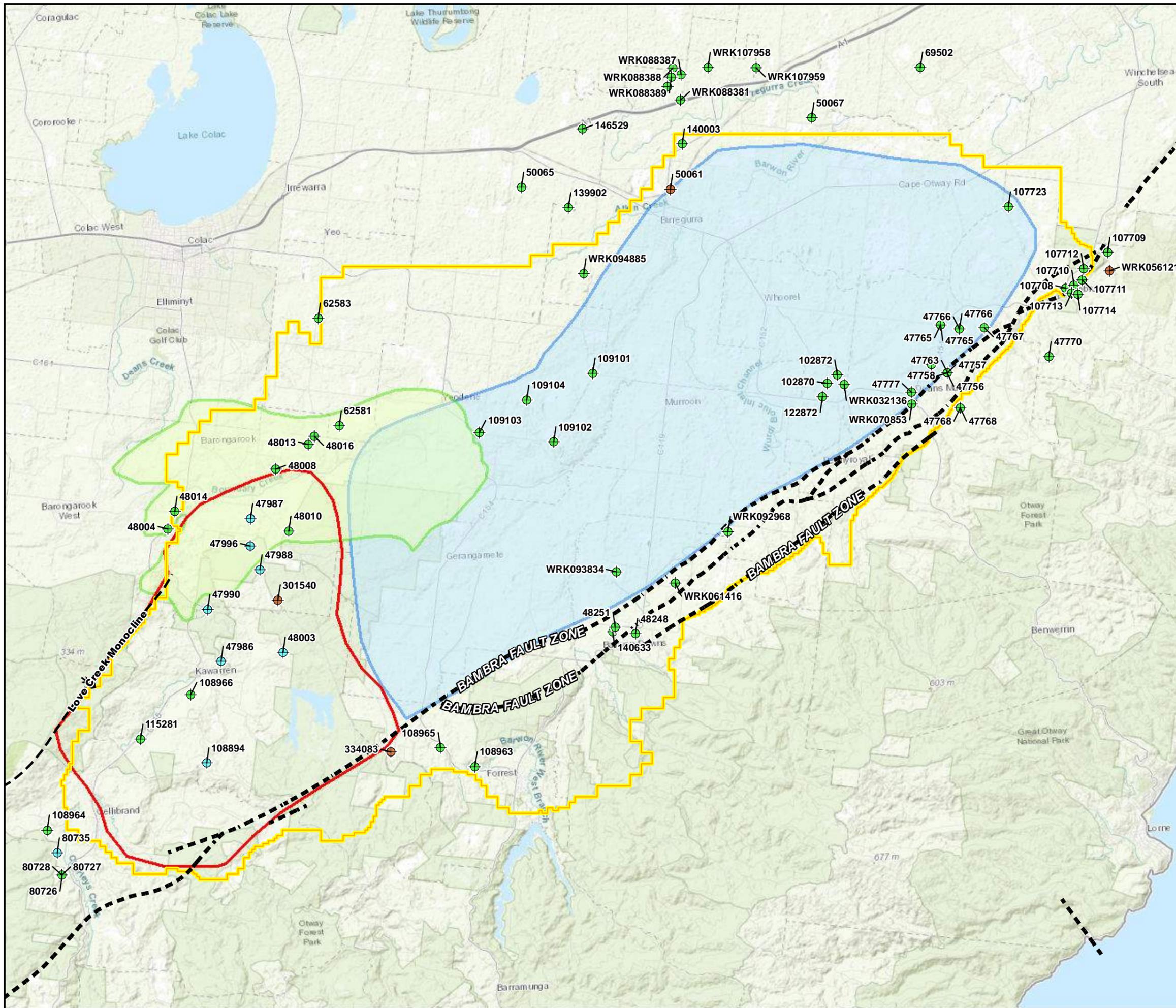
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 Imagery: Nearmap 19/02/2022

ECOLOGICAL VEGETATION CLASSES

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F5



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



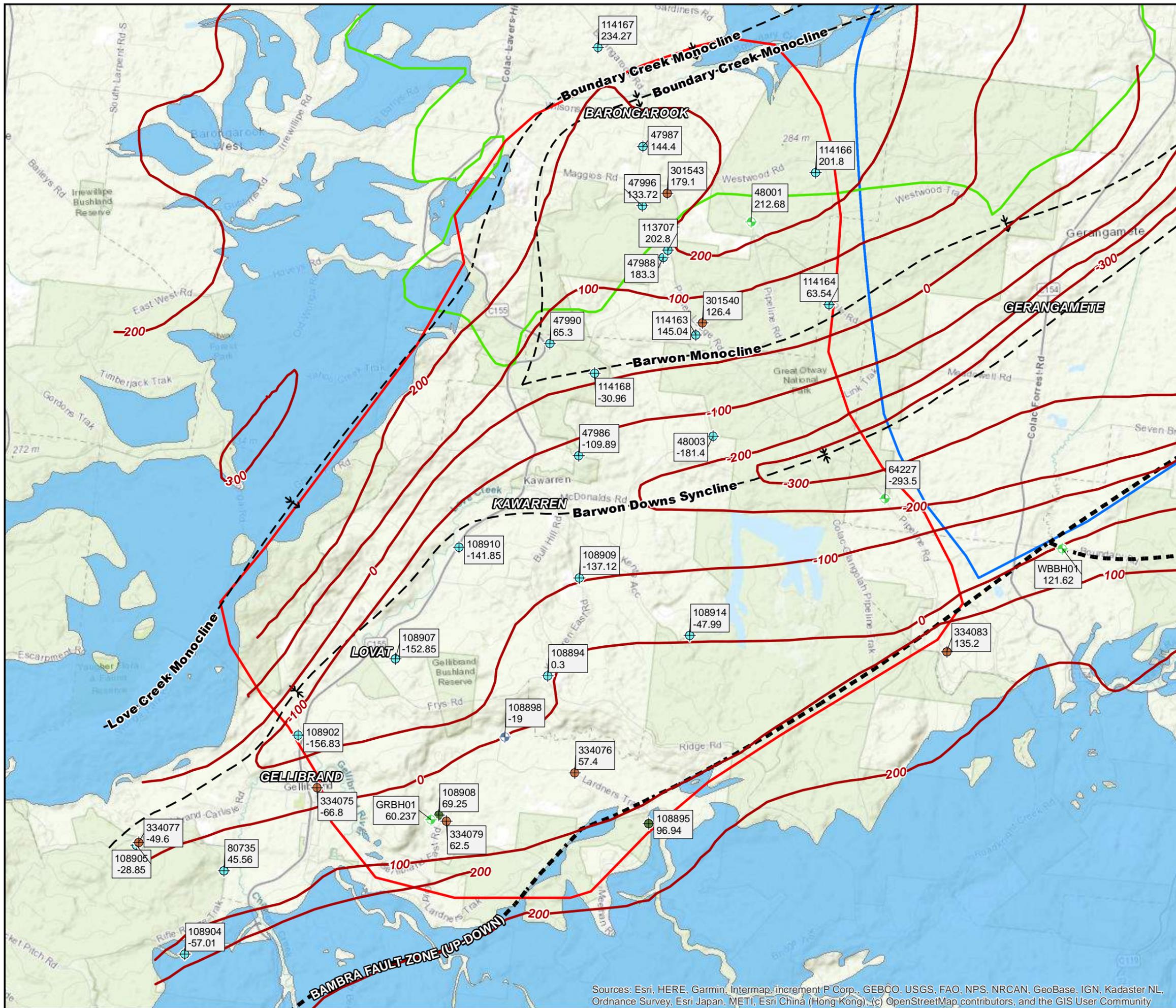
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REGISTERED EXTRACTIVE USE BORES

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

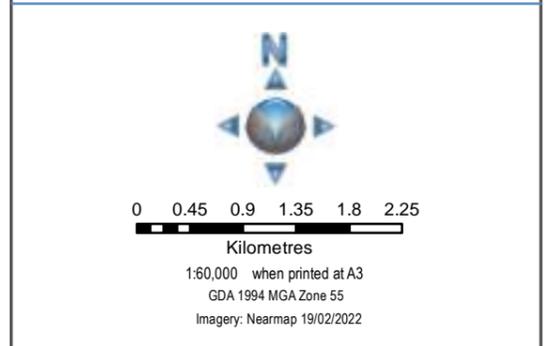
Figure
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- Legend**
- ▭ Kawarren Sub-basin Investigation Area (approx. extent)
 - ▭ Approximate Extent of Barwon Downs Sub-basin
 - ▭ Approximate Area of Barongarook High (Intake areas)
- Structural Features**
- Monocline
 - Syncline
 - Geological Faults
- Surface Geology (1:50,000) (DELWP)**
- ▭ Otway Group
- Barwon Water Monitoring Assets**
- Groundwater Observation Bore
 - 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

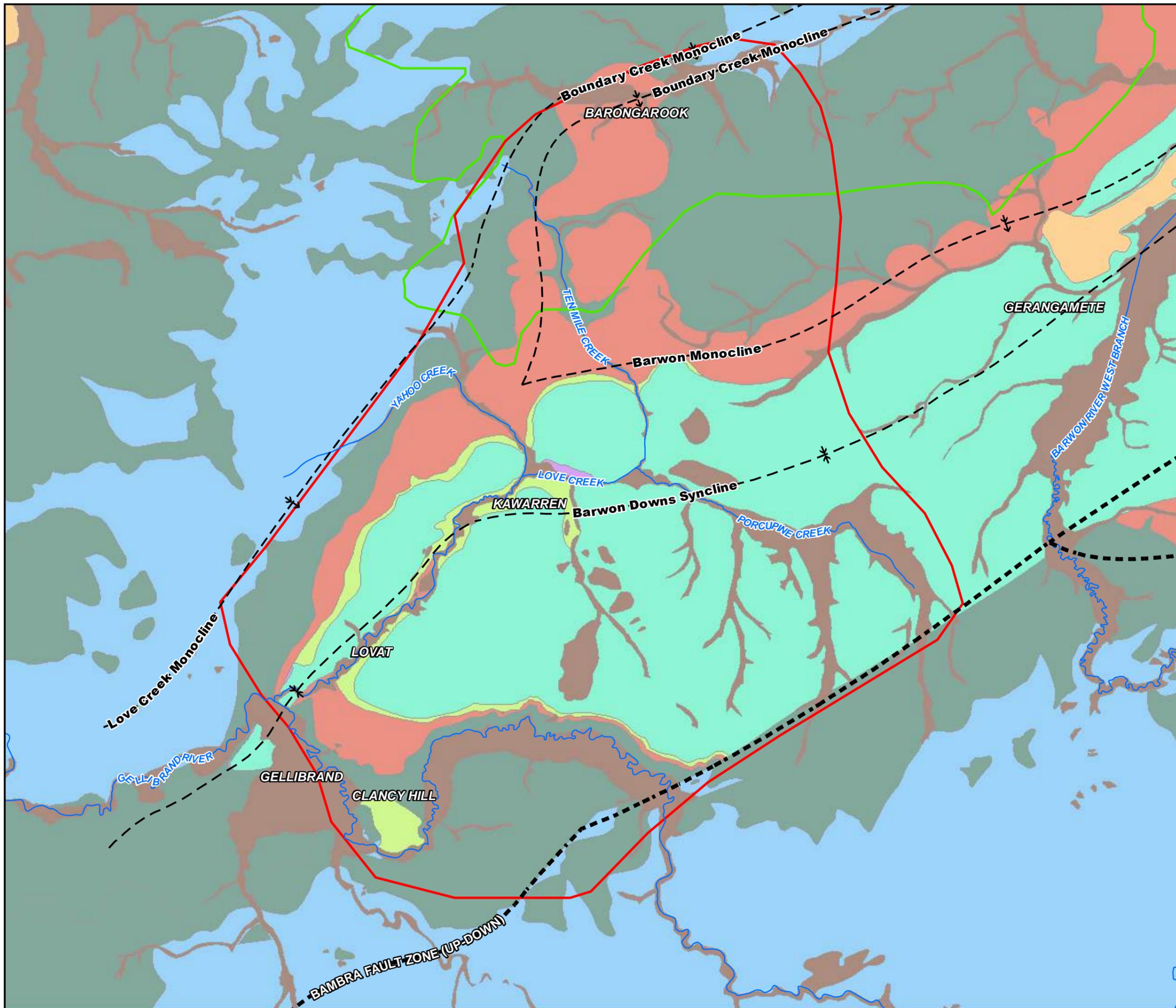


ELEVATION OF THE TOP OF THE OTWAY GROUP

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F8



Legend

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

Structural Features

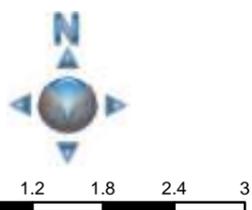
- Monocline
- Syncline
- Geological Faults

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

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

} Heytesbury Group

Note: Modified surface geology nomenclature.



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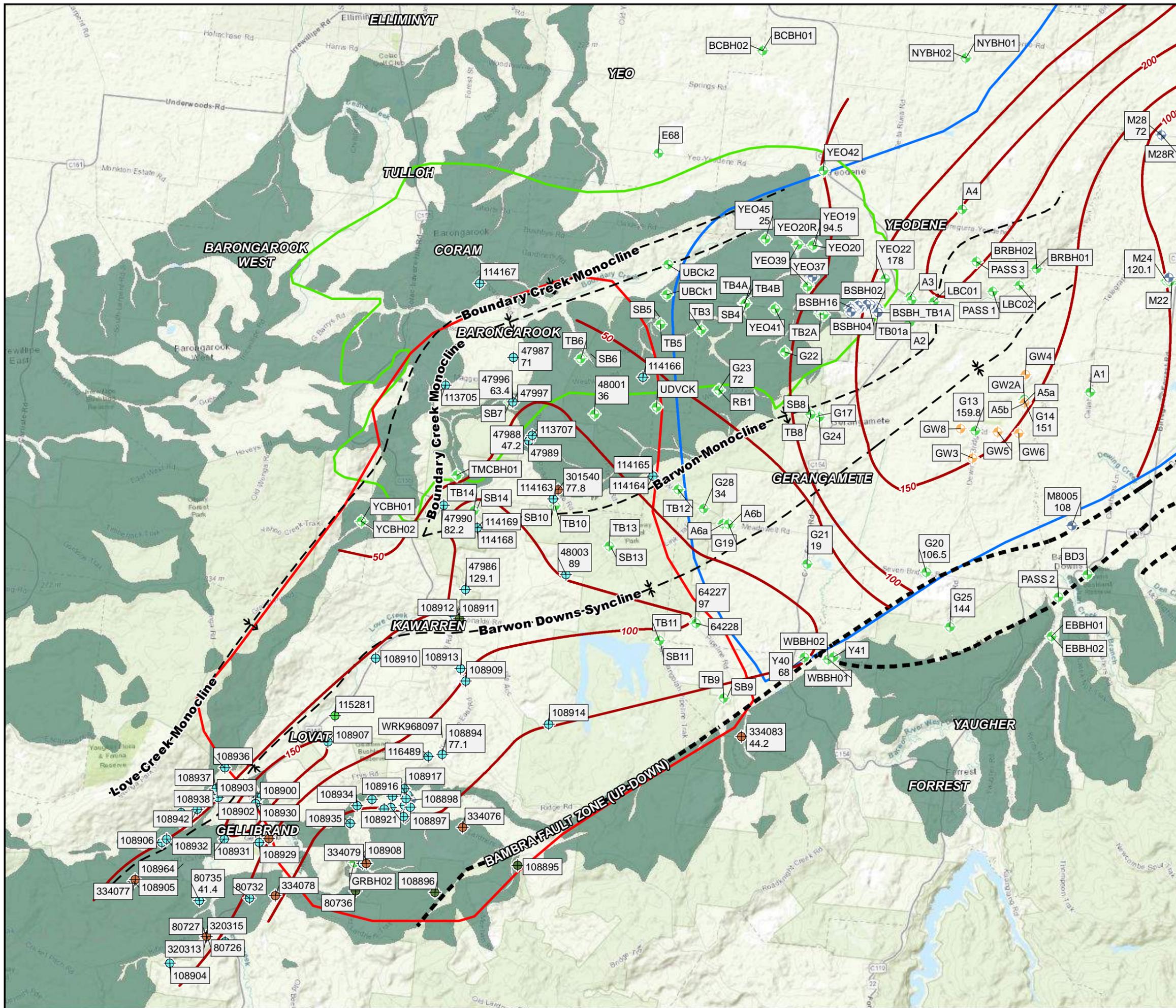
1:60,000 when printed at A3
 GDA 1994 MGA Zone 55
 Imagery: Nearmap 19/02/2022

SURFICIAL GEOLOGY

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

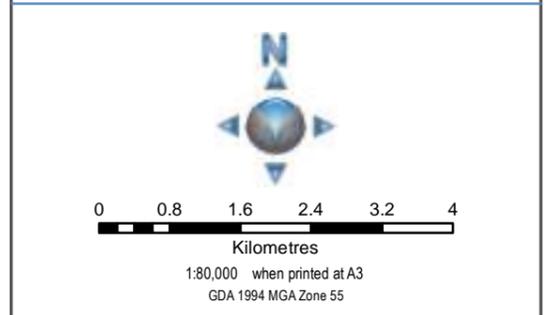
Figure
F9



- Legend**
- ▭ Kwarren 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)
114167	
47987	71
47996	63.4
47997	
47988	47.2
113707	
47989	
301540	77.8
114165	
114164	
47986	129.1
108912	
108911	
108910	
108913	
108909	
115281	
108907	
WRK968097	
108894	77.1
116489	
108917	
108934	
108916	
108898	
108902	
108930	
108935	
108921	
108897	
334076	
108906	
108932	
108931	
108929	
334079	
108908	
80735	41.4
80732	
334078	
GRBH02	
108896	
80736	
80727	
320315	
320313	
80726	
108904	

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

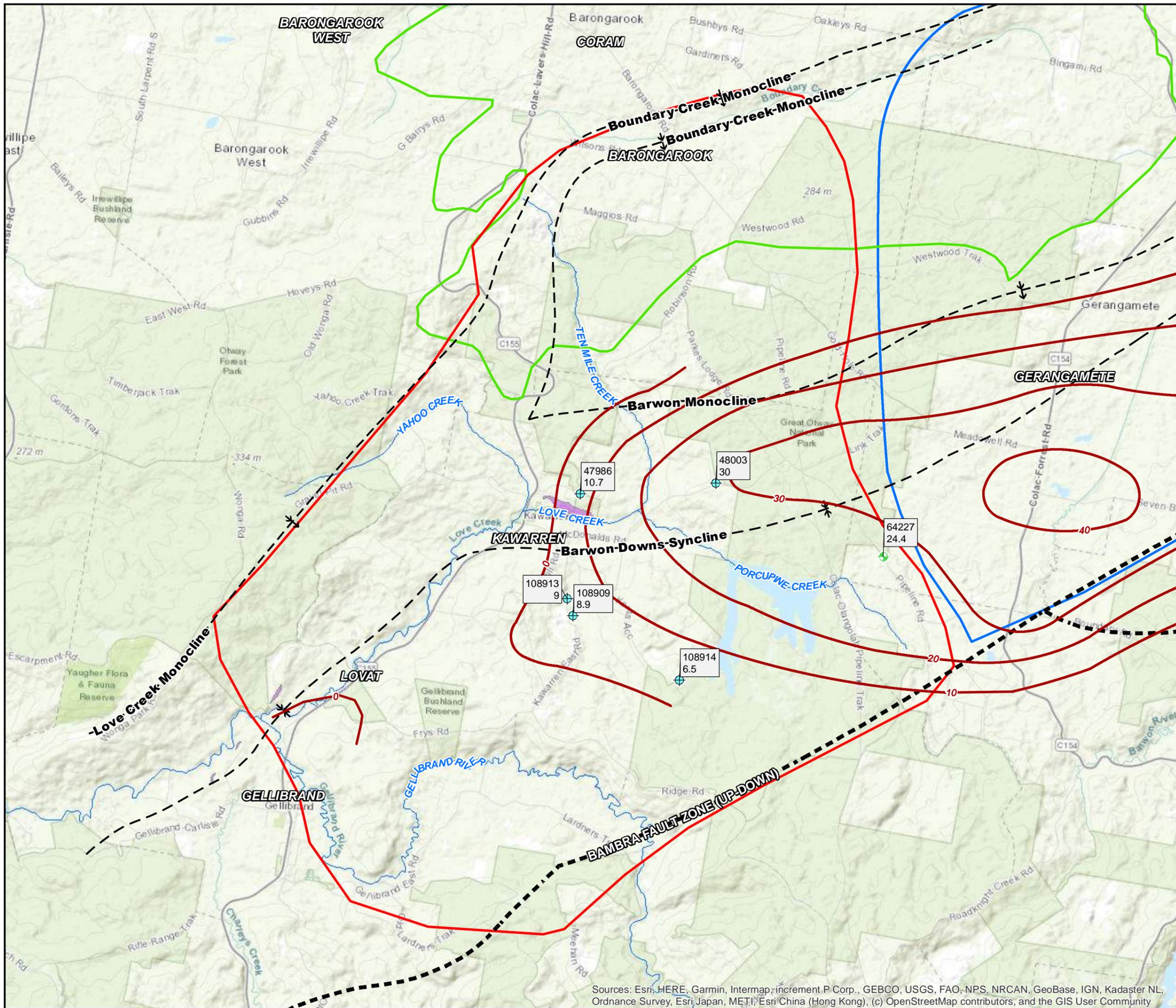


LTA THICKNESS

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

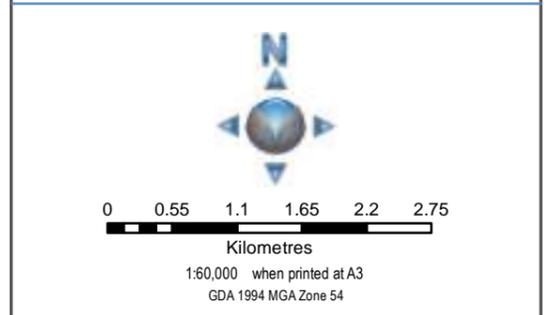
Figure
F10



- Legend**
- ▭ Kwarren 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)
47986	10.7
48003	30
64227	24.4
108913	9
108909	8.9
108914	6.5

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

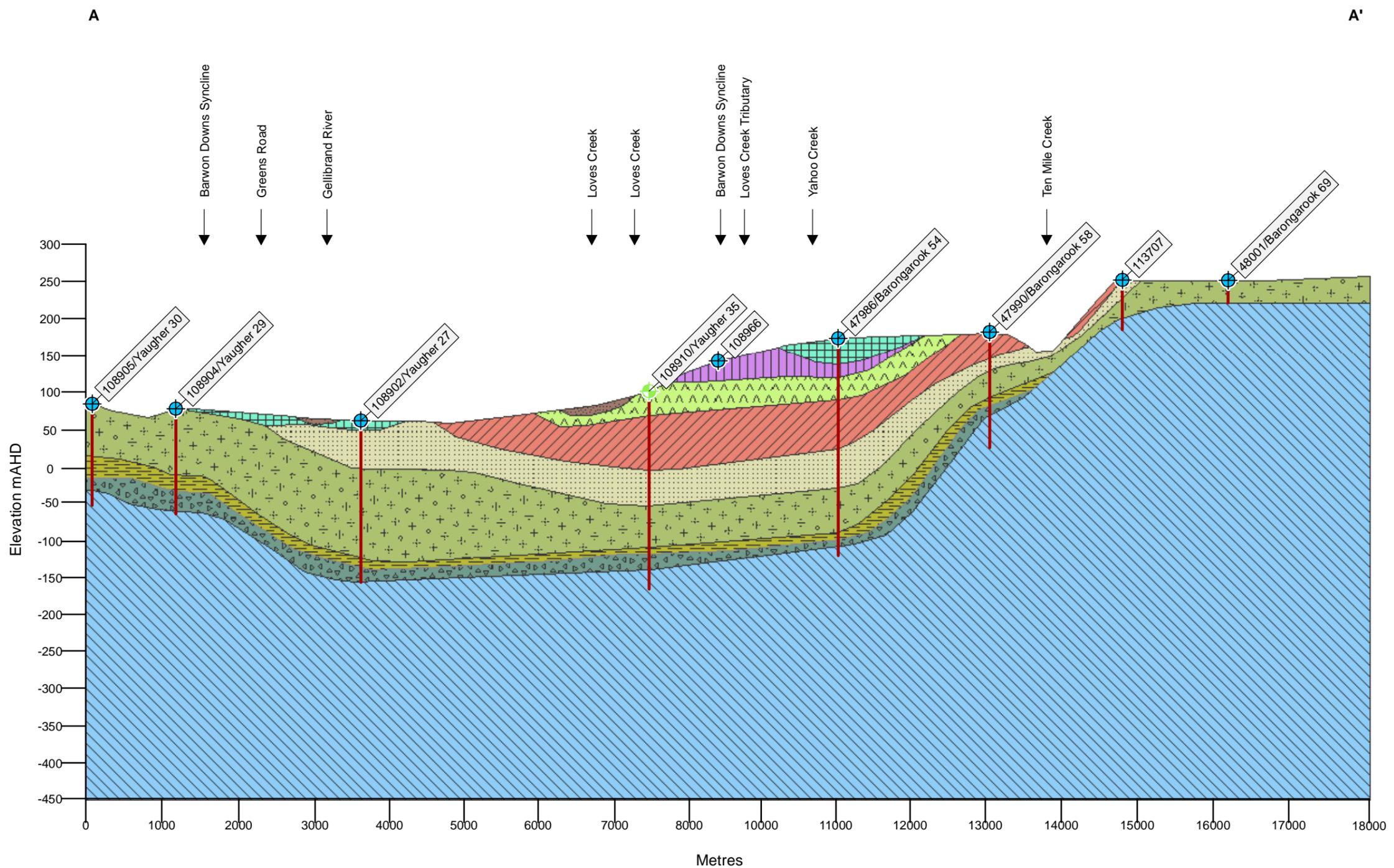


CLIFTON FORMATION THICKNESS

Hydrogeological Assessment - Kwarren Sub-basin

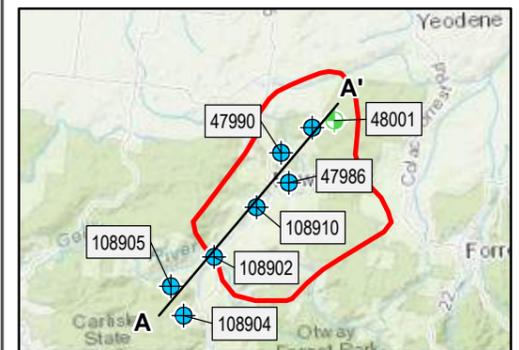
Kwarren Sub-basin
 Barwon Water

Figure
F11



Legend

- Borehole
 - Quaternary Sediments
 - Gellibrand Marl Formation
 - Clifton Formation
 - Yaughter Volcanics
 - Narrawaturk Marl
 - Mepunga Sands Formation
 - Dilwyn Formation
 - Pember Mudstone Formation
 - Pebble Point Formation
 - Otway Group
- Barwon Water Monitoring**
- WMIS Groundwater Observation Bore
 - Groundwater Observation Bores



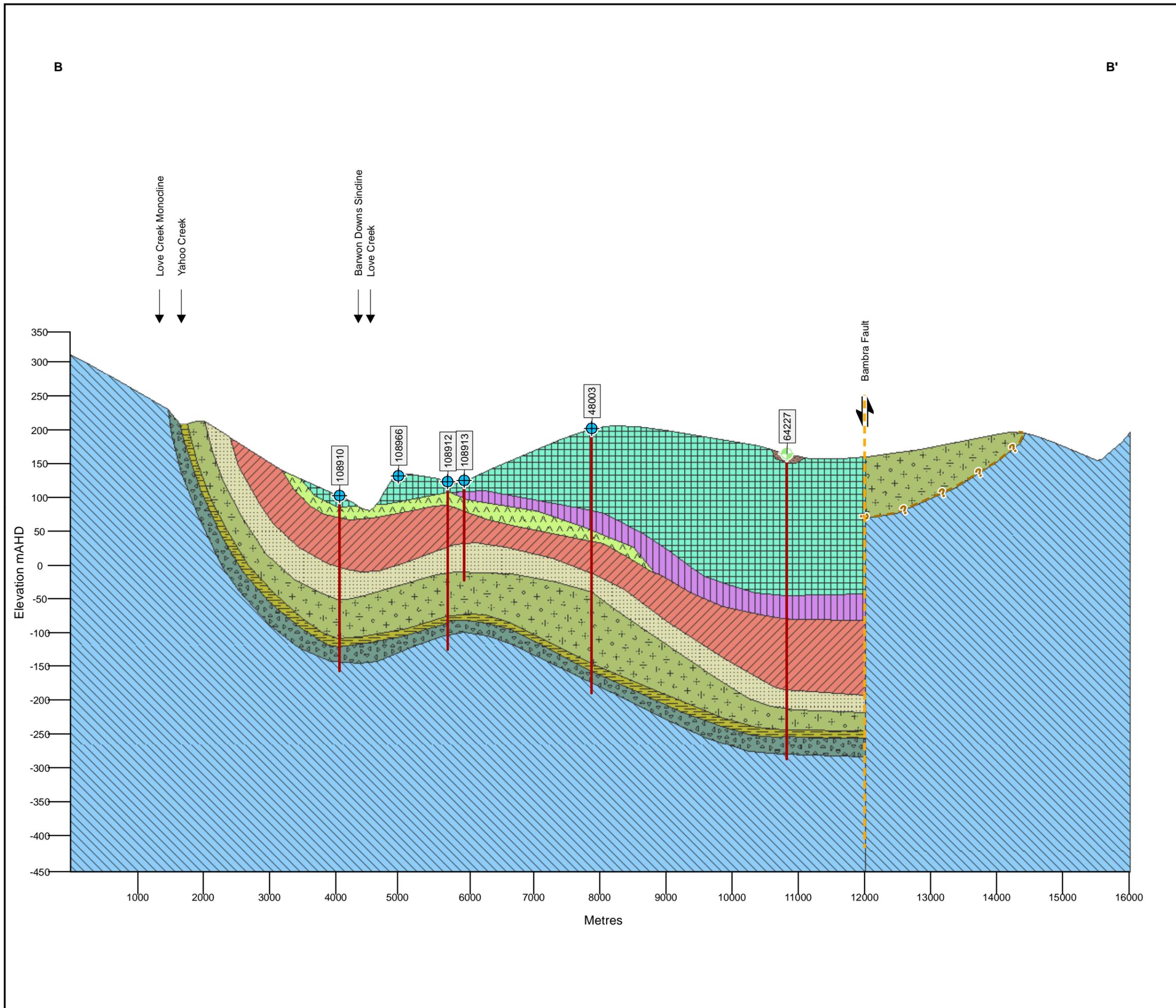
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

CONCEPTUALISED GEOLOGICAL CROSS SECTION A-A'

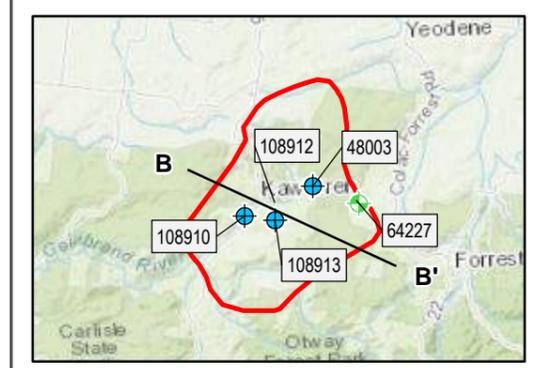
Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F12



- 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
- Structural Features**
- - - Bamba Fault
- Barwon Water Monitoring Assessts**
- Barwon Water Groundwater Monitoring Bore
 - WMIS Groundwater Observation Bores



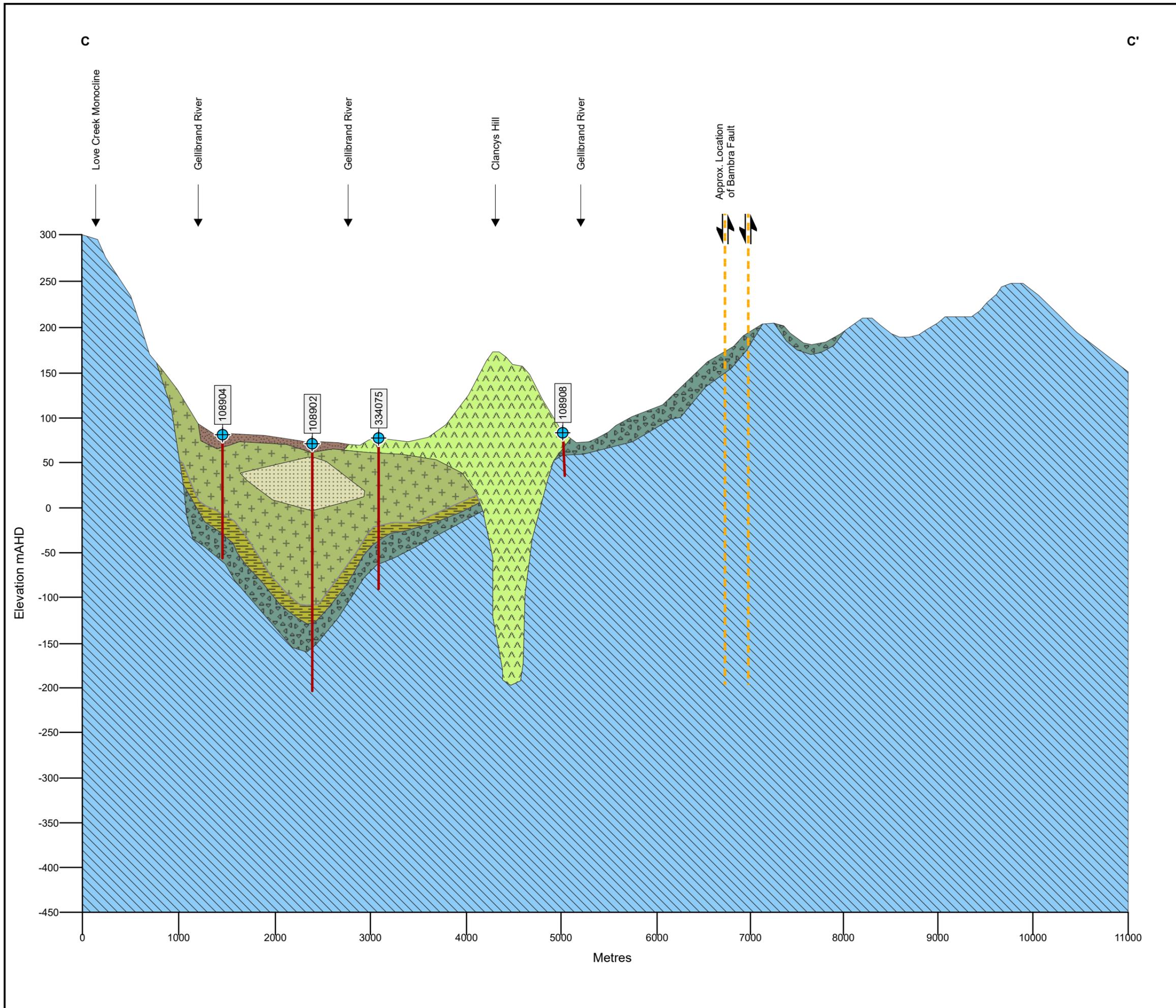
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

CONCEPTUALISED GEOLOGICAL CROSS SECTION B-B'

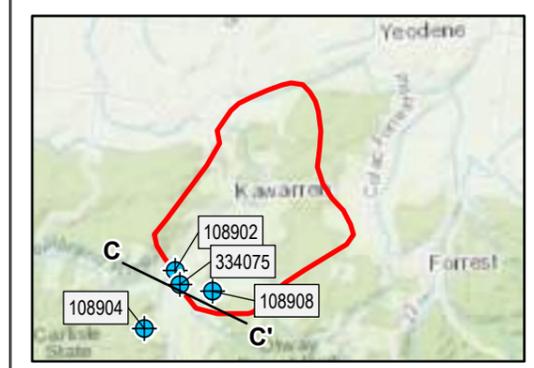
Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

Figure F13



- Legend**
- Borehole
 - Quaternary Sediments
 - ▲ Yaagher Volcanics
 - Mepunga Sands Formation
 - Dilwyn Formation
 - Pember Mudstone Formation
 - Pebble Point Formation
 - Otway Group
- Structural Features**
- - - Bamba Fault
- Barwon Water Monitoring Assets**
- WMIS Groundwater Observation Bore
- } LTA



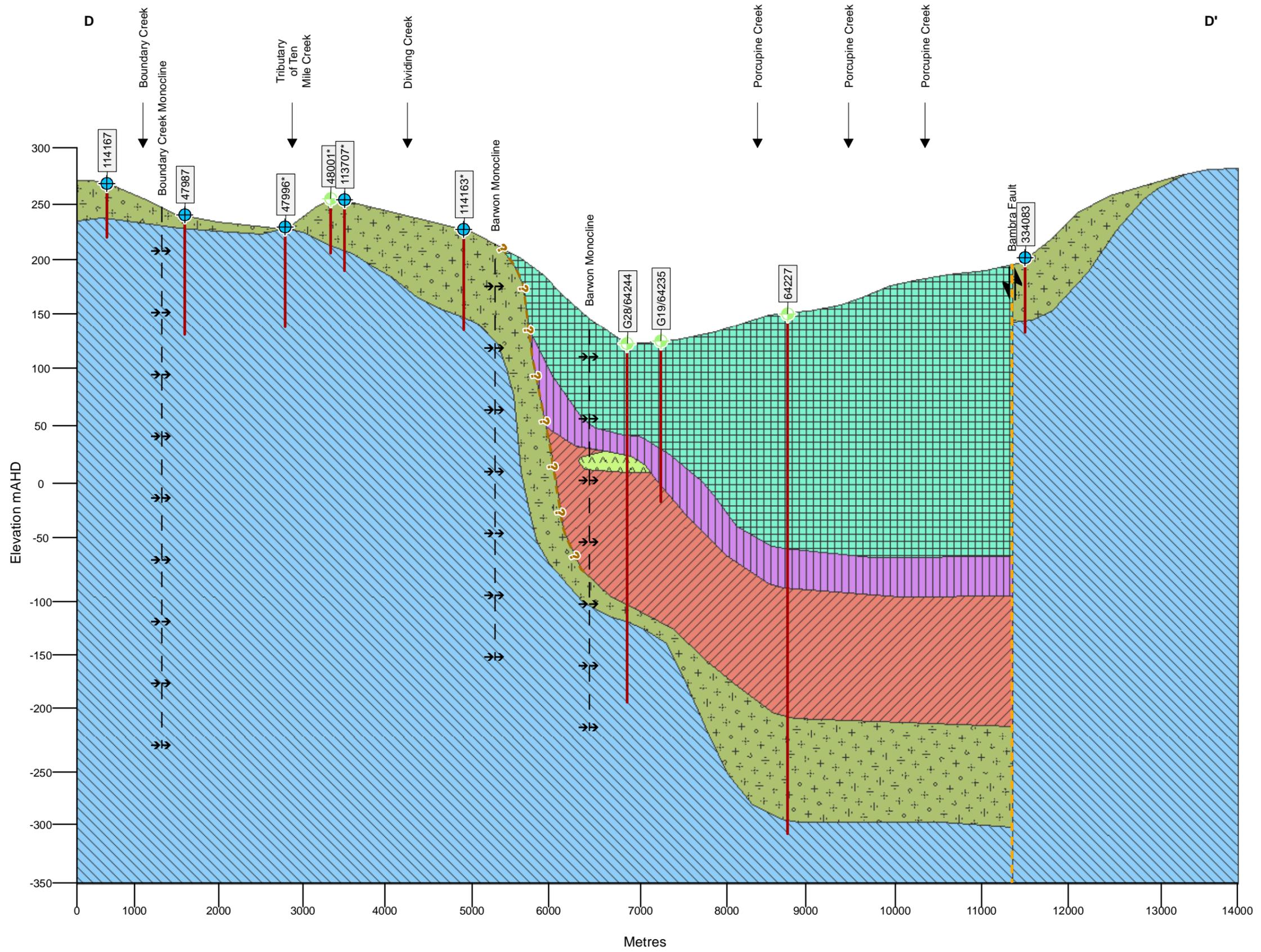
Service Layer Credits: World Topographic Map: Esri, HERE, Garmin, USGS, NGA

CONCEPTUALISED GEOLOGICAL CROSS SECTION C-C'

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

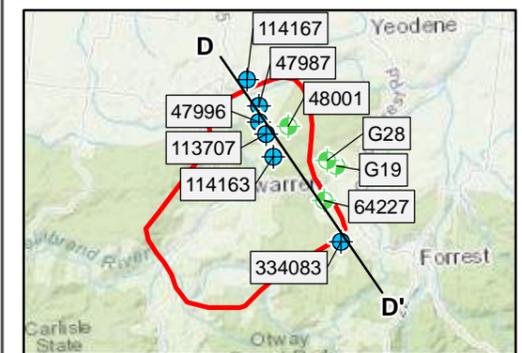
Figure
F14



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
- Structural Features**
- - - Bamba 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



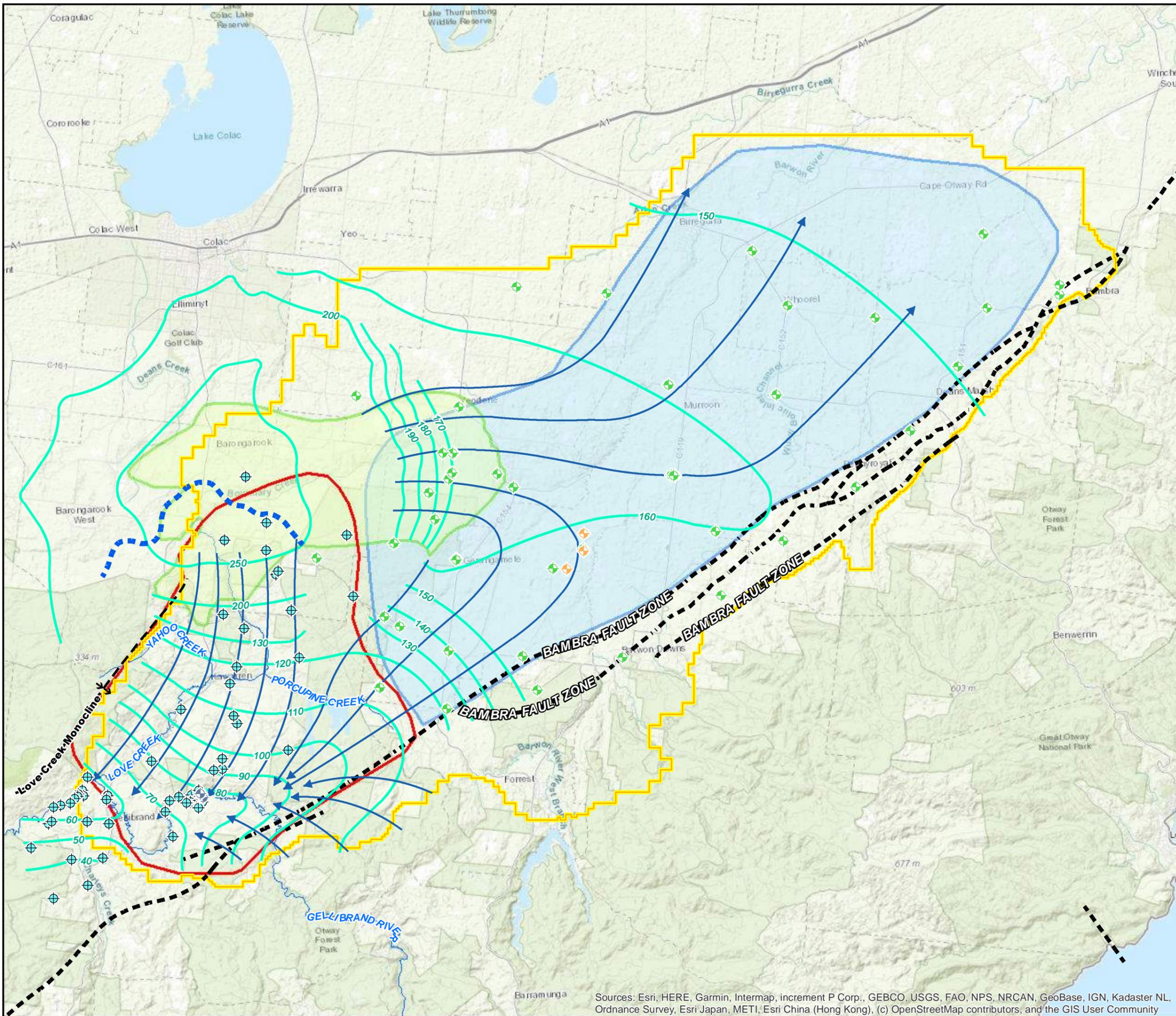
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

CONCEPTUALISED GEOLOGICAL CROSS SECTION D-D'

Hydrogeological Assessment - Kawarren Sub-basin

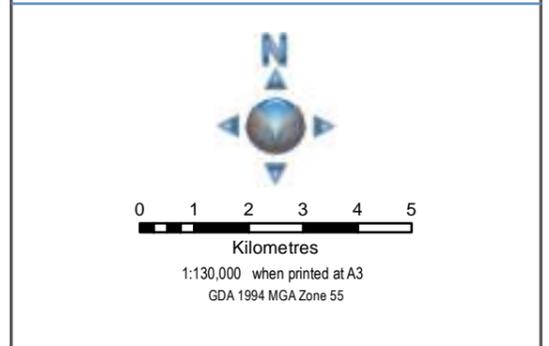
Kawarren Sub-basin
 Barwon Water

Figure
F15



- Legend**
- Kwarren 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 Gradient, Otway Basin, Victoria. International Conference on Groundwater and Man Sydney, 1983. Unpublished.

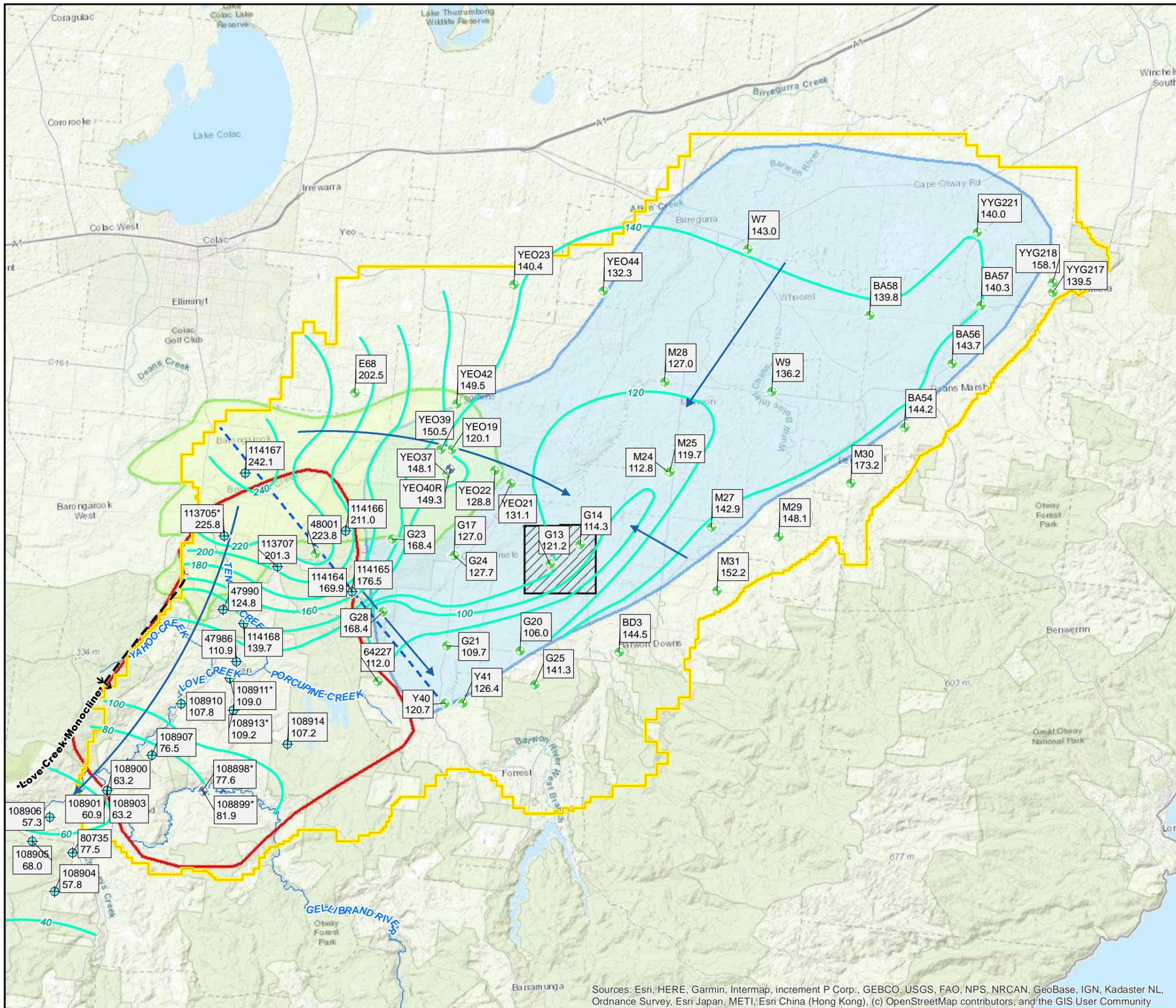


**POTENTIOMETRIC SURFACE
 CONTOURS - LTA (LEONARD, 1983)**

*Hydrogeological Assessment - Kwarren
 Sub-basin*

Kwarren Sub-basin
 Barwon Water

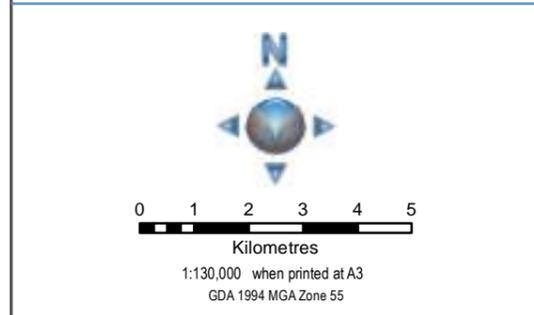
Figure
F16



- 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

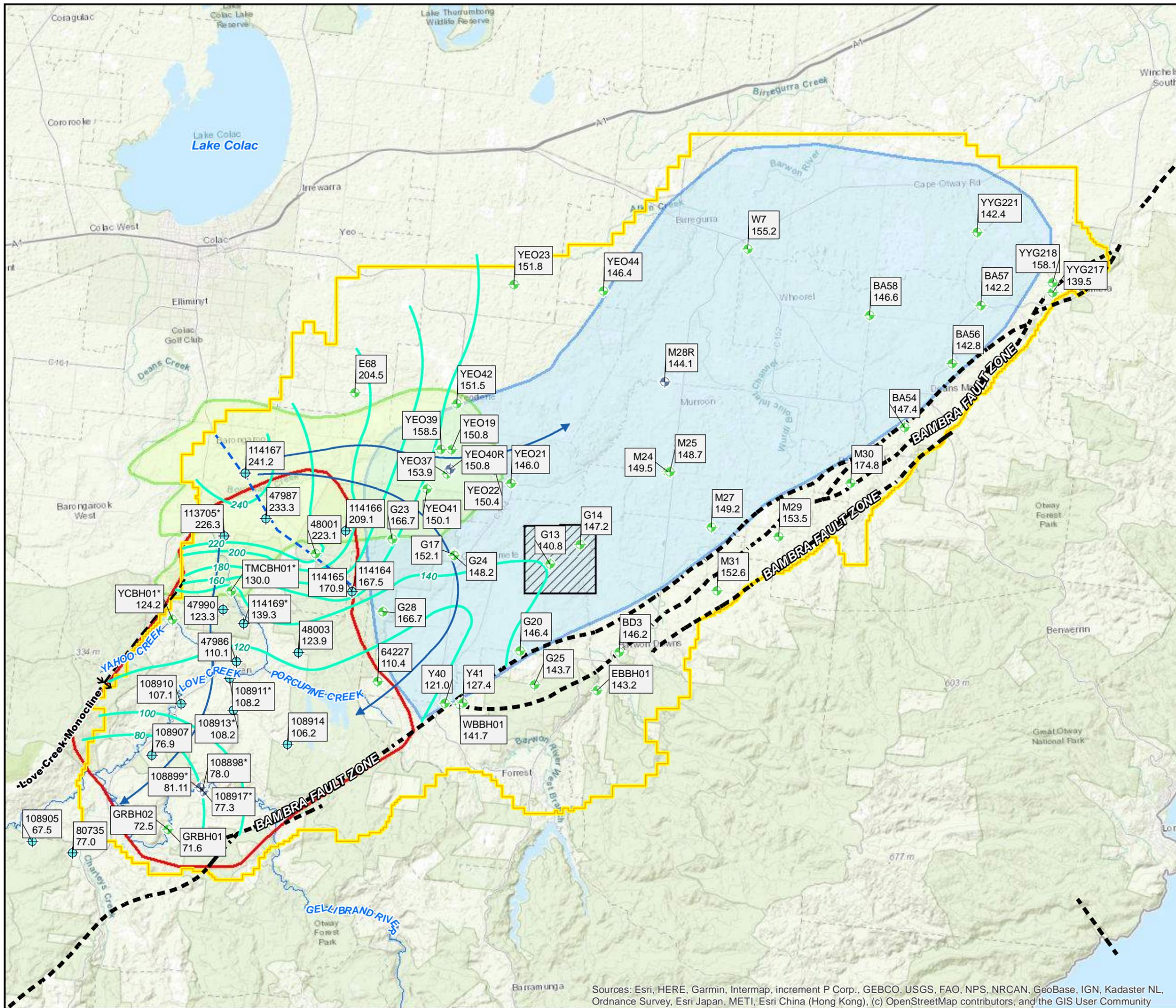


**POTENTIOMETRIC SURFACE
 CONTOURS – LTA (MAY 2010)**

*Hydrogeological Assessment - Kawarren
 Sub-basin*

Kawarren Sub-basin
 Barwon Water

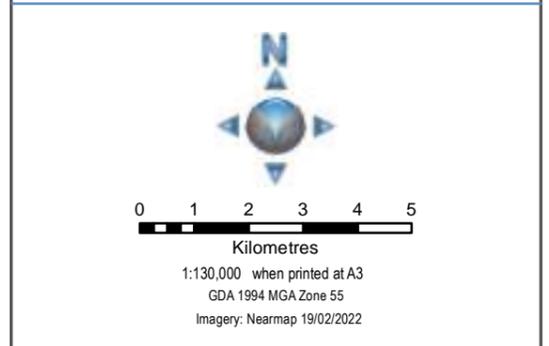
Figure
F17



- 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 Bore
 - ⊕ 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



POTENTIOMETRIC SURFACE CONTOURS – LTA (MAY 2022)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F18



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



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)

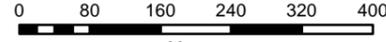
Surface Geology (1:50,000) (DELWP)

- 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)



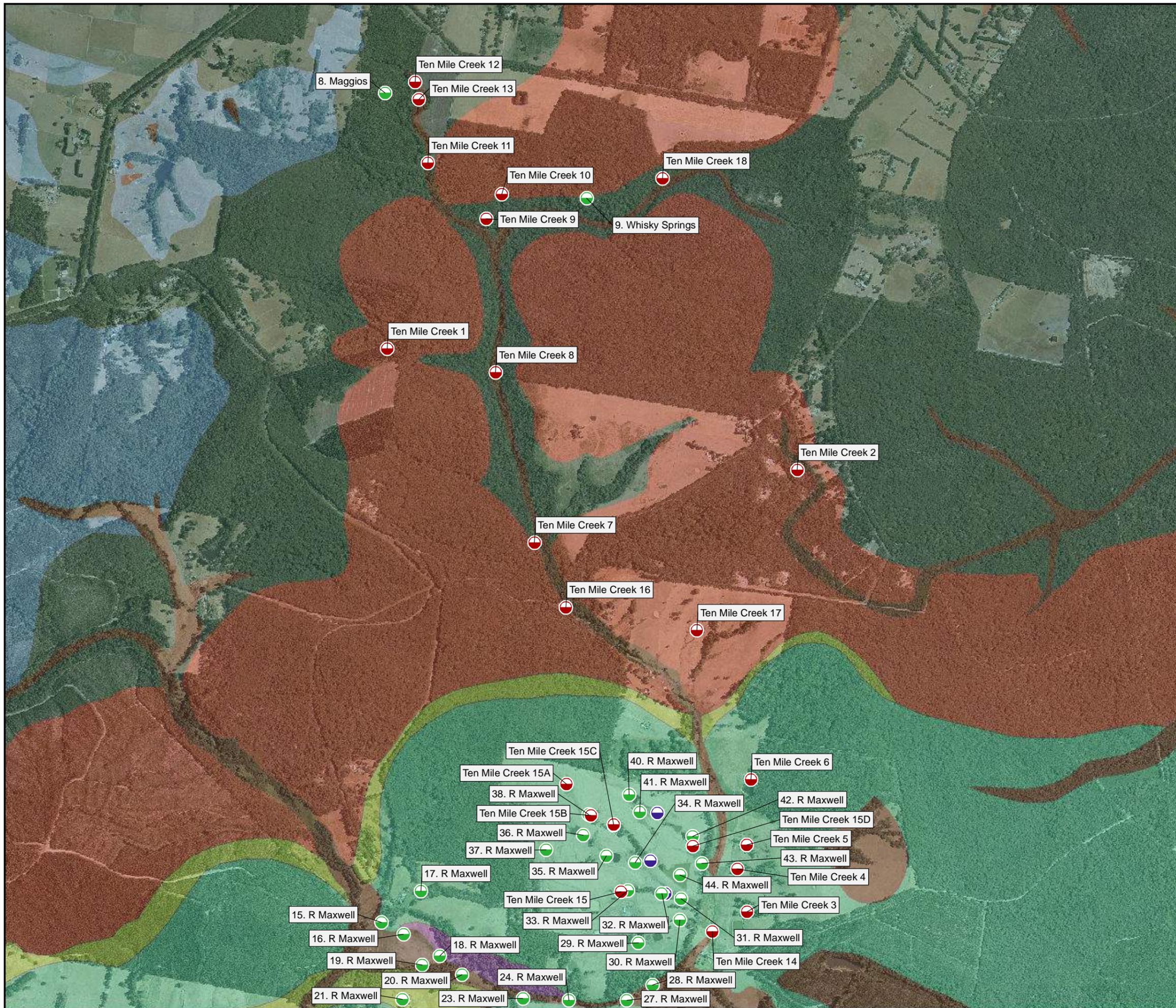
1:8,000 when printed at A3
 GDA 1994 MGA Zone 54
 Imagery: Nearmap 2019

MAPPED SPRINGS (PORCUPINE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
F19



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)

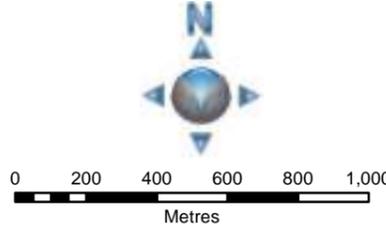
- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation
- Older Volcanics
- Nirranda Group (Narrawaturk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
- Otway Group

} 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)



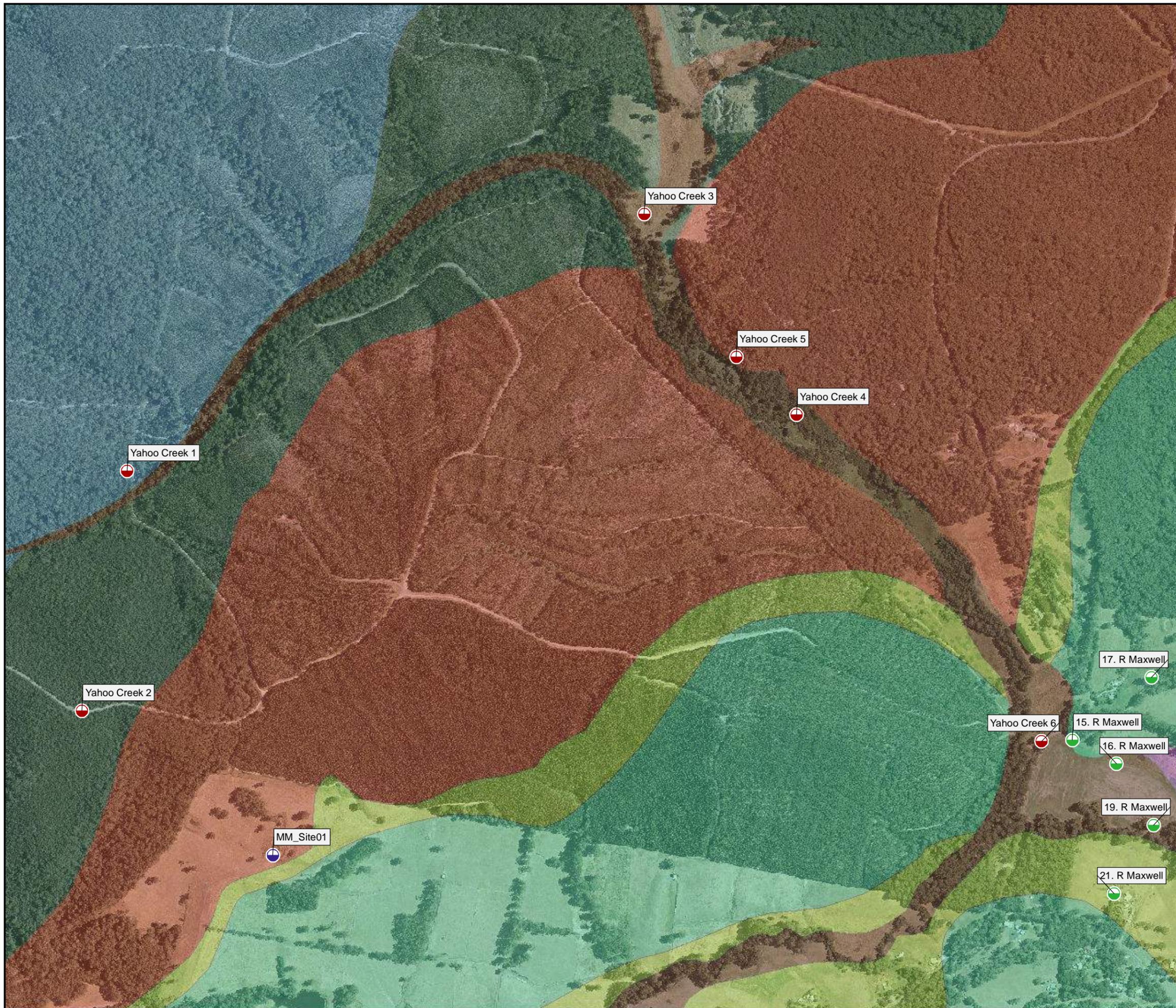
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 GDA 1994 MGA Zone 54
 Imagery: Nearmap 2019

MAPPED SPRINGS (TEN MILE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

Figure
F20

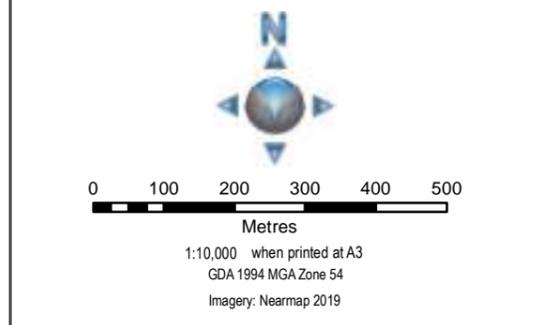


- Legend**
- Spring Locations (surveyed and anecdotal)**
- Private Spring Location (community survey)
 - Private Spring Location (SKM 2012)
 - Surveyed Spring Location (SKM 2012)
- Surface Geology (1:50,000) (DELWP)**
- Quaternary Sediments
 - Gellibrand Marl Formation
 - Clifton Formation
 - Older Volcanics
 - Nirranda Group (Narrawaturk Marl)
 - Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
 - Otway Group
- } 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)

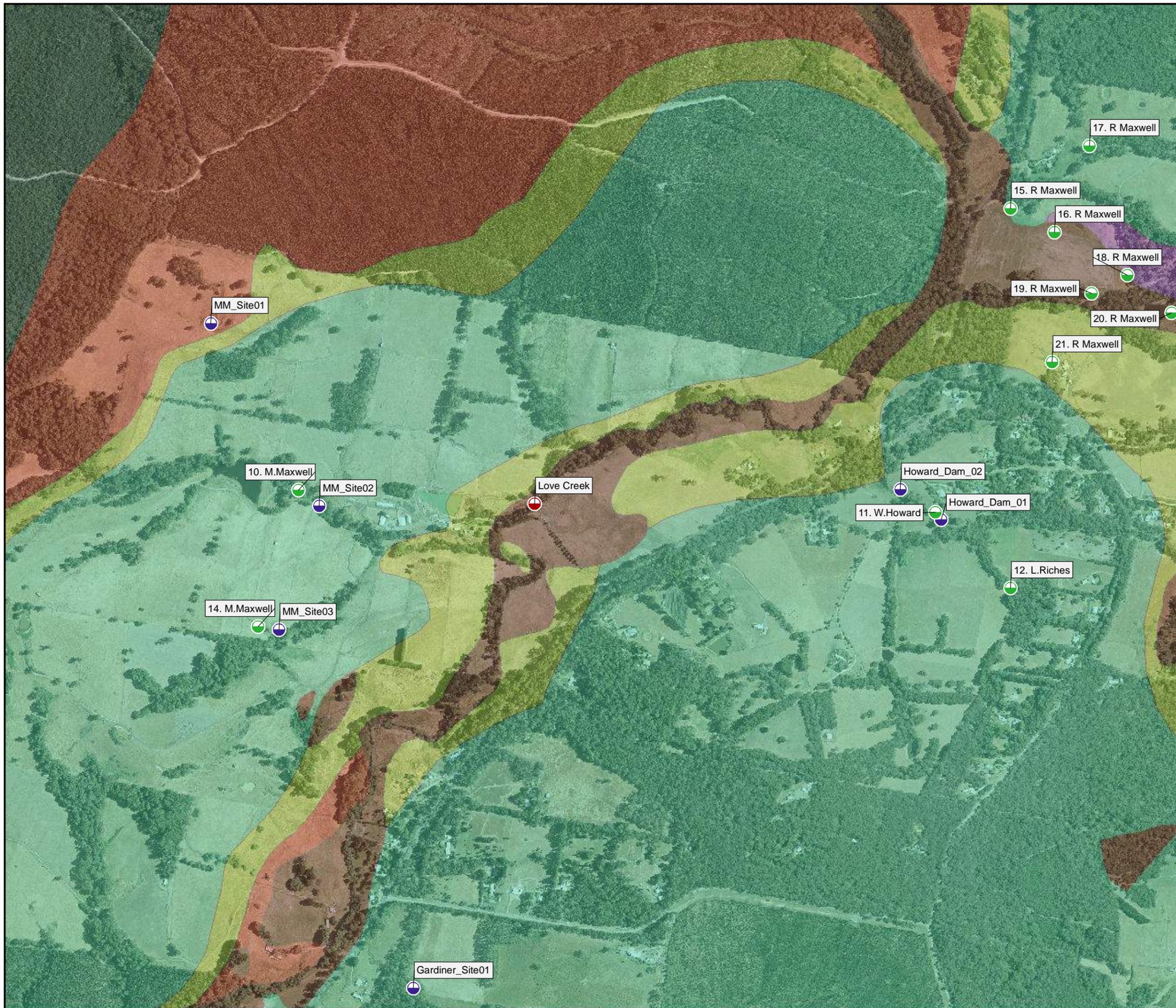


MAPPED SPRINGS (YAHOO CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
 Barwon Water

Figure
F21



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)

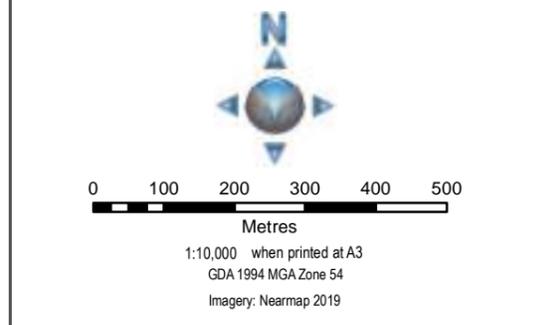
- Quaternary Sediments
- Gellibrand Marl Formation
- Clifton Formation
- Older Volcanics
- Nirranda Group (Narrawatuk Marl)
- Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)

} 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)

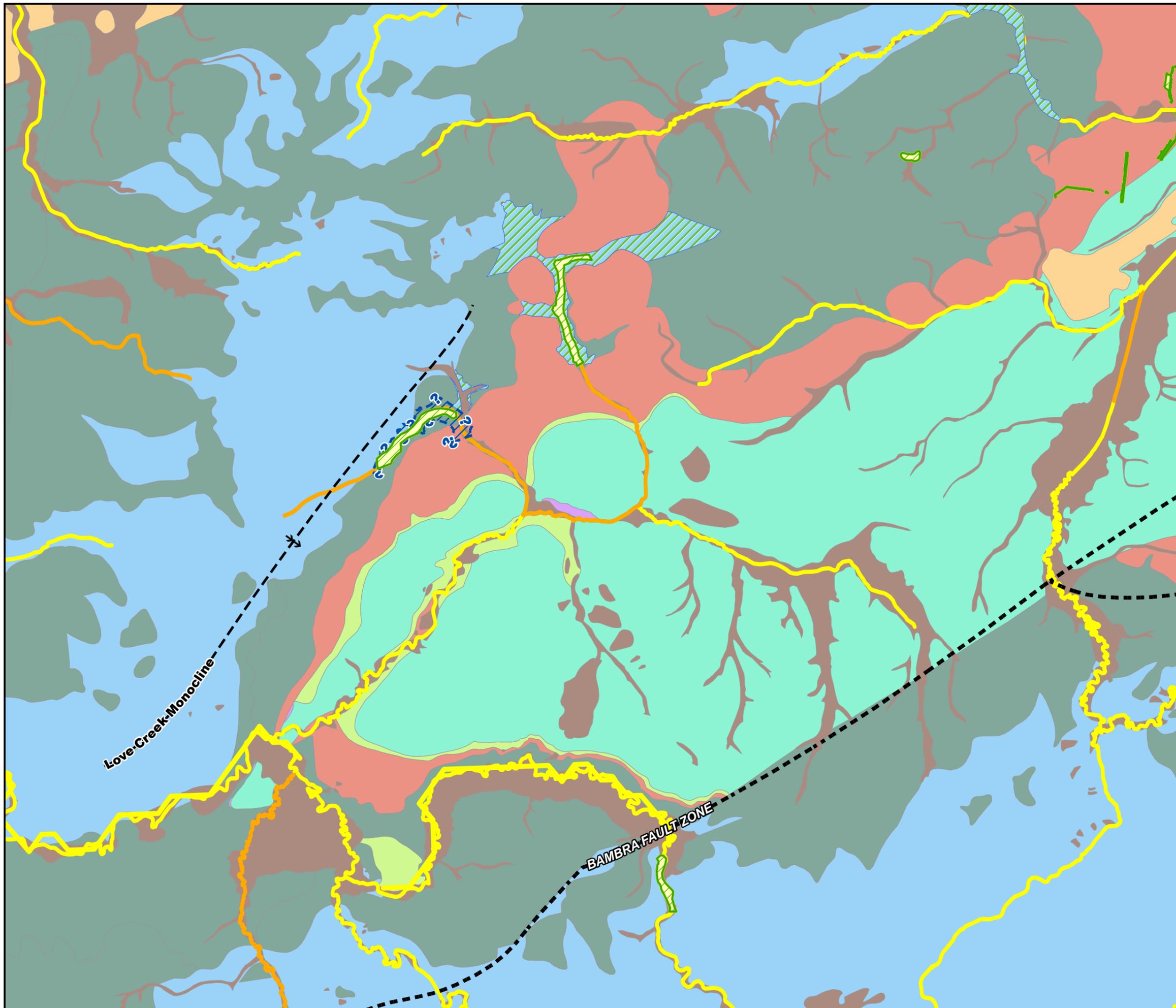


MAPPED SPRINGS (LOVE CREEK SUB-CATCHMENT)

Hydrogeological Assessment - Kwarren Sub-basin

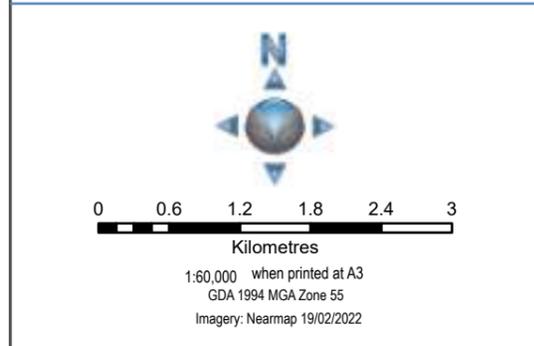
Kwarren Sub-basin
 Barwon Water

Figure F22



- Legend**
- Structural Features**
- ✚ Monocline
 - Geological Faults
 - ▨ Expected Groundwater Discharge (LTA)
 - ⊕ Expected Groundwater Discharge (LTA) (Low certainty as to extent)
- Validated Vegetation (ELA 2022)**
- ▭ Native - remnant
- GDE Likelihood of Vegetation (ELA 2022)**
- ▭ High
- Likelihood of Groundwater Interaction (ELA 2022)**
- ▭ High
 - ▭ Moderate
- Surface Geology (1:50,000) (DELWP)**
- ▭ Quaternary Sediments
 - ▭ Sandringham Sandstone
 - ▭ Gellibrand Marl Formation
 - ▭ Clifton Formation
 - ▭ Older Volcanics
 - ▭ Nirranda Group (Narrawaturk Marl)
 - ▭ Lower Tertiary Aquifer (Pebble Point, Pember Mudstone, Dilwyn and Mepunga Formations)
 - ▭ Otway Group

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

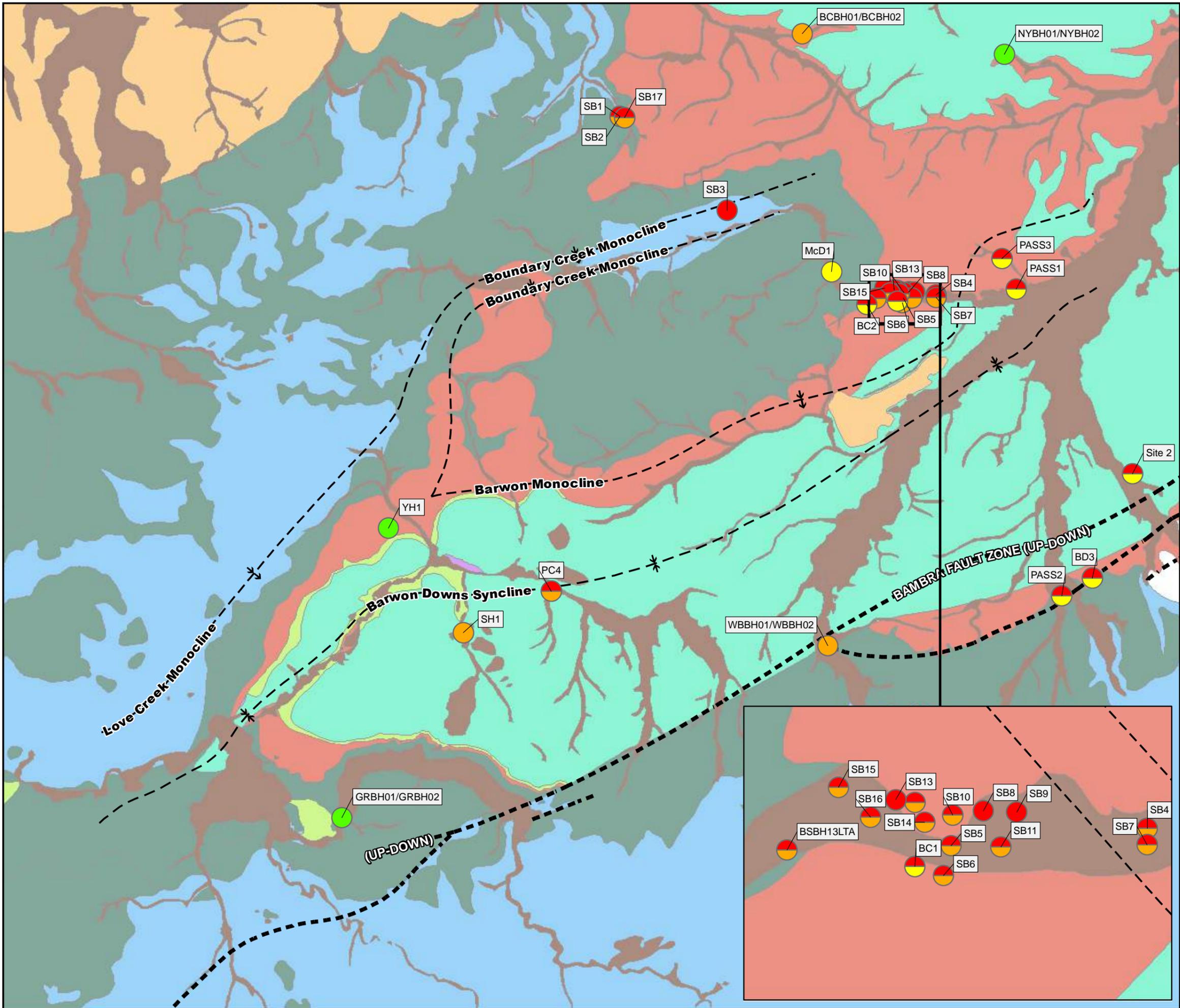


GROUNDWATER DEPENDENT ECOSYSTEMS

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
F23



Legend

- Kwarren Sub-basin Investigation Area (approx. extent)
- Approximate Extent of Barwon Downs Sub-basin

Structural Features

- Monocline
- Syncline
- Geological Faults

Acid Sulfate Soil Sampling Locations (Barwon Water)

ASS Classification

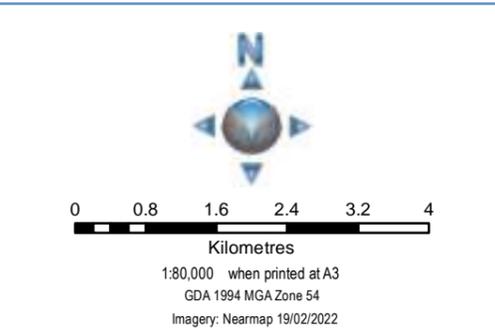
- Actual ASS
- Potential ASS
- Possible ASS
- Not identified

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

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

} Heytesbury 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

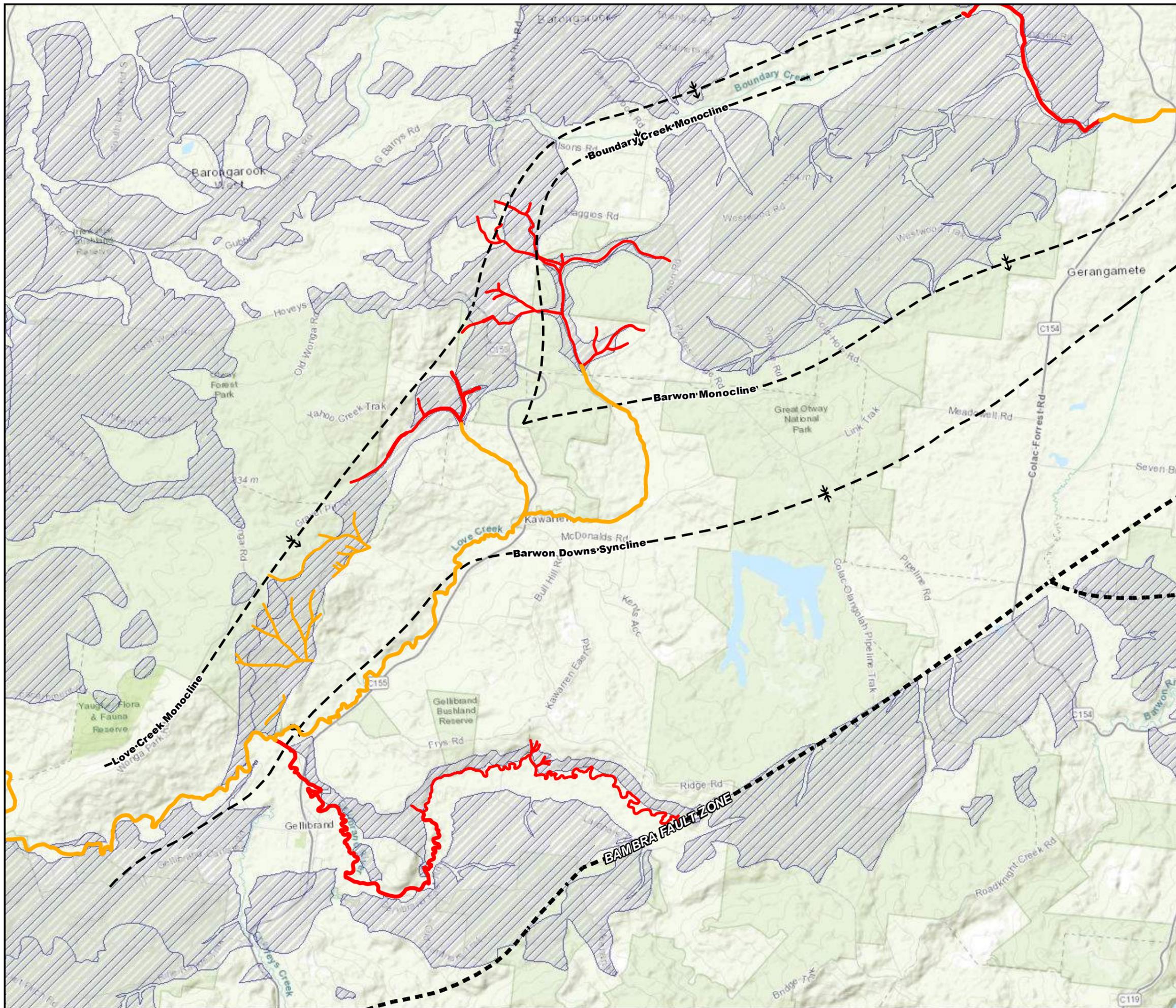


ACID SULFATE SOILS DISTRIBUTION

Hydrogeological Assessment - Kwarren Sub-basin

Kwarren Sub-basin
Barwon Water

Figure
F24



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)



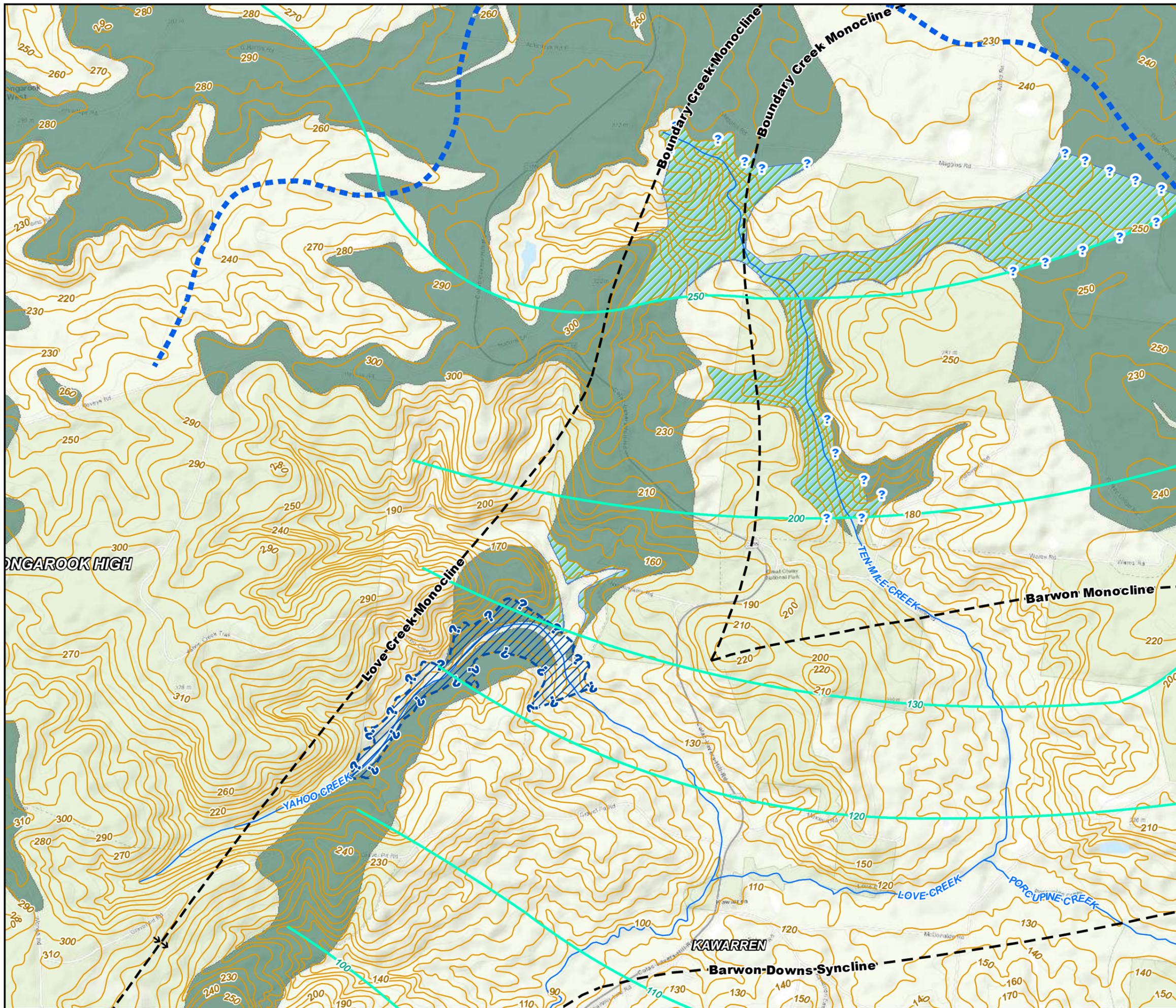
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 Kilometres
 1:60,000 when printed at A3
 GDA 1994 MGA Zone 55
 Imagery: Nearmap 19/02/2022

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

*Hydrogeological Assessment - Kwarren
 Sub-basin*

Kwarren Sub-basin
 Barwon Water

Figure
F25



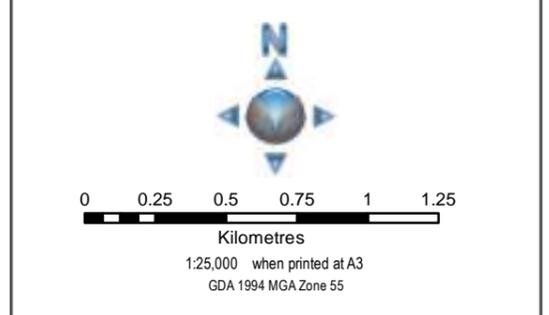
Legend

-  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

Structural 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



EXPECTED RECHARGE AND DISCHARGE AREAS - LTA

Hydrogeological Assessment - Kawarren Sub-basin

DRAFT

Figure **F26**

Kawarren Sub-basin
Barwon Water

Appendix A

Section 78 Notice

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



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.

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:
- continue no extraction, other than for maintenance and emergency response, and
 - prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and
 - describe the environmental outcomes for the waterways to be achieved by the remediation plan.
- 1.2 It is acknowledged that:
- 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.
 - 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	<p>On 7 August 2018 the notice was issued requiring Barwon Water to:</p> <ol style="list-style-type: none"> a) <i>Continue no extraction, other than for maintenance and emergency response, and</i> b) <i>Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs, and</i> c) <i>Describe the environmental outcomes for the waterways to be achieved by the remediation plan.</i> <ul style="list-style-type: none"> • A report (Barwon Downs Hydrogeological Studies 2016-17: Numerical model calibration and historical impacts, Jacobs June, 2017) indicated that the operation of the borefield over 30 years was responsible for 2/3 of the reduction of groundwater base flow into Boundary Creek. This was based on a 1ML/day reduction from climate under no pumping scenarios, and 3 ML/day reduction with pumping (i.e. an additional reduction of 2 ML/day). Noting that this modelling did not factor in the role of the private on-stream dam. • 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 '<i>Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan</i>'. Which was to (among others) include: <ul style="list-style-type: none"> – 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, 2024, Boundary Creek, Big Swamp and surrounding environment – Remediation and Environmental Protection Plan, October 2024	
Scope of Work	Preparation of REPP to address and meet the requirements of the section 78 Ministerial Notice.
Key Findings	<p>The following findings were noted regarding Boundary Creek and Big Swamp.</p> <ul style="list-style-type: none"> • 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 1982-1983, 1997-1990, 1997 – 2001, 2005 – 2010 and 2016. ~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.

Item	Details
	<ul style="list-style-type: none"> • June 2017 Barwon Water acknowledge that the historic management of periodic groundwater pumping activities had led to a reduction in groundwater contribution from the Lower Tertiary Aquifer into select reaches of Boundary Creek. • . • May 2018 a community and stakeholder working group was established by Barwon Water to participate in the development of the REPP. • 2019 During development of the REPP Barwon Water let their groundwater extraction licence expire • Two objectives of the REPP are twofold: <ul style="list-style-type: none"> - The Boundary Creek & Big Swamp Remediation Plan – that outlines the controls and actions that have and will be implemented to: <ul style="list-style-type: none"> o Ensure no further harm from Barwon Water’s historic groundwater pumping or remediation actions. o Protect the water quality and ecological values of the Barwon River. o Improve the water quality and streamflows within Boundary Creek. o Improve the ecological values of Big Swamp. - The Surrounding Environment Investigation – To investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction activities at the Barwon Downs borefield. • 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: <ul style="list-style-type: none"> - 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). • 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. • Groundwater pumping, in conjunction with the changes in land use, Millennium Drought , and the complexities associated with management and regulation of a private on-stream dam that controls flow into the lower reaches of Boundary Creek, resulted in the occurrence of cease to flow event in Boundary Creek and the increased severity of wet-dry cycling processes within Big Swamp – a wetland that is primary fed by inflows from Boundary Creek (Barwon Water, 2019). • Remedial actions for Boundary Creek and Big Swamp included:

Item	Details
	<ul style="list-style-type: none"> - Cessation of groundwater pumping activities; - Decommissioning of the Barwon Downs borefield extraction bores; - Provision of supplementary flows, where required, to maintain flows of at least 0.2 ML/day at the Boundary Creek at Yeodene stream gauge (site 233228) - Provide suitable conditions for wetland species to recolonise impacted areas; and - Development of risk-based contingency measures to be implemented in the unlikely event that they are required. <ul style="list-style-type: none"> • Environmental Monitoring Program is provided in Appendix A of REPP. <p>Actions completed to help inform the Surrounding Environment Investigation:</p> <ul style="list-style-type: none"> • Installation of 21 additional groundwater monitoring bores and 5 additional stream gauges in the modelled high-risk areas • Development and re-instatement of 3 existing groundwater monitoring bores that were previously part of the state observation bore network • Completion of additional vegetation monitoring within the modelled high-risk areas • Review of potential groundwater dependent ecosystems within the Barwon Downs region more broadly <p>Technical Response to Notice:</p> <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> - 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: <ul style="list-style-type: none"> - Quaternary Aquifer: Quaternary Alluvium - Lower Mid-Tertiary Aquifer: Sandringham Sandstone; Gellibrand Marl, Clifton Formation & Older Volcanics); - Lower mid-Tertiary Aquitard: Demons Bluff Group & Narrawaturk Marl; - Lower Tertiary Aquifer: Mepunga Formation & Wangerrip Group – primarily Mepunga, Dilwyn and Pebble Point formations; and - Basement (Otway Group Aquifer): Otway Group • 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. • Big Swamp has had a significant reduction/change in vegetation cover and type over the past 30 years.

Item	Details
Blake, W.J.R., 1974, A preliminary report on the geology and hydrogeology of the Barwon Downs area (unpublished)	
Scope	<p>Study of the groundwater resources of the Otway Ranges.</p> <p>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).</p> <p>Works included:</p> <ul style="list-style-type: none"> • Drilling bores for both stratigraphic and hydrogeologic purposes (15 bores); and • Interpretation of magnetic, gravity and seismic data.
Key Findings	<ul style="list-style-type: none"> • 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 <i>quartz-clastic, deltaic sedimentation separated by a marine transgression in the middle Paleocene</i> (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: <ul style="list-style-type: none"> – 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.	
Scope	

Item	Details
Key Findings	<ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> – Enhanced natural recharge as a result of lowered water levels; – Induced stream bed infiltration as water levels fall below stream level; – Leakage from 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 Bamba 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.
Lakey 1983, GSV Gellibrand Groundwater Investigation – Kawarren Pumping Test Report	
Scope	Pumping test on Yaughar 51 bore to determine hydraulic characteristics of Dilwyn Formation and Mepunga Formation to inform possible construction of borefield in Kawarren area.
Key Findings	<ul style="list-style-type: none"> • Yaughar 51 bore not installed within the Pebble Point Formation. • Both Dilwyn and Mepunga Formations were found to not comprise a homogeneous aquifer. Slow and incomplete recovery considered due to <i>'partial and permanent collapse of aquifer skeleton resulting from depressurising the system from its pristine and possibly slightly over-</i>

Item	Details
	<p><i>pressured system</i>. Similar residual drawdowns observed in Barwon Downs borefield – potentially due to same issue.</p> <ul style="list-style-type: none"> An area of concern in relation to the development of a borefield in the Kwararren 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 Kwararren 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.
<p align="center">Gellibrand Groundwater Investigation – Stage II Report – August 1983, R Lakey & J Leonard (PDF pg 35 of (Lakey R. , 1984)</p>	
<p>Scope</p>	<p>Draws together all geological and hydrogeological information from investigations completed along western flanks of the Otway Ranges.</p> <p>Investigations completed included geological mapping, geophysical surveys, borehole drilling, wireline logging, aquifer tests, water level monitoring and water quality analysis.</p>
<p>Key Findings</p>	<ul style="list-style-type: none"> 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-Kwararren East area due to half grabens associated with Loves Creek and Kwararren 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.
<p align="center">HydroTechnology, 1994, Delineation of the Barongarook High Recharge Area, Kwararren Groundwater Resource Evaluation, May 1994.</p>	
<p>Key Findings</p>	<ul style="list-style-type: none"> Investigation into the Kwararren Groundwater sub-basin of Barwon Downs graben considered as an area to construct a borefield. 12 km² of the outcropping aquifer material on the Barongarook High acts as a recharge area (out of 28 km² outcropping area total). Groundwater primarily moves through a narrow paleo-valley extending northwards from the extracting site at Kwararren 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.

Item	Details
	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Groundwater level data collection; River elevation and EC collection; Spring discharge estimates and water quality sampling; and Surface water and groundwater sampling.
Key Findings	<ul style="list-style-type: none"> 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 studied.

Item	Details
	<ul style="list-style-type: none"> 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.
Aquade, 2015, Preliminary Consideration of the Likely Impact of Barwon Downs Groundwater Extraction on Groundwater in the Kawarren/Gellibrand Area (Completed for LAWROC)	
Scope	<ul style="list-style-type: none"> 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.
Key Findings	<ul style="list-style-type: none"> 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).
Jacobs, 2016, Barwon Downs Hydrogeological Studies 2015/16 – Recharge Rate Assessment, 16 September 2016.	
Scope	<ul style="list-style-type: none"> 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.
Key Findings	<ul style="list-style-type: none"> Results found that the <i>'best representation of current/modern recharge to the LTA on the Barongarook High are derived from the application of independent and interface methods'</i>. Modern recharge rates are most likely around 9 – 11% of average annual rainfall in the area of aquifer outcrop. 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.

Item	Details
Aquade, 2017, Impacts of Barwon Downs Extraction on Groundwater and Surface Water in the Kawarren Area, 27 January 2017 (prepared for LAWROC).	
Scope	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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. • 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.

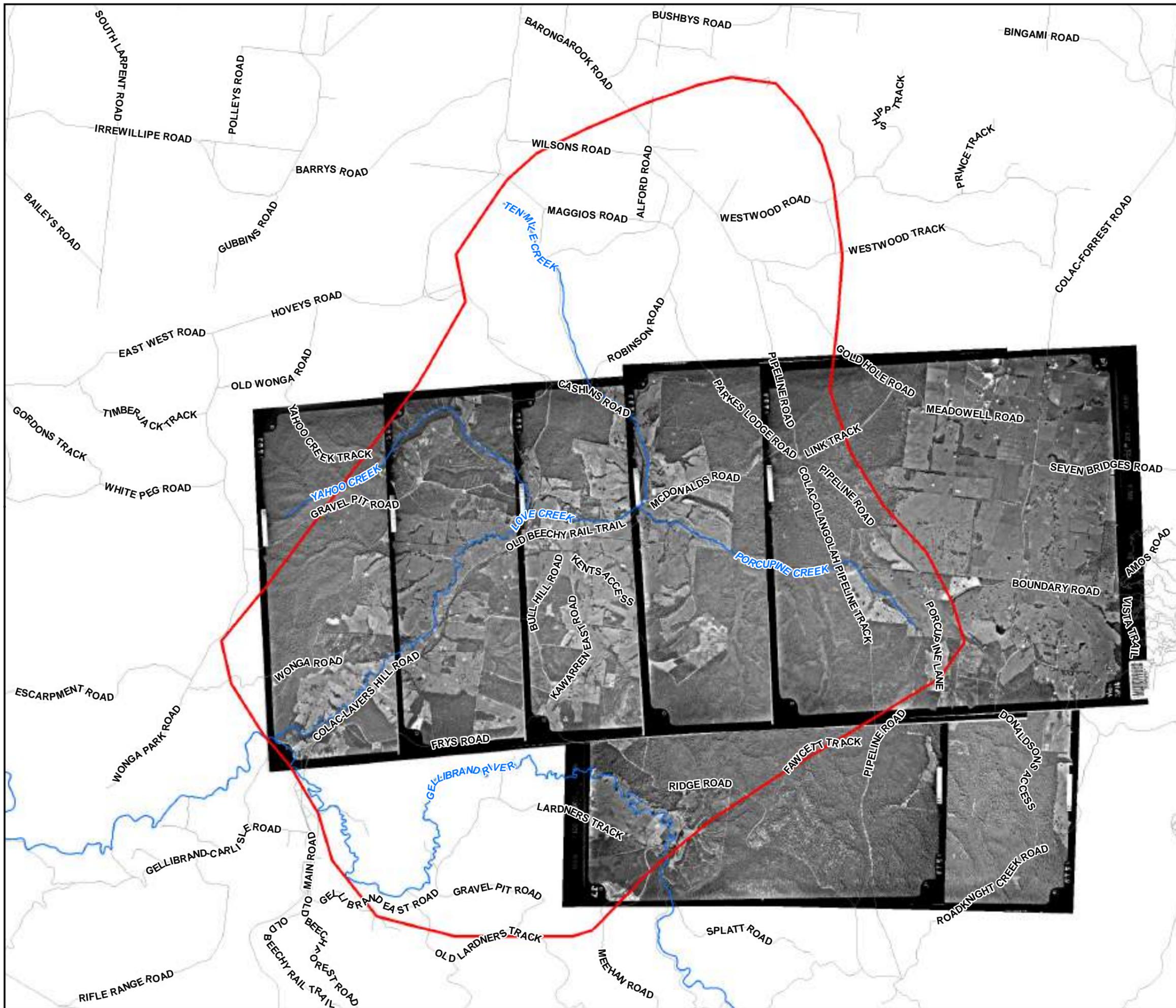
Item	Details
	<ul style="list-style-type: none"> Loves Creek considered to flow over aquitard, however, there are small outcrops of the LTA near the confluence of Gellibrand River. Risk considered to be low. Several trigger levels set including for Ten Mile Creek and Gellibrand River .
Aquade, 2019, Potential impacts of Barwon Downs extraction on groundwater in Barongarook Creek Catchment	
Scope	<ul style="list-style-type: none"> Assess apparent connection between Barwon Downs pumping and drawdown in the Barongarook Creek Catchment.
Key Findings	<ul style="list-style-type: none"> It was understood (based on previous reports) that; <ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Renew and update existing numerical model to assess historic impacts associated with groundwater extraction.
Key Findings	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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 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.

Item	Details
Otway Water Book 28: The Western Front, Ten Mile and Loves Creek Catchment 2015	
Scope	<ul style="list-style-type: none"> • Draws together various studies to clarify potential impacts of groundwater extraction on the upper reaches of the Gellibrand River Catchment.
Key Findings	<ul style="list-style-type: none"> • '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 mm. 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 '<i>reflect a reasonably full aquifer system if it had not been for a significant groundwater extraction.</i>' • 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.
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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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.

Item	Details
	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> The identification of GDEs based solely on risk-based modelling was difficult. Uncertainty whether vegetation that was surveyed was relying 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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)

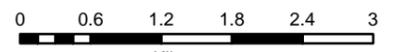


PROJECT ID 31155.01
 DATE 29/03/2023
 CREATED BY AF



Legend

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



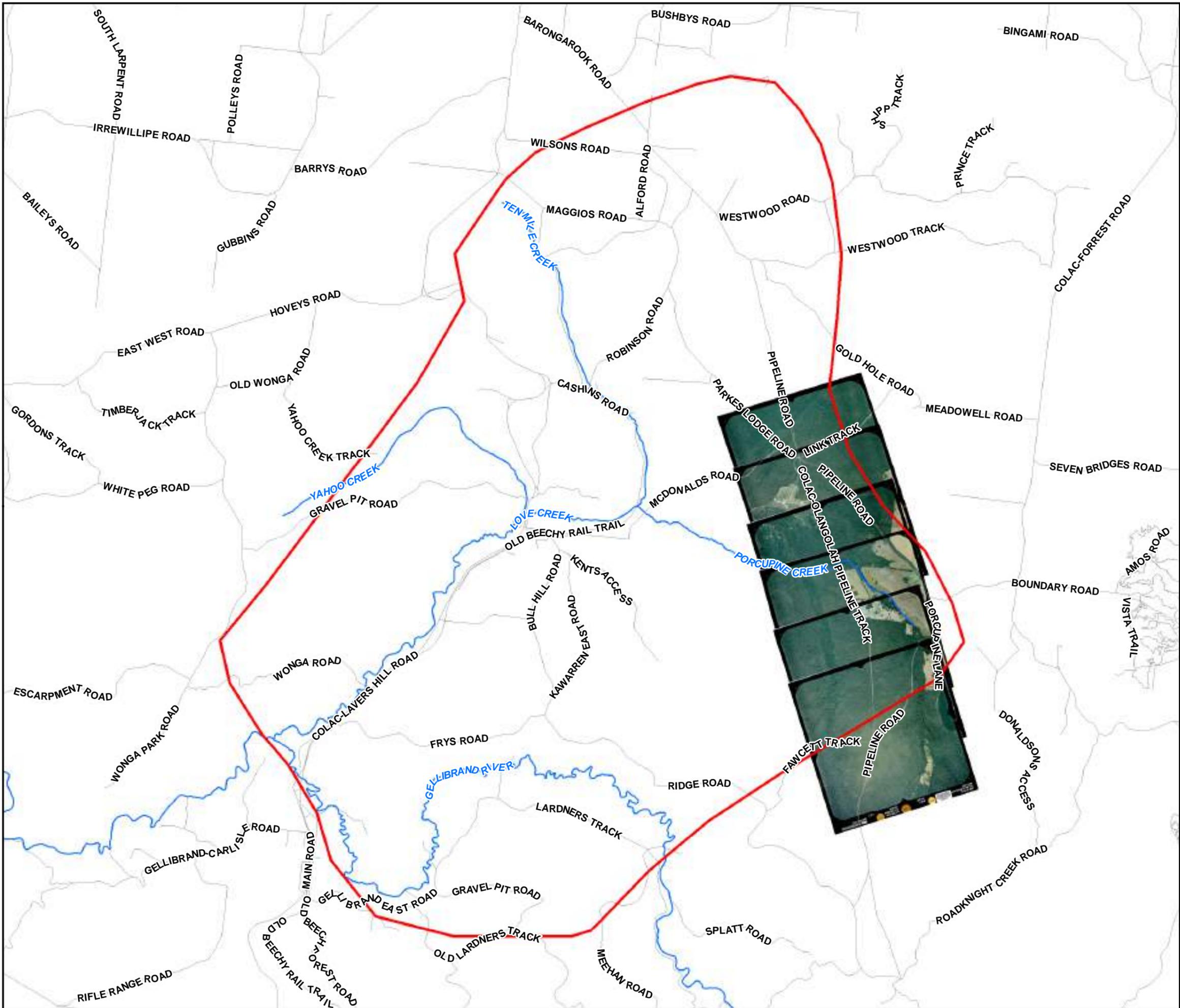
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 GDA 1994 MGA Zone 55

HISTORICAL AERIAL - 1983

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
 Barwon Water

Figure
A2

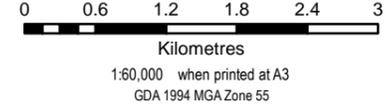


PROJECT ID 31155.01
 DATE 29/03/2023
 CREATED BY AF



Legend

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

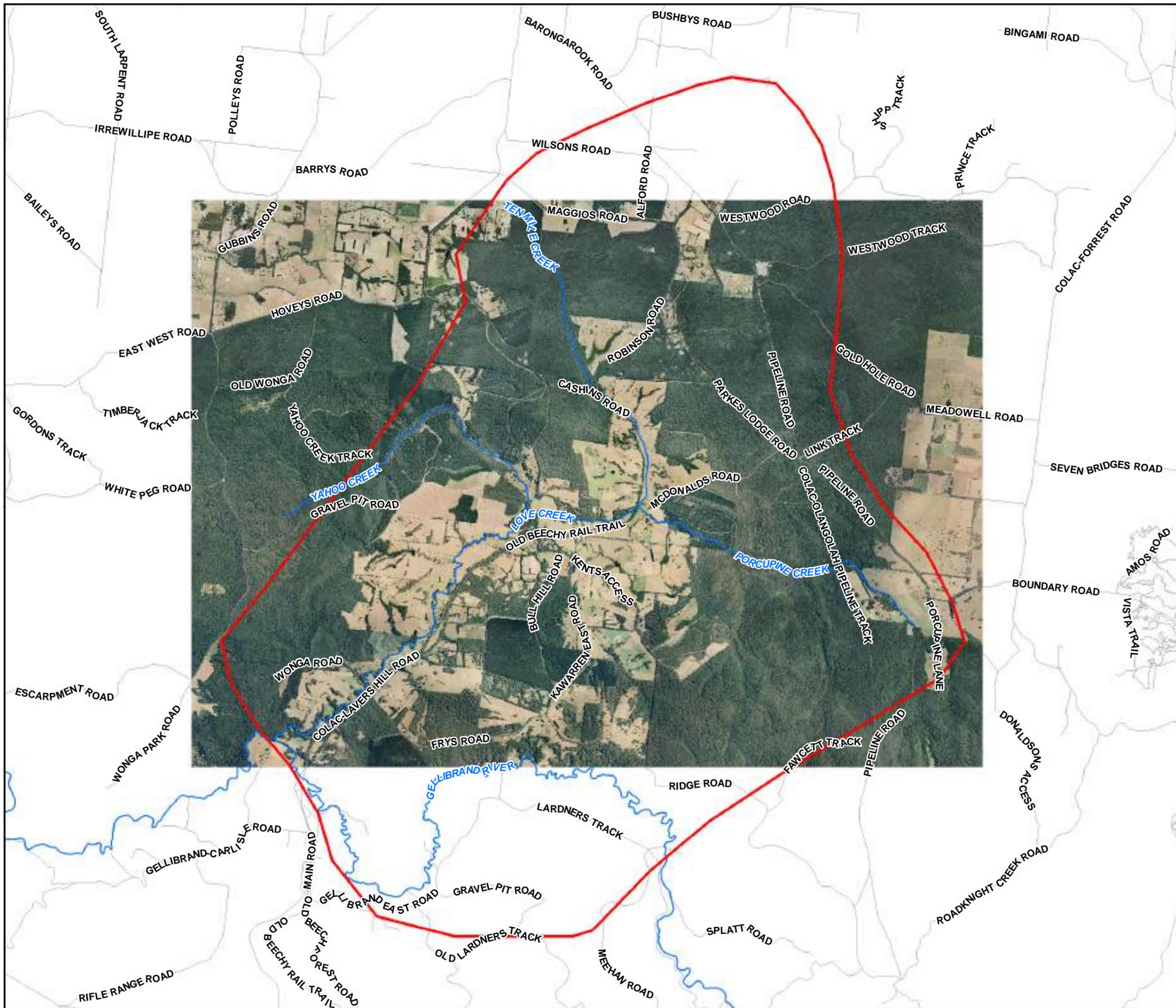


HISTORICAL AERIAL - 1998

Hydrogeological Assessment - Kawarren Sub-basin

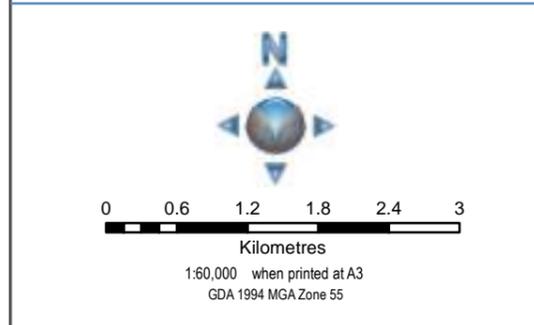
Kawarren Sub-basin
 Barwon Water

Figure
A3



Legend

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



HISTORICAL AERIAL - 2007

Hydrogeological Assessment - Kawarren Sub-basin

Kawarren Sub-basin
Barwon Water

Figure
A5

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	<p>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 Yaughner Volcanics and in lower reaches appears to be Dilwyn Formation. The flow of the spring is estimated to be ~1 ML/day.</p> <p>Other observations: Plantations in vicinity of Yahoo Creek have been rotated between gums and pines since ~1970s.</p> <p>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.</p> <p>It is understood anecdotally that farmers take water from Loves Creek and that both Porcupine Creek and Loves Creek don't dry up.</p> <p>Following removal of plantations sediment build up washes off into the adjacent waterways.</p>
M & C Maxwell 1840 Colac-Lavers Hill Road, Kawarren	<p>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.</p> <p>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.</p> <p>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.</p>
L & V Riches 20 Riches Road, Kawarren	<p>The Riches have been at the property since 1983.</p> <p>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.</p> <p>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.</p> <p>At the time of the inspection the spring was light grey in colour.</p>
D & B Dawes 380 Frys Road, Kawarren	<p>One spring located on southern slope of property towards Gellibrand River.</p> <p>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.</p> <p>D Dawes pers comms: sand hills at base of the track above the river flats.</p>
D & J Jukes 1845 Colac-Lavers Hill Road, Kawarren	<p>~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.</p> <p>Believes there is acid sulfate soil on property in swamp area at lower end of the creek on alluvial flats.</p> <p>Creek on property runs all year round quite well and also during drought. Springs dry out during periods of drought.</p> <p>Soils have approximately 4 inches of topsoil before moving to red clays. Also coffee rock around.</p> <p>The property is susceptible to tunnel erosion, as well as surface erosion.</p> <p>Not aware of rock outcrops on the property.</p>

Landholder and Location	Observations / Comments
	<p>The property was cleared ~50 years ago and since the Jukes have been at the property they have been re planting trees.</p>
<p>R Maxwell 35 Kawarren East Road, Kawarren</p>	<p>~40 springs on property, with some drying up (mid-late 1980s) and some continuing to flow.</p> <p>Between ~1906 to 1956 a quarry and lime kiln operated at the property at the outcrop of Clifton Formation. The Clifton Formation outcrops are approximately 20 m high.</p> <p>Springs present along the base of the Clifton Formation and the Quaternary flats along Loves Creek.</p> <p>Historically irrigated in the 1970s and 1980s from Loves Creek – after ~10 minutes of pumping the creek was dry.</p> <p>M. Maxwell also historically irrigated – pumping ~40 gallons ?/minute?</p>
<p>M Calvert Kents Access, Kawarren</p>	<p>Numerous springs on property.</p> <p>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</p> <p>Springs all along Spinyhorn Creek, generally at break in slope.</p> <p>Anecdotally a spring along Kents Access flows straight out of the ground and has capacity to fill and keep full an ~20 ML dam.</p> <p>A reduction in the flow of springs has been observed.</p> <p>At end of Kents Access on an outcrop of ?LTA or marl is a spring that feeds into Porcupine Creek.</p>
<p>D & J Hopkins</p>	<p>No permanent springs exist on their property.</p> <p>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.</p> <p>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.</p> <p>The property does not have any dams or irrigation licence for water supply.</p> <p>The property below Hopkins was at one point a tobacco plantation and had an irrigation dam built 30 yrs ago but stopped.</p>
<p>Neville & Christine Towers</p>	<p>Have one creek running through their property as well as a spring in the paddock.</p> <p>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.</p> <p>They run a pump out of the creek for use as a domestic firefighting mechanism, no permit for this.</p>
<p>Peter & Anette McDonald</p>	<p>Porcupine and Ten Mile creek runs along their property.</p> <p>One major source coming out from their paddock runs into porcupine creek at a consistent level, all others stop running over summer.</p> <p>On the Ten Mile creek side of their property there are only a few springs next to their boundary.</p> <p>They haven't irrigated their property in years, and have said that only a few people with permits actually pump out of Loves Creek.</p>

Landholder and Location	Observations / Comments
	<p>The McDonalds pump out approximately 4 mL/year from porcupine creek and have done this for the past 15 years, creek has gone dry.</p>
<p>Keith & Maxine Armistedd</p>	<p>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.</p> <p>An extensive spring runs along horn creek, runs across to P McDonalds property.</p> <p>The dam on their property is continually wet, in the 67 drought they could shovel enough water from it all the time.</p> <p>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.</p>
<p>Other notes</p>	<p>N. Longmore pers comms: Lime kilns used to operate at Kawarren.</p> <p>Jock (?) pers comms: peats located along Yahoo Creek. Additionally prickly tea tree found to be associated with PASS.</p> <p>M. Calvert pers comms: P McDonald pumped from Porcupine Creek in the 1980s which resulted in no flow to Loves Creek from Porcupine Creek.</p>

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

Appendix F

Hydrographs

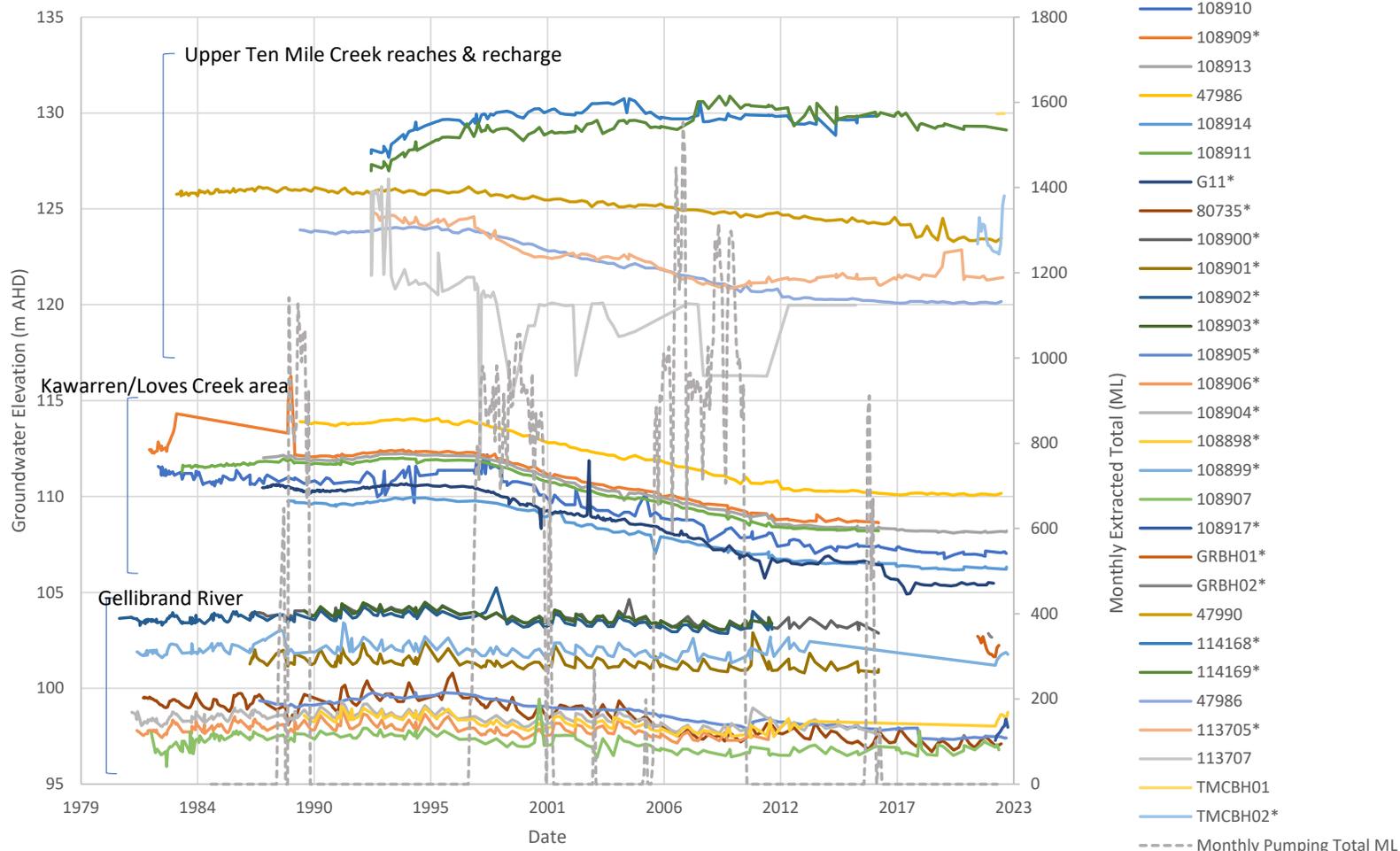


Figure F1 - Groundwater Bore Hydrographs
 Hydrogeological Investigation of the Kawarren sub-basin
 Surrounding Environment Investigation
 Barwon Water

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

