Barwon Downs Borefield

Investigation plan for areas of potential high risk

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Barwon Water

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Executive Summary

Background

Barwon Water received a Section 78 Notice (under the Water Act 1989 (Vic)) and the purpose of the Notice is to ensure that Barwon Water successfully remediate impacts caused by historic groundwater extraction. The Section 78 Notice directs Barwon Water to develop and implement a Remediation Plan for Boundary Creek and Big Swamp and surrounding environment.

The Remediation Plan is divided into two areas with different action plans:

- *Boundary Creek and Big Swamp remediation plan* includes areas where impact has been confirmed by monitoring data and remediation actions have been recommended and
- *Surrounding Environment investigation plan* includes areas where impact has not yet been confirmed due to insufficient monitoring to validate groundwater model predictions and further work is required.

This report documents the recommendations for the Surrounding Environment investigation plan. A key input to the assessment that supports the plan is results from the regional groundwater model. The following description provides context for the results that are utilised in this report.

Regional Groundwater Model

The regional groundwater model has evolved over more than two decades as more information has become available. The most recent groundwater model was completed in 2016-17 when the model was expanded, re-built and re-calibrated. The update of the model includes new layers, new monitoring data and a significant improvement in the conceptual understanding.

Although the regional model has significant improvements in the conceptualisation, there are still several limitations of this model. The regional groundwater model is understood to over-state potential drawdown in regional aquitards and in areas where Quaternary aquifers have been confirmed to be present but have not been included in the model. These layers are known to act as physical constraints, such as clay layers within the formations that restrict groundwater flow from the regional aquifer and therefore may limit groundwater drawdown. As these physical constraints have not been included in the regional groundwater model, the model does not account for the restriction of vertical groundwater flow and subsequent decrease in drawdown observed at these locations.

The regional groundwater model was developed to assess the historical impacts of pumping in terms of drawdown and changes in baseflow to rivers. The model estimates drawdown in all layers, with the exception of the alluvial aquifer as this layer is not represented in the model. For the reasons described above, exclusion of the alluvial aquifer from the model was considered not to limit the assessment of pumping impacts across the regional aquifer. The predicted drawdown and change in baseflow to rivers were used to inform the risk to groundwater dependent ecosystem (GDEs) using the risk assessment framework outlined in the The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015).

Barwon River Catchment

The Barwon River East and West Branches rise in the Otway Ranges around the township of Forrest. The Barwon River East Branch joins the West Branch near Gerangamete Flats, and below the confluence of these two branches, the river becomes the Barwon River. Boundary Creek also joins the Barwon River near Gerangamete Flats.

Three rivers in the Barwon River catchment (outside Boundary Creek) were classified as potential high risk:

- Barwon River East Branch;

- Barwon River West Branch; and,
- Barwon River downstream of the confluence.

The Barwon River East Branch is represented as a gaining river in the regional groundwater model. The model estimated it remained a gaining river until around 2000, when a decline in groundwater level is interpreted to have caused the creek to become a losing river. The potential high risk areas are located near the headwaters of the Barwon River East Branch, immediately upstream of the Bambra Fault (south east) and downstream of the fault. In other areas, the risk to the river is moderate to low due to the predicted drawdown being much less at these locations.

The Barwon River West Branch is represented as a losing river in the regional groundwater model. Where the river flows over the MTD, the model predicts there is no observable difference between the pumping and no pumping scenarios, which indicates that groundwater pumping is not predicted to impact the river in this location. The potential high risk areas are located near the headwaters of the Barwon River West Branch and immediately upstream of the Bambra Fault (south east). In other areas, the risk to the river is moderate to low due to the predicted drawdown being much less at these risk locations.

Downstream of the confluence with Boundary Creek, the Barwon River is represented generally as a gaining river with seasonal variability. During summer months (low flows), the river is predicted to be gaining and during the winter months (high flows), the river is predicted to become losing. The potential high risk area is located downstream of the confluence with Boundary Creek and the risk to the Barwon River is moderate to low in other areas.

Gellibrand River Catchment

The Gellibrand River is located in the south western corner of the LTA extent with tributaries rising in the Otway Ranges and the Barongarook High. Tributaries include Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren. Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

Like the Barwon River catchment, three rivers in the Gellibrand catchment were classified as potential high risk:

- Gellibrand River;
- Ten Mile Creek; and,
- Yahoo Creek.

The Gellibrand River is represented as a gaining river and the volumes of groundwater flux to the river are reasonably large (greater than 50 L/sec), consistent with the conceptualisation that the Gellibrand River is a key discharge site. The regional groundwater model indicates there is a small impact on reduction in baseflow to the river. The potential high risk areas are located downstream of the Bambra Fault further downstream in the middle of the model and near the southern boundary of the model. The risk to the river is moderate in other areas.

Ten Mile Creek is represented as a gaining river and the volumes of groundwater flux to the river is typically less than 10 L/sec. The regional groundwater model predicts that the groundwater contribution to the river declines marginally over the model period (1979 to 2016) in response to climate. However there is also a noticeable difference in groundwater flux to the river predicted between the pumping and no pumping scenarios. The potential high risk areas are located near the headwaters of the creek and further downstream on the LTA outcrop. The risk to the river is low to moderate in other areas.

Yahoo Creek is represented as a losing river and the regional groundwater model predicts there is a difference in groundwater flux to the river between the pumping and no pumping scenarios. The potential high risk areas are located near the headwaters of the creek where the LTA outcrops and the risk to the river is low to moderate in other areas.

Vegetation and PASS

The risk to groundwater dependent vegetation across the catchment was determined using the depth to water table from the regional groundwater model and the drawdown predicted in the water table aquifer as a result of historical groundwater extraction. Vegetation and PASS in some areas is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to water table as a result of historic groundwater pumping.

There are three key (large) areas the model estimates the potential risk to be high. Further investigations may be recommended in other isolated areas of potential high risk based on the outcomes of the investigation plan focussed on the following areas:

- West of the Barwon River to the north of Yeodene;
- East of the Barwon River between Barwon Downs and Yeodene; and,
- Along the Gellibrand River.

The regional aquitard (MTD) outcrops across most of the area to the west of the Barwon River. The LTA outcrops on the Barongarook High located in the south of this area and alluvial sediments are present along the Barwon River. Areas of potential high risk to groundwater dependent vegetation and PASS are located around Barongarook Creek and north east of Yeodene, however there is limited information to inform the accuracy of the assigned risk in these areas.

The area east of the Barwon River around Deans Marsh is bounded by the Bambra Fault to the south east and the Barwon River to the north west. Several tributaries of the Barwon River flow in a north westerly direction from the Otway ranges to the Barwon River, including Mathews Creek, Deans Marsh Creek and Yan Yan Gurt Creek. The regional aquitard (MTD) outcrops across most of the area and the LTA outcrops on the south eastern side of the Bambra Fault. Alluvial sediments are present along the tributaries and the Barwon River and although there are no bores located in the alluvial sediments, these are likely to contain the water table aquifer. Areas of potential high risk to groundwater dependent vegetation and PASS in this area of the catchment is focussed in areas where there are alluvial sediments, for example, around Mathews Creek and Deans Marsh Creek. Other areas of high risk are located in the north east of the area.

Vegetation and PASS in some areas around the Gellibrand River is classified as high risk as there are particular sections considered to have “certain” likelihood of connection to the regional groundwater system and modelling indicates a significant impact on drawdown as a result of historic groundwater pumping (see Appendix A for detail on the risk assessment framework). Areas of potential high risks are expected to be in the areas to the east and close to the Bambra Fault. The risk across the remainder of the area is considered to be moderate and low.

Recommendations for Surrounding Environment Investigation Plan

Currently there is limited data to confirm surface water groundwater connection between the rivers and GDEs with the regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers/aquitards;
- The nature of groundwater-surface water interactions (i.e. are the rivers gaining flow or losing flow to groundwater);
- If there is baseflow contribution from the LTA; and,

- If impacts on baseflow from drawdown are buffered by the presence of the MTD and alluvial aquifers.

Further work is required in all these areas to install additional monitoring assets to inform further investigations. An overview of the recommendations for additional monitoring assets to install as part of the investigation plan, together with the rationale is provided in Table E.1.

After 12 months of data has been collected, it is recommended that the data be reviewed and the risk re-evaluated. The review would confirm the following:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer, LTA or MTD;
- Vertical gradients between aquifers and rivers;
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers); and,
- Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS).

The review of the additional data and hydrological conceptual model could result in one of the following three scenarios:

1. Site specific monitoring data confirms a lower risk than that predicted by the regional groundwater model, presumably based on the following criteria:
    - Regional groundwater model over-predicts impact;
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed upward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or water table decline predicted by model with the observed flow data confirms low risk.
2. Site specific monitoring data confirms the high risk predicted by the regional groundwater model, based on the following criteria:
    - Confirmed absence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer consistent with regional groundwater model predictions; and,
    - Groundwater flux predicted by model confirmed with observed data.
3. Site specific monitoring data confirms a high risk, based on the following criteria:
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed downward gradient exists between LTA and alluvial aquifer; and,

- Comparison of groundwater flux or watertable flux predicted by regional model with the observed flow data confirms high risk.

If scenario 1 occurs – no further action is required, results presented to Southern Rural Water for consideration

If scenario 2 occurs – it is recommended that the regional groundwater model is used to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for any further action.

If scenario 3 occurs – recommended that a local groundwater model(s) is/are developed for each location to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for further action.

Table E.1: Rationale and recommendations for additional monitoring

Area	Why	What is the information gap	Recommended additional monitoring assets
BARWON RIVER CATCHMENT			
Barwon River east branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River east branch and regional groundwater system / outcropping LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing), if there is baseflow contribution from the LTA and if borefield impacts on baseflow are buffered by the presence of alluvial aquifers.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores PASS 2 and 48249 **Additional Surface water monitoring** Install one stream gauge on the East Branch near Seven Bridges Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. **Survey data** Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction. Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.
Barwon River west branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact	Currently there is limited data to confirm surface water groundwater connection between Barwon River west branch and regional groundwater system / outcropping LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

Area	Why	What is the information gap	Recommended additional monitoring assets
	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 64237 and 108915. **Additional Surface water monitoring** Install one stream gauge on the West Branch near Boundary Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Barwon River downstream of confluence	Rated as high risk as there are particular sections considered to have a possible likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River downstream of the confluence and the regional groundwater system / MTD. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the MTD.	**Additional Groundwater Monitoring** Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 82838. **Additional Surface water monitoring** Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Area	Why	What is the information gap	Recommended additional monitoring assets
GELLIBRAND CATCHMENT			
Gellibrand River	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between the Gellibrand River and the regional groundwater system / LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Ten Mile Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. Survey the stream bed elevation in the vicinity of the gauge and the bores.
Yahoo	Rated as high risk as there are particular sections considered to have a certain	Currently there is limited data to confirm surface water groundwater connection	**Additional Groundwater Monitoring**

Area	Why	What is the information gap	Recommended additional monitoring assets
	likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	between Yahoo Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. **Survey data** Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.
Vegetation and PASS investigations			
Yeodene	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA).	**Additional Groundwater Monitoring** Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level.

Area	Why	What is the information gap	Recommended additional monitoring assets
			Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. Survey the elevation of the creek bed close to the bores and at any gauge locations. **Additional Vegetation monitoring** Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.
Deans Marsh	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA). Vegetation assessments are required to confirm vegetation types and their reliance groundwater.	**Additional Groundwater Monitoring** Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Vegetation monitoring** Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition. Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.
Gellibrand	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling	Currently there is limited data to confirm the depth to watertable and connection with the LTA. This data is required to understand the nature of groundwater dependence from the LTA.	**Additional Groundwater Monitoring** See recommendations for Gellibrand River **Additional Vegetation monitoring**

Area	Why	What is the information gap	Recommended additional monitoring assets
	indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions		Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to outline the required investigations to confirm (or amend) the risk to groundwater dependent features from groundwater pumping in areas identified as high risk. These works have been carried out in accordance with the scope of services as set out in our proposal to investigate areas of potential high risk submitted to Barwon Water on 3rd September 2019.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and concludes as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Barwon Water and DELWP as outlined in this report.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by the law.

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1. Introduction

1.1 Background

Barwon Water received a Section 78 Notice (under the Water Act 1989 (Vic)) and the purpose of the Notice is to ensure that Barwon Water successfully remediate impacts caused by historic groundwater extraction. The Section 78 Notice directs Barwon Water to develop and implement a Remediation Plan for Boundary Creek and Big Swamp and surrounding environment.

In response to the Section 78 Notice, Barwon Water developed a scope of works in consultation with the Boundary Creek Remediation Working Group, their nominated experts and Jacobs, which was submitted to Southern Rural Water in July 2019.

The scope of works used the groundwater model and risk assessment framework outlined in the Ministerial Guidelines for High Value GDEs to assess areas of potential low, moderate and high risk of impact from the Barwon Downs borefield. The risk assessment framework considers the likelihood of a groundwater dependent feature (river, vegetation or PASS) being connected to the regional groundwater system and the consequence of drawdown induced by pumping on the feature. The important part of this assessment is the link to the regional groundwater system, as it is this system which is affected by pumping.

The risk assessment identified several areas of potential high risk. These include some areas in the Boundary Creek catchment and other areas along the Barwon River East Branch, Gellibrand River, Ten Mile Creek and Yahoo Creek. These areas of potential high risk are the focus for the remediation plan.

The remediation plan is divided into areas with different action plans:

- Areas where impact has been confirmed will transition into the *Boundary Creek and Big Swamp remediation plan*.
- Areas where impact has not yet been confirmed due to insufficient monitoring to validate groundwater model predictions will be covered by the *Surrounding Environment investigation plan*.

An overview of the approach taken to prioritise areas for remediation is shown in Figure 1.1.

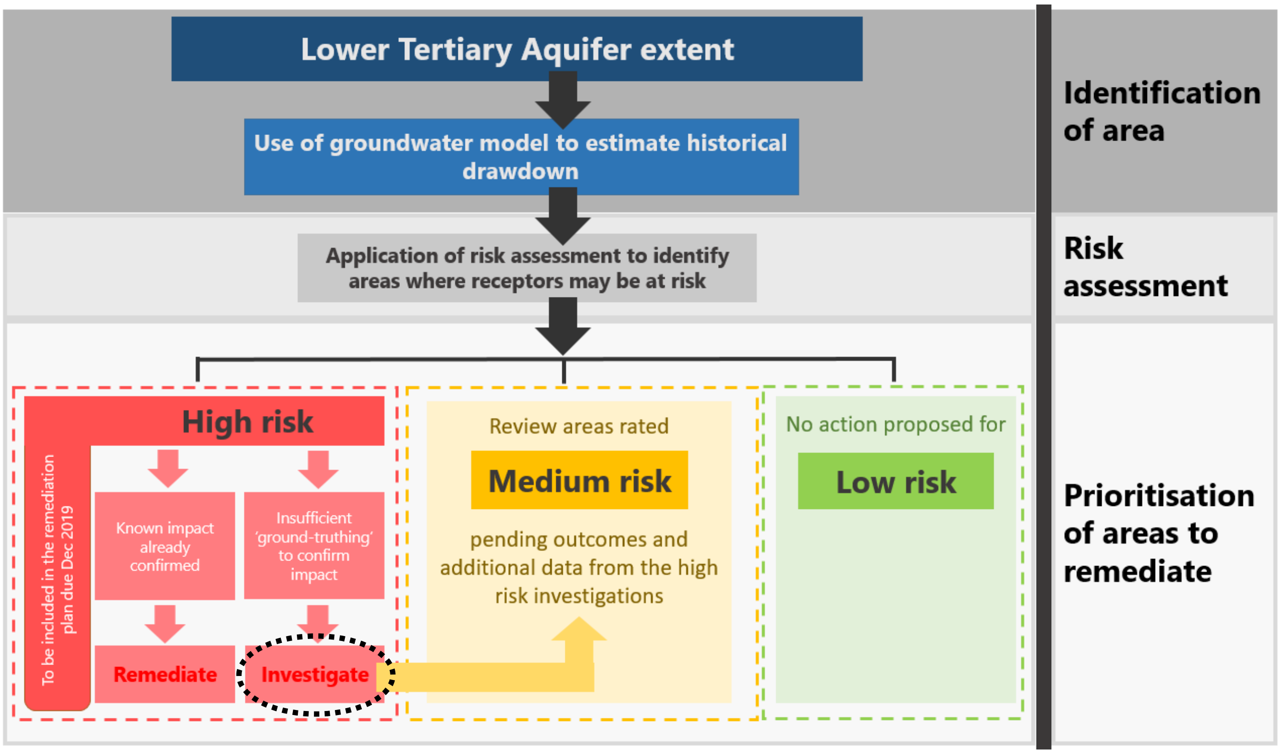
This report outlines the rationale for the recommendations in the *Surrounding Environment investigation plan* for areas of potential high risk that cannot be confirmed with historical monitoring data. Areas with potential moderate risk will be reviewed pending the outcomes of the investigation plan. No further action is recommended for areas classified as low risk.

1.2 Objectives

The objectives of this study are to:

- Review the monitoring data available for areas that have been identified previously through the revised ‘scope of works’ as potential high risk from impact of historical groundwater extraction; and
- Recommend additional monitoring and/or environmental assessments required to confirm if historical groundwater extraction has caused a measurable impact at high risk areas.

Figure 1.1: Approach taken to prioritise areas for remediation



1.3 Areas included in the investigation plan

Areas of potential high risk included in the investigation plan include:

- Barwon River catchment:
  - Barwon River East and West Branches
  - Barwon River downstream of the confluence
- Gellibrand River catchment:
  - Ten Mile Creek
  - Yahoo Creek
  - Gellibrand
- Groundwater dependent vegetation in three areas of the model:
  - West of Barwon River to the north of Yeodene
  - East of Barwon River between Barwon Downs and Deans Marsh and
  - Along the Gellibrand River.

2. Regional groundwater model

The regional groundwater model has been developed and refined over many years to reflect the continual gathering of groundwater data and improved conceptual understanding of the regional aquifer that resulted from ongoing Barwon Water studies. The most recent calibrated model was completed in 2016-17 when the model was expanded, re-built and re-calibrated. The update of the model includes new layers, new monitoring data and a significant improvement in the conceptual understanding. A summary is provided below and more detail on the re-calibration is outlined in Jacobs (2018).

2.1 Regional stratigraphy and model layers

The extent of the Barwon Downs regional groundwater model is determined by the extent of the Lower Tertiary Aquifer (LTA). The model area covers most of the aquifer extent. While the aquifer units that comprise the LTA are widespread and also are found south west of the Gellibrand River, the River provides a strong hydraulic influence on the aquifer, so the numerical model and the limit of interest for this risk assessment is the Gellibrand River in the south west. The LTA is located in a graben, which is a valley defined by escarpments on each side. The LTA outcrops near the edges of the graben and dips down in the centre of the graben, where it is found at around 500 m depth. The areas where groundwater level decline in the LTA in response to pumping has the greatest potential to cause adverse impacts is where the aquifer outcrops around the margins of the graben.

Surficial geology together with the extent of regional groundwater model is shown in Figure 2.2. A cross section through the centre of the aquifer is shown in Figure 2-1 and the location of this cross section is shown in Figure 2.2. The key hydrogeological units and their corresponding layer in the regional groundwater model are outlined in Table 2-1. Due to the relatively very small spatial extent of the Quaternary Alluvium combined with the difficulty of representing this discontinuous unit in a regional groundwater model, this unit was excluded as a layer from the model.

Table 2-1 Hydrogeological units of the Barwon Downs Graben and relationship to model layers in the regional groundwater model

VAF aquifer	Geological Unit	Description	Type	Model layer
Minor surficial sediments	Quaternary Alluvium	Sands, silts and gravels.	**Aquifer (minor)**	Not modelled
Mid Tertiary Aquitard (MTD)	Gellibrand Marl	Calcareous silty clay and clayey silt. Fossiliferous.	**Aquitard**	1
	Clifton Formation	Calcarenite with marine fossils and minor quartz and limonite sands	**Aquifer (minor)**	2
	Narrawaturk Marl	Calcareous mudstone with thin carbonaceous beds, sand beds and fossiliferous beds	**Aquitard**	3
Lower Tertiary Aquifer (LTA)	Mepunga Formation	Medium to coarse grained quartz sand with some carbonaceous clays and silt layers	**Aquifer**	4
	Dilwyn Formation	Carbonaceous, sandy clays and silts, with some quartz sand and silty sand beds, and minor gravel. Coal and carbonaceous clays also occur in this unit.	**Aquifer**	
	Pember Mudstone	Clays, silts and fine grained sand with carbonaceous, micaceous and pyritic horizons.	**Aquitard (minor)**	5
	Pebble Point Formation	Fine-grained sand with carbonaceous silt and quartz pebble beds. This unit is an equivalent to the Moomowroong Sand Member, Wiridjil Gravels that occur in the Gellibrand sub-basin to the south west of the study area.	**Aquifer**	6
Bedrock (BSE)		Sandstone, siltstone and mudstone with feldspar and quartz grains, well-bedded and consolidated.	**Aquitard/Minor aquifer**	7

Figure 2-1 Representative cross section of the Barwon Downs Graben (Alluvial aquifers not modelled in the regional groundwater model)

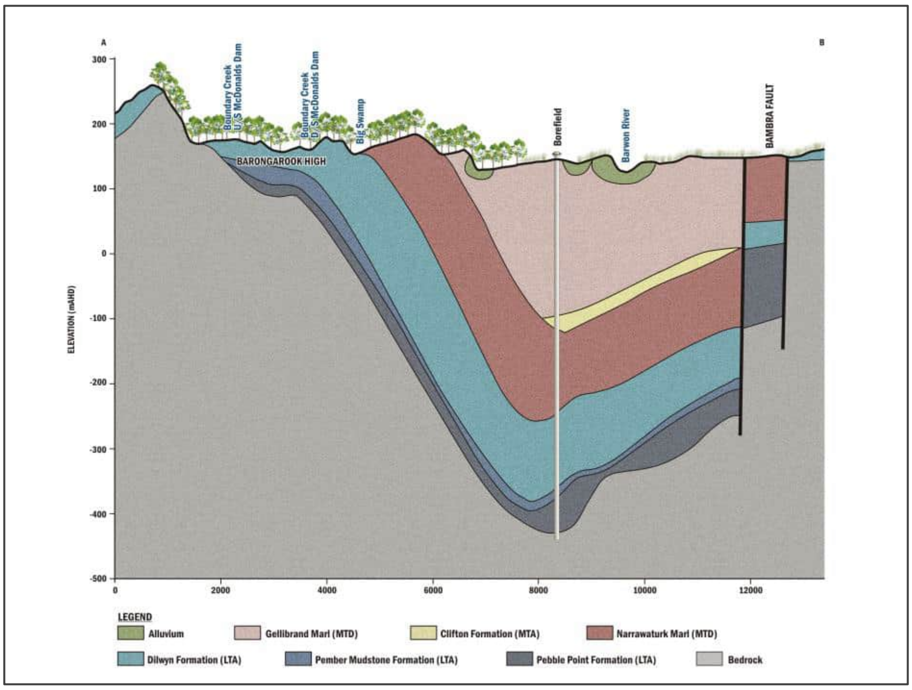
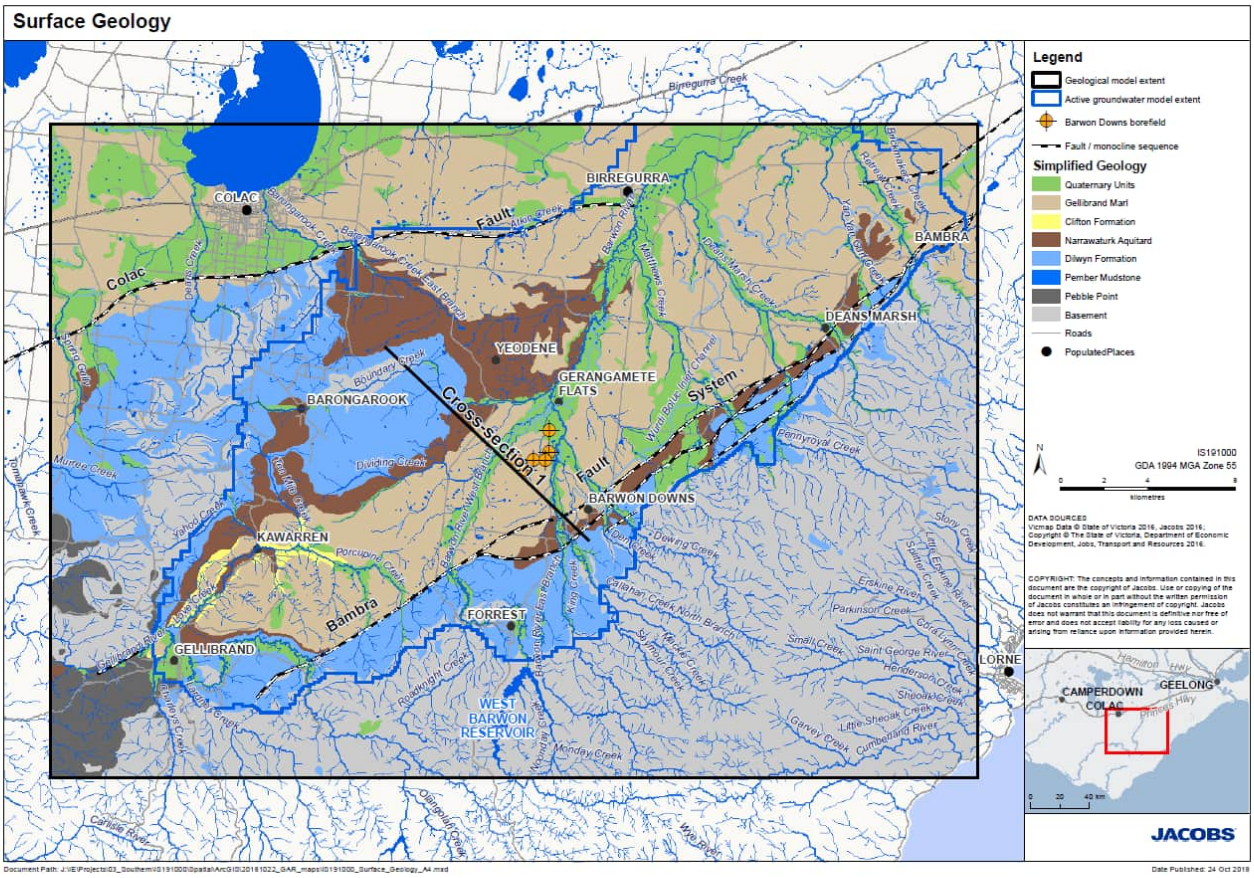


Figure 2.2: Surficial geology in vicinity of the Barwon Downs borefield (cross section 1 is shown in figure above)



The regional groundwater model does not explicitly include the alluvial aquifer as this aquifer is not continuous across the study area and is highly variable where it is present. The exclusion of the alluvial aquifer as a layer in the model limits the ability of the regional groundwater model to represent drawdown propagation to the watertable aquifer in those areas where the alluvial aquifer is significant in controlling water level. This inherently extends to subsequent potential impacts to ecosystems dependent on the shallow groundwater (e.g. rivers, wetlands and vegetation). Where there are alluvial aquifers, the impact to the watertable represented by the regional groundwater model reflects changes in the regional aquitard (MTD) or regional aquifer (LTA), rather than the alluvial aquifer.

2.2 Faults

Faults are hydrogeologically important to the Barwon Downs Graben as they cause discontinuities in groundwater flow. The most important faults are the Colac Fault and Bambra Fault. The Colac Fault restricts the extent of groundwater flow to and from the north. The Bambra Fault causes aquifer units to be upthrown on the southeast side of the fault, resulting in partial or complete discontinuity in the aquifer, aquifer outcrop and termination of the Dilwyn Formation south east of the Fault.

Faults are generally found on the steeply dipping sides of the graben. The Colac Fault was previously used to define the northern model boundary (SKM, 2001 and SKM, 2011). Analysis of observed drawdown responses found that there was limited connectivity across the Colac Fault (Jacobs, 2015), which indicates that the fault acts as a boundary that significantly reduces the migration of groundwater responses to the north of the fault.

The Bambra Fault, or Bambra Fault zone, is characterised by a series of sub-parallel faults that have resulted in the upward displacement of aquifer layers to the southeast of the fault. In a recent review of borefield related groundwater responses in the Lower Tertiary Aquifer, Jacobs (2015) found that the Bambra Fault was best represented in a regional groundwater model by a 95% reduction in aquifer transmissivity to the southeast of the fault. The apparent loss of transmissivity to the southeast of the fault is due to the combined effects of aquifer thinning and displacement related disruption to aquifer continuity. The section of the Bambra Fault located further to the southwest is likely to have an even lower apparent transmissivity and it was concluded that it should be represented as a partial barrier to flow in the regional groundwater model.

2.3 Natural recharge and discharge processes

The LTA, consisting of the Pebble Point, Dilwyn and Mepunga Formations, is the major aquifer in the region. The major recharge process is rainfall infiltration where the aquifer outcrops at the edges of the graben (see Figure 2.2), with the largest area being the Barongarook High in the western part of the graben. Some additional recharge is also received from downward leakage from overlying formations and leakage from some rivers where they cross the aquifer outcrops.

Natural discharge processes include evapotranspiration from shallow groundwater and vegetation, discharge to some rivers and aquifer throughflow to the north and south of the graben. The most significant is discharge process is discharge to rivers including the Gellibrand River, Barwon River East Branch and Ten Mile Creek where the LTA provides baseflow to these rivers.

2.4 Groundwater flow directions

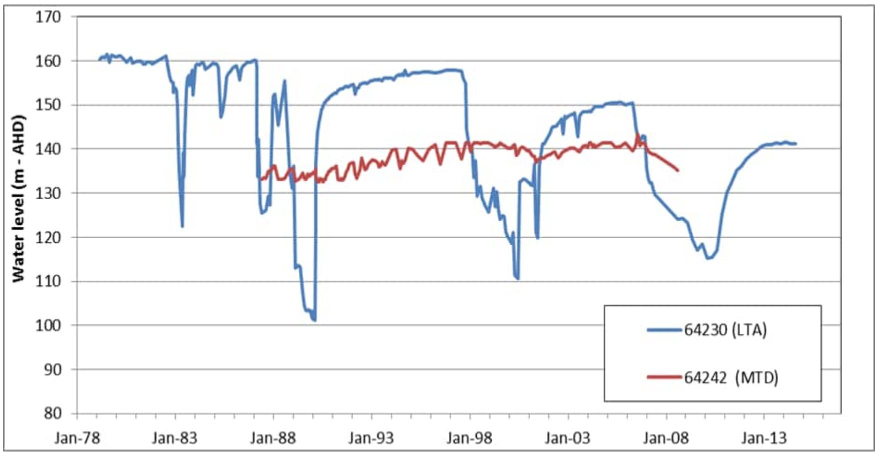
Groundwater levels at the Barongarook High are currently greater than 240 m AHD (at the top of the groundwater system) and this drives horizontal groundwater flow to the east towards the Gerangamete Flats and south towards Gellibrand. Groundwater flow within the graben discharges to the south west (towards Gellibrand) and north east (towards Bambra).

Vertical flow processes also play a key role in groundwater flow in the Barwon Downs graben. Vertical gradients exist within the LTA and between the LTA and the overlying hydrogeological units. It is generally understood that upward hydraulic gradients naturally exist between the Dilwyn and Pebble Point aquifers and the overlying Narrawaturk Marl aquitard through the central portion of the graben. This facilitates upward leakage from the aquifers into the overlying aquitard and is a key discharge process for the aquifer. Groundwater pumping from the LTA has the potential to generate water level declines that induce downward leakage from the overlying MTD. This downward leakage results in reduced groundwater levels in the MTD which has the potential to subsequently result in negative environmental impacts at the surface.

As part of recent investigations between 2014 and 2016, bores were constructed in the Gellibrand Marl above the LTA (Jacobs, 2016). Groundwater monitoring in these bores indicates upward hydraulic gradients from the LTA to the Gellibrand Marl, consistent with those observed by Witebsky (1995).

Groundwater monitoring has identified that groundwater levels in the LTA have fallen below the overlying MTD during periods of pumping (see Figure 2-3). This shows that when groundwater levels in the LTA fall below the groundwater level in the MTD, the water levels in the MTD display a corresponding decline which consequently has the potential to cause adverse environmental impacts at the surface.

Figure 2-3 Bore hydrographs in LTA and MTD near the borefield



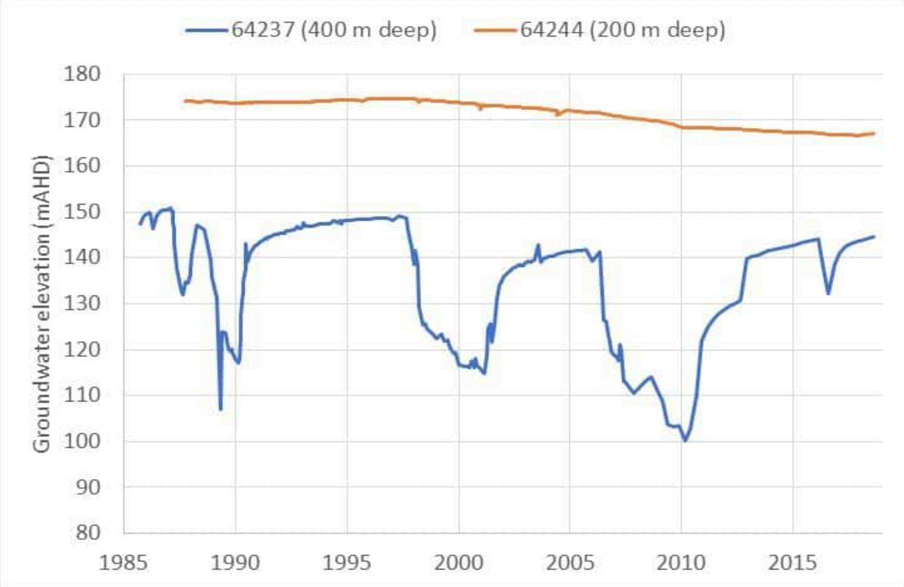
There are also vertical flow gradients present within the LTA. Figure 2-4 shows two hydrographs for bores in the LTA located at the centre of the study area near Seven Bridges Road. In the deeper LTA where the groundwater is extracted, there is a strong response to pumping, whereas shallower bores in the LTA show a much more subdued response to pumping. This is consistent with stratigraphic variability in the LTA and whilst there is a downward gradient within the LTA, the effects of pumping are buffered through the LTA.

Downward trends in the LTA are observed closer to the edges of the graben, while the upwards trends from the LTA to the MTD are observed in the centre of the graben.

In addition to variability in the LTA, the presence of alluvial aquifers and minor perched aquifers have been confirmed on the Barongarook High. Analysis of data collected by Barwon Water from shallow groundwater monitoring bores in this area have confirmed that groundwater levels in these aquifers are more influenced by seasonal climate and have been buffered from drawdown in the LTA (Jacobs, 2017a, 2017b).

The presence and thickness of the alluvial aquifers have not been confirmed outside of Barongarook High. PASS bores 2 and 4 are shallow bores installed by Barwon Water located near the Barwon River East Branch and Yan Yan Gurt Creek in the north east of the study area, respectively. These bores are located in terrace landscapes adjacent to waterways where the alluvial sediments comprise of fine grained silts and clays deposited in a low energy environment. The alluvial aquifers in these locations are not significant aquifers, even at this local scale.

Figure 2-4 Examples of groundwater level trends at different depths in the LTA which demonstrate the vertical gradient (upward pressure potential)



2.5 Limitations of the regional groundwater model

The regional groundwater model is understood to over-state potential drawdown in regional aquitards and in areas where Quaternary aquifers have been confirmed to be present but have not been included in the model. These layers are known to act as physical constraints, such as clay layers within the formations that restrict groundwater flow from the regional aquifer and therefore may limit groundwater drawdown. As these physical constraints have not been included in the regional groundwater model, the model does not account for the restriction of groundwater flow and subsequent decrease in drawdown observed at these locations.

The Technical Works Monitoring Program undertaken by Barwon Water to inform the Barwon Downs licence application has confirmed the presence of many Quaternary alluvial aquifers which are not influenced by pumping (Jacobs 2018). In these areas, monitoring indicates that the model over predicts drawdown caused by pumping and thus also over-predicts the subsequent risk to environmental receptors at the surface. The predicted drawdown in these areas and associated risk will need to be confirmed with further technical site-specific investigations to confirm or amend predicted drawdown and subsequent risk to environmental receptors at the surface. This data can then also be used to help confirm the presence and level of impact at the surface to inform decisions regarding any further actions required.

3. Barwon River Catchment

The Barwon River East and West Branches rise in the Otway Ranges around the township of Forrest. The Barwon River East Branch joins the West Branch near Gerangamete Flats, and below the confluence of these two branches, the river becomes the Barwon River. Boundary Creek also joins the Barwon River near Gerangamete Flats.

Flow in the Barwon River is regulated from its upper reaches through releases from the West Barwon Dam and diversions from some tributaries.

Outcropping geology is shown in Figure 3-1 and Figure 3-2 . Figure 3-1 shows that the East and West branches of the Barwon River originate where the Basement outcrops in the Otway Ranges, and then flow over the outcropping Lower Tertiary Aquifer (LTA) on the south east side of the Bambra Fault. Further downstream (north west of the Bambra Fault), the rivers flow over outcropping Mid Tertiary Aquitard (MTD) towards the Gerangamete Flats. According to the geological mapping, alluvial sediments are present along both rivers, however the presence and thickness of an alluvial aquifer in these sediments has not been confirmed. Alluvial sediments can hold local aquifers that provide an additional source of water which may not be influenced by groundwater pumping from Barwon Downs.

Figure 3-2 shows that downstream of the confluence with Boundary Creek, the Barwon River flows through the centre of the graben over alluvial sediments, which in turn, overlie the regional Mid Tertiary Aquitard (MTD). The alluvial sediments are more extensive downstream (to the north) as the floodplain widens, however the thickness of the alluvium is not known. Monitoring indicates that the MTD is up to 300 meters thick in the centre of the graben.

Figure 3-1 Outcropping geology around the Barwon River East and West Branches

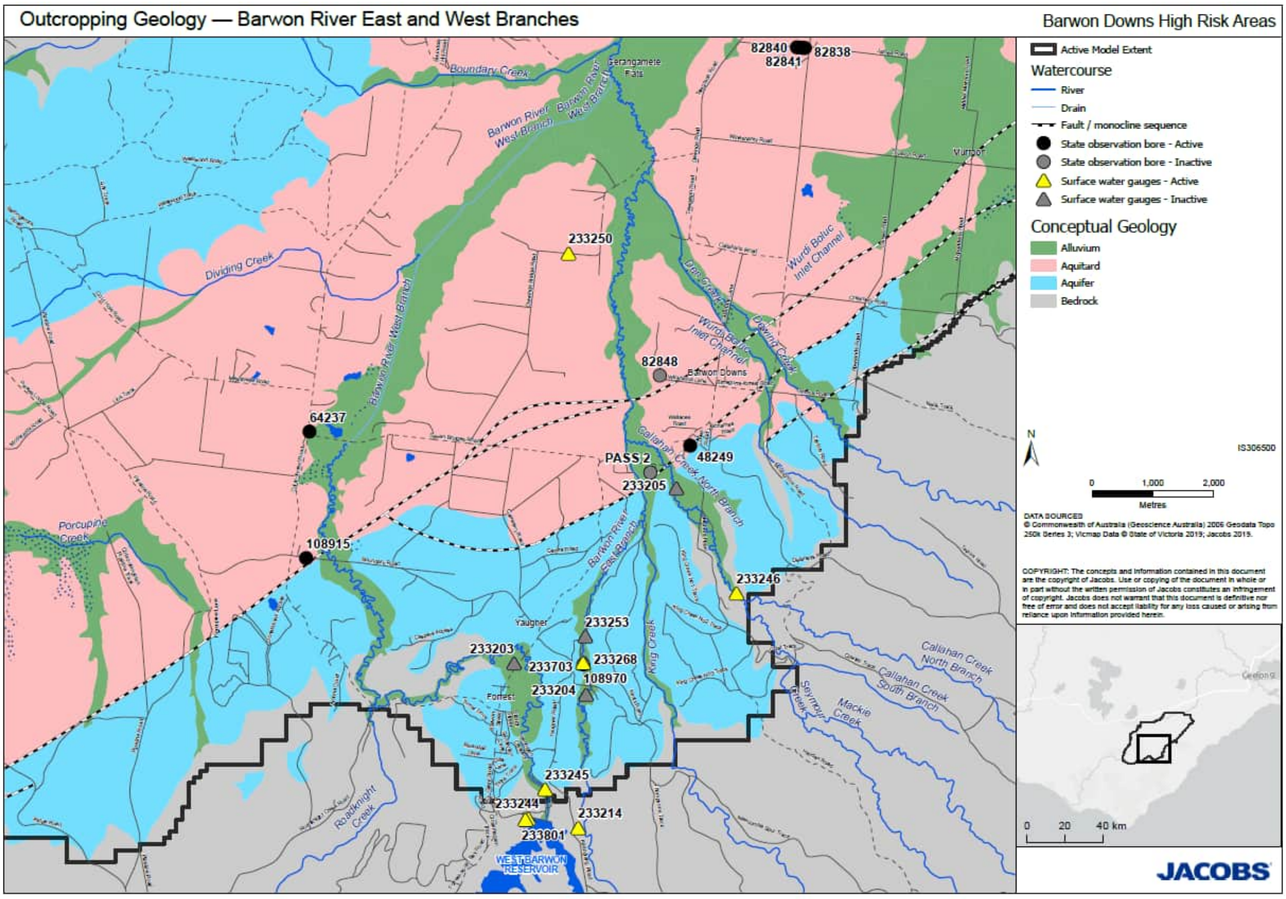
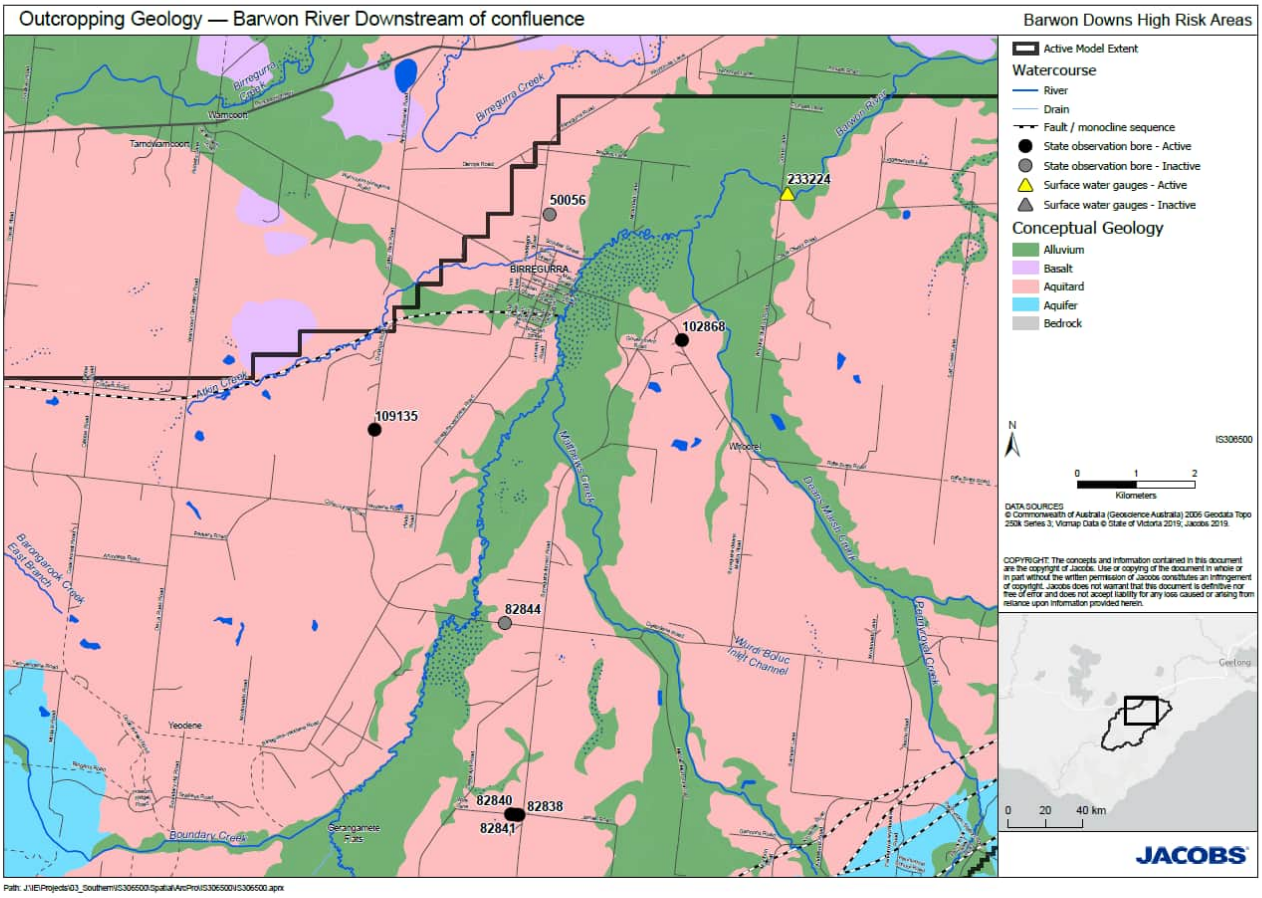


Figure 3-2 Outcropping geology around Barwon River downstream of confluence with Boundary Creek



3.1 Barwon River East Branch

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River East branch. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

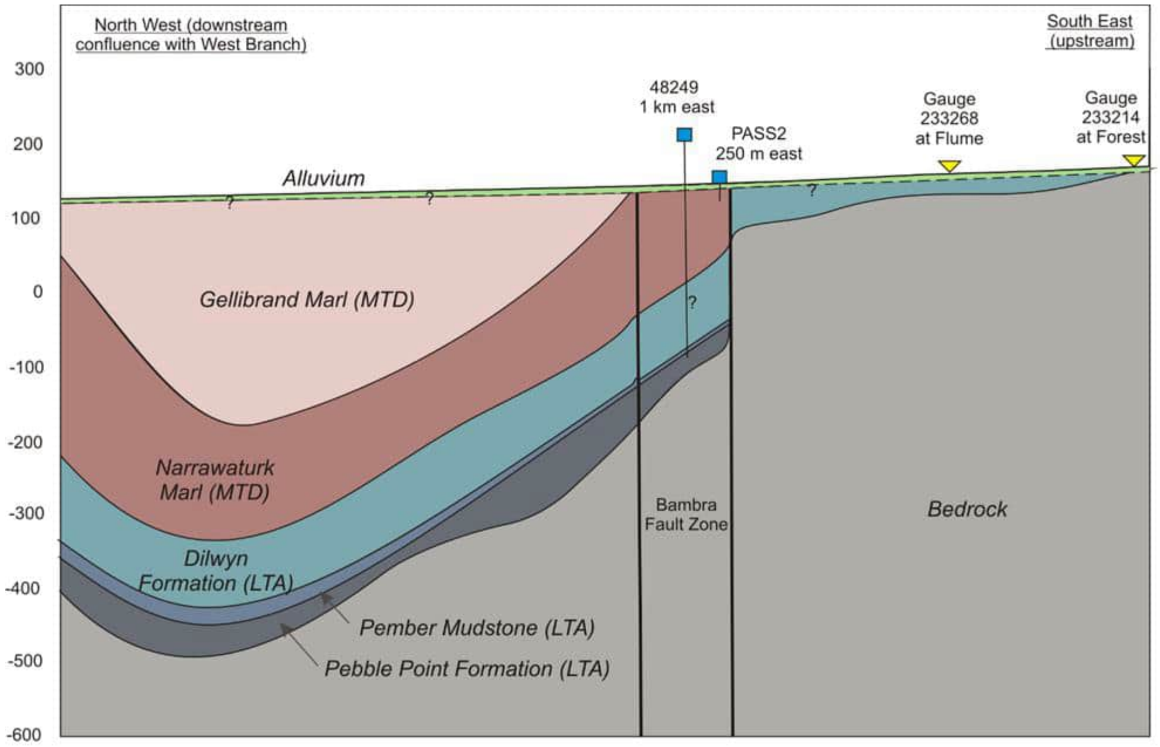
3.1.1 Why it was classified high risk

The Barwon River East Branch is classified as potential high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.3 shows a long section along the East Branch of the Barwon River, which shows the stratigraphy as presented in the regional groundwater model. This highlights that the LTA has the greatest potential to impact the river upstream of the Bambra Fault zone, where the LTA outcrops at the surface. North west of the fault zone (downstream), the MTD overlies the LTA and is between 70 and 100 m thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.3: Long section along Barwon East Branch. Bore 48249 is assumed to be in the LTA based on depth.



Regional groundwater model results

Figure 3.4 and Figure 3.5 shows the estimate of river seepage calculated by the model for the Barwon East Branch where it flows over the LTA and MTD respectively. The East Branch is represented as a gaining river where it flows over the LTA (represented by positive river seepage values). The model estimated it remained a gaining river until around 2000, when a decline in groundwater level is interpreted to have caused the creek to become a losing river.

Where the East Branch flows over the MTD, the river is also represented as a gaining river until about 2000, when groundwater level is interpreted to have declined and the creek becomes losing.

Figure 3.6 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios (from the regional groundwater model). This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 18 L/sec in each river reach (combined total 36 L/sec), at the end of the Millennium Drought.

Figure 3.4: Predicted river seepage from the Barwon River East Branch where it flows over the LTA

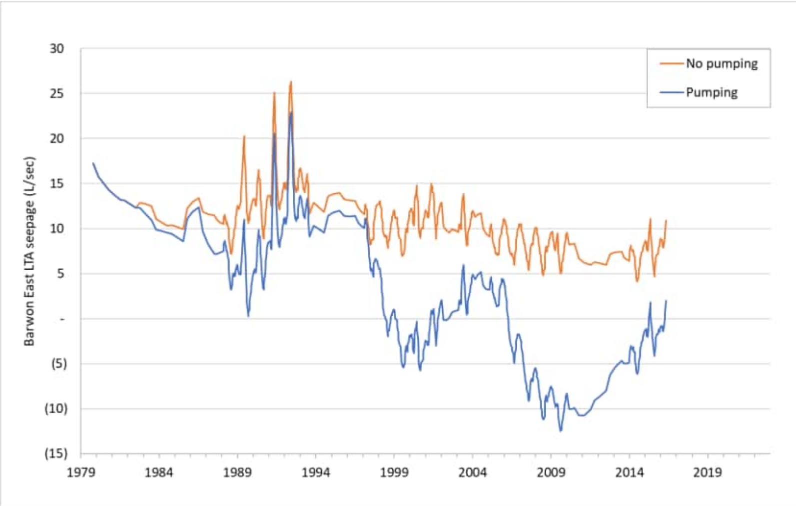


Figure 3.5: Predicted river seepage from the Barwon River East Branch where it flows over the MTD

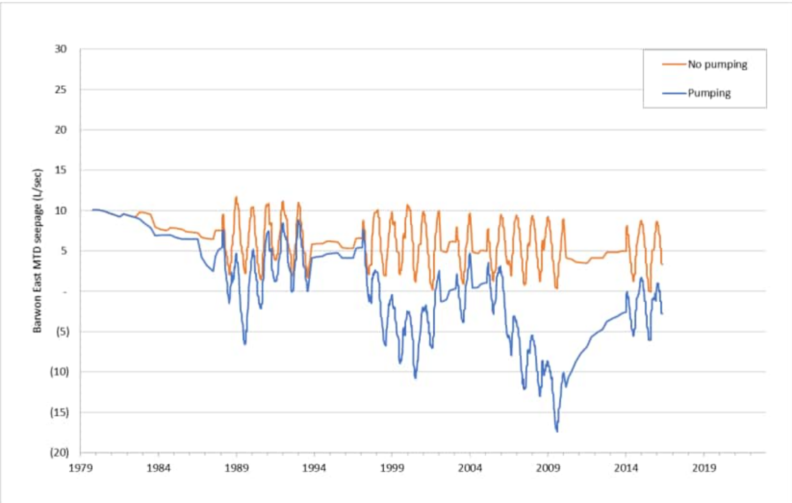


Figure 3.6: Change in river flux between no pumping and pumping

Risk assessment results

Areas of potential high risk are shown in Figure 3-7. This was calculated using the risk assessment framework outlined in Appendix A and using the likelihood defined in Figure A.1 and Table 3.1 and the drawdown predicted by the model.

Figure 3-7 shows the spatial distribution of risk to Barwon River East Branch, which has three areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk area is located near the headwaters of the Barwon River East Branch, immediately upstream of the Bambra Fault (south east) and downstream of the fault. In other areas, the risk to the Barwon River East Branch is moderate to low due to the predicted drawdown being much less at this location.

Along this reach, the Barwon River East Branch flows over outcropping aquifer (LTA) and aquitard (MTD). Where the river flows across outcropping LTA, the likelihood of the river being connected to the regional groundwater system is classified as certain. Where the river flows over the regional aquitard, the likelihood of it being connected is classified as possible.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 3.6).

There are three active streamflow gauge monitoring the Barwon River and the Barwon River East Branch. One gauge is upstream and outside the model domain and another gauge monitors the intake to Wurdee Bullock reservoir. The most relevant active streamflow gauge within the model domain is Site 233224 Barwon River @ Ricketts Marsh, which monitors flow in the Barwon River downstream of the confluence with Boundary Creek. The 10th percentile of flow (Q90) from this gauge is 4.9 ML/day based on monitoring data collected between 1971 – 2017.

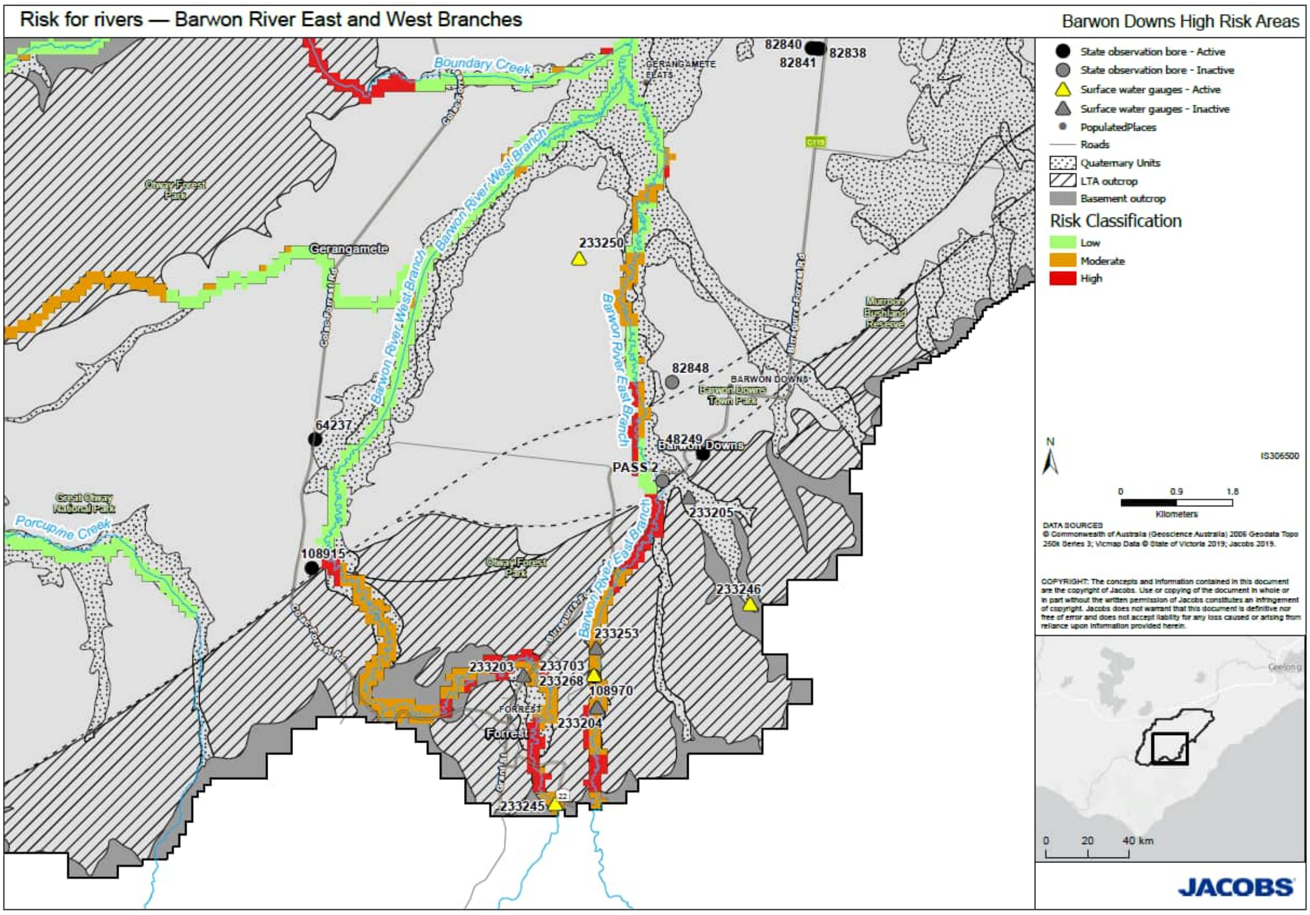
The change in river flux was calculated for reaches that flow over the LTA and the MTD. This shows that the maximum impact predicted by the model is almost 36 L/sec for both reaches (3.3 ML/day total). The maximum predicted impact equates to 33% of low flow for the Barwon River East Branch where it flows over the LTA and 35% of low flow where it flows over the aquitard. The combined total reduction in groundwater contribution to the river is 68% of low flows. The predicted reduction in groundwater contribution is expected to be similar for both as the MTD is thinner along this reach (downstream of the Bambra Fault zone), and the model indicates that the MTD does not provide a significant buffer to drawdown in this location.

Based on the likelihood and consequence (based on change in river flux) classifications, both river reaches are classified as potential high risk (see Table 3.1). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.1: Risk assessment results for Barwon River East Branch

River Reach	Likelihood	Consequence	Risk
Barwon River East Branch LTA	Certain	Significant	High
Barwon River East Branch MTD	Possible	Significant	High

Figure 3-7 Location of areas of potential high risk along the Barwon River East (and West) Branches using drawdown to define the consequence



3.1.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River East Branch and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River East Branch gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix C.

The primary data gaps identified for the Barwon River East Branch relate to information that can be used to determine if the rivers are gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores along the Barwon River East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Bores should be located on the south eastern side of the Bambra Fault.

- Monitoring bores to be installed with a data logger, with a monitoring frequency of at least daily readings. Quarterly manual water level readings are also recommended for a minimum period of 5 years. The datalogger is recommended to be downloaded on a quarterly basis, when the manual readings are collected.

- Ongoing monitoring of existing bores PASS 2 and 48249 to the same frequency as above.

Additional Surface water monitoring

- Install one stream gauge on the Barwon River East Branch near Seven Bridges Road to record all flows (with a priority to accurately measure low flows) and level. Include recording of the elevation of the stream bed.

- The stream gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Survey data

- Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction.

- Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

3.2 Barwon River West Branch

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River West branch. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

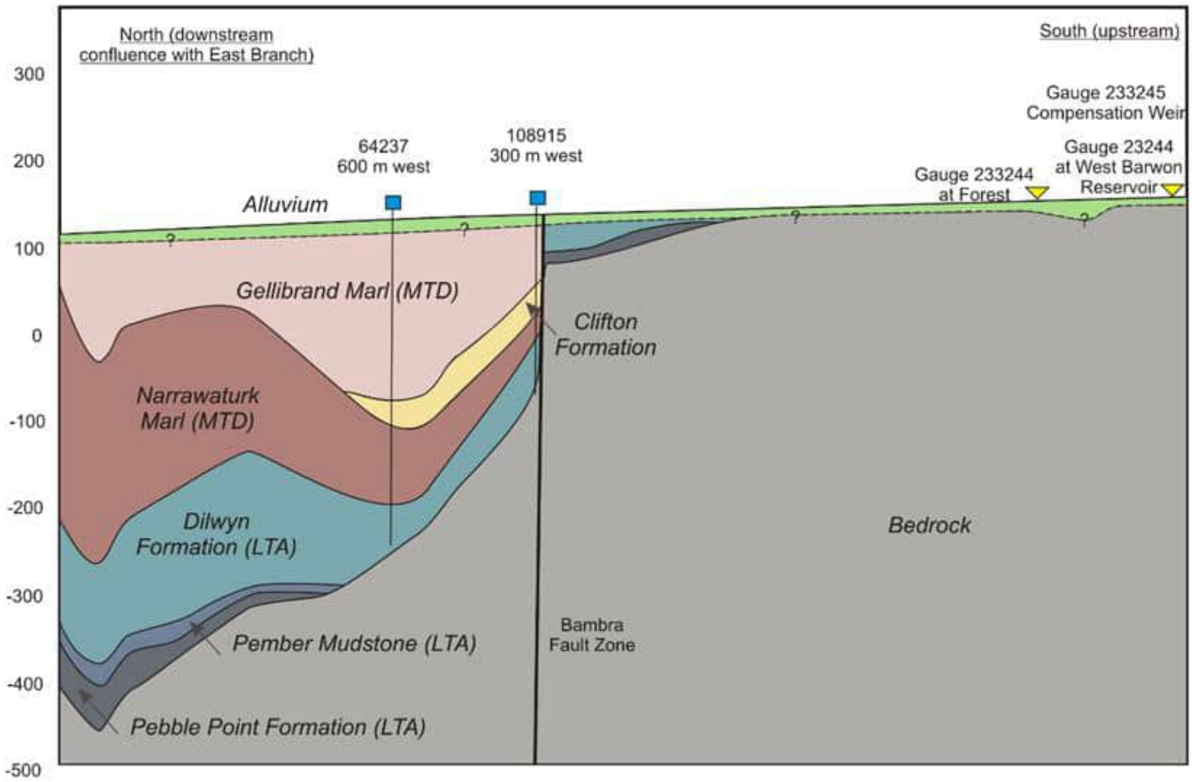
3.2.1 Why it was classified high risk

The Barwon River West Branch is classified as high risk as there are particular reaches considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.8 shows a long section along the West Branch of the Barwon River, which shows the stratigraphy as presented in the regional groundwater model. This highlights that the LTA has the greatest potential to impact the river upstream of the Bambra Fault zone, where the LTA outcrops at the surface. North west of the fault zone (downstream), the MTD overlies the LTA and is between 70 and 100 m thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.8: Long section along Barwon West Branch



Regional groundwater model results

Figure 3.9 and Figure 3.10 shows the estimate of river seepage calculated by the model for the Barwon West Branch where it flows over the LTA and MTD respectively. The Barwon River West Branch is represented as a losing river where it flows over the LTA (represented by negative river seepage values). There is no observable difference between the pumping and no pumping scenarios, which indicates that groundwater pumping is not predicted to impact the river in this location.

Where the Barwon River West Branch flows over the MTD, the river is also represented as a losing river. The regional groundwater model predicts there is a potential impact of around 1-2 L/sec in response to pumping.

Figure 3.6 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model where the river flows over the MTD was an increase in river losses to groundwater of around 1.5 L/sec, experienced at the end of the Millennium Drought.

Figure 3.9: River seepage from Barwon River West Branch where it flows over the LTA (no impact of pumping is predicted at this location and so the two lines in this plot appear as one)

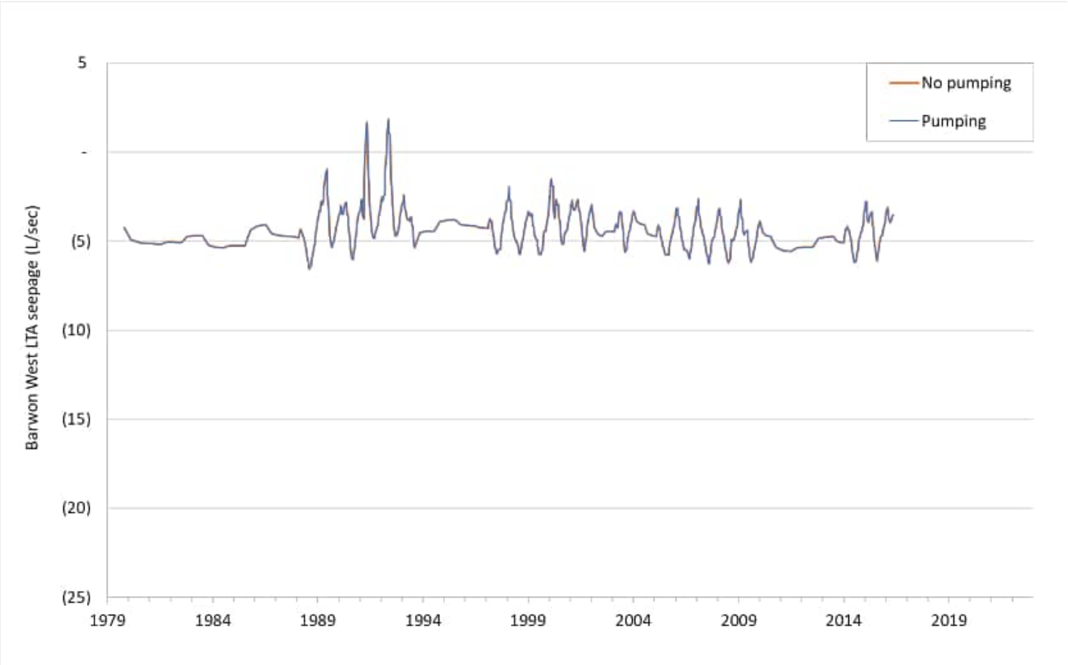


Figure 3.10: River seepage from Barwon River West Branch where it flows over the MTD

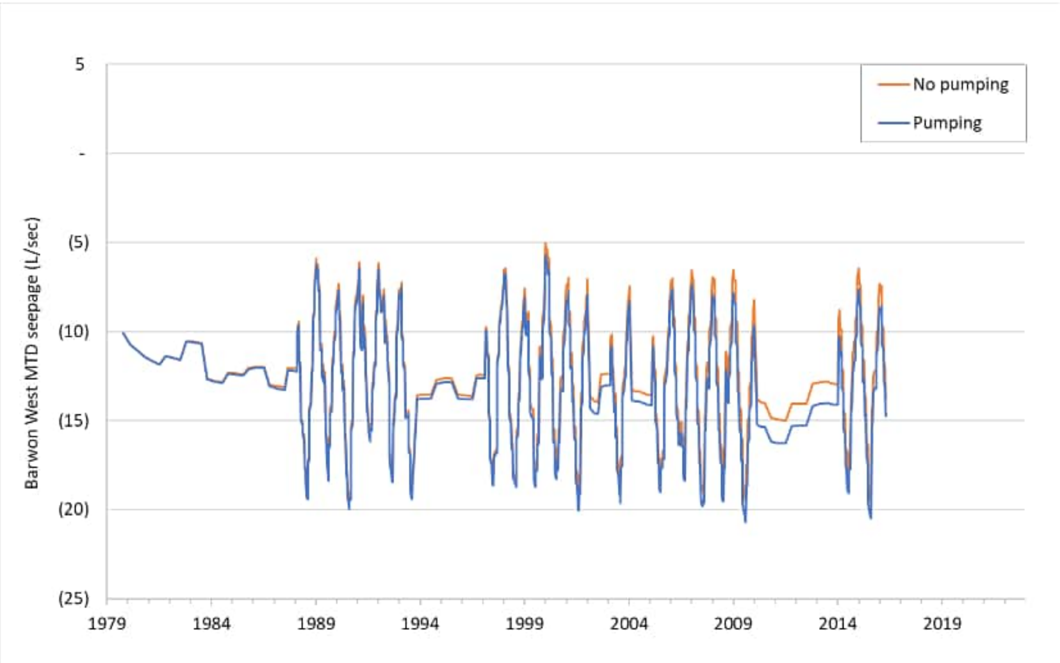


Figure 3.11: Change in river flux between no pumping and pumping

Risk assessment results

Areas of potential high risk are shown in Figure 3-12. This was calculated using the risk assessment framework outlined in Appendix A, and using the likelihood defined in Figure A.1 and Table 3.1, and consequence defined by drawdown predicted in the model.

Figure 3-12 shows the spatial distribution of risk to Barwon River West Branch (together with the East Branch), which has two areas of potential high risk within the model boundary (based on drawdown). The potential high risk areas are located near the headwaters of the Barwon River West Branch and immediately upstream of the Bambra Fault (south east). In other areas, the risk to the Barwon River West Branch is moderate to low due to the predicted drawdown being much less at this risk location.

Along this reach, the Barwon River West Branch flows over outcropping aquifer (LTA) and aquitard (MTD). Where the river flows across outcropping LTA, the likelihood of the river being connected to the regional groundwater system is classified as certain. Where the river flows over the regional aquitard, the likelihood of it being connected is classified as possible.

The risk outcome is classified as moderate when the consequence is based on the change in flux to rivers (shown in Figure 3.11) estimated by the groundwater model.

There are three active streamflow gauge monitoring the Barwon River and the Barwon River West Branch. The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and the very edge of the model domain. The most relevant active streamflow gauge within the model domain is Site 233224 Barwon River @ Ricketts Marsh, which monitors flow in the Barwon River downstream of the confluence with Boundary Creek. The 10th percentile of flow (Q90) from this gauge is 4.9 M/day based on monitoring data collected between 1971 – 2017.

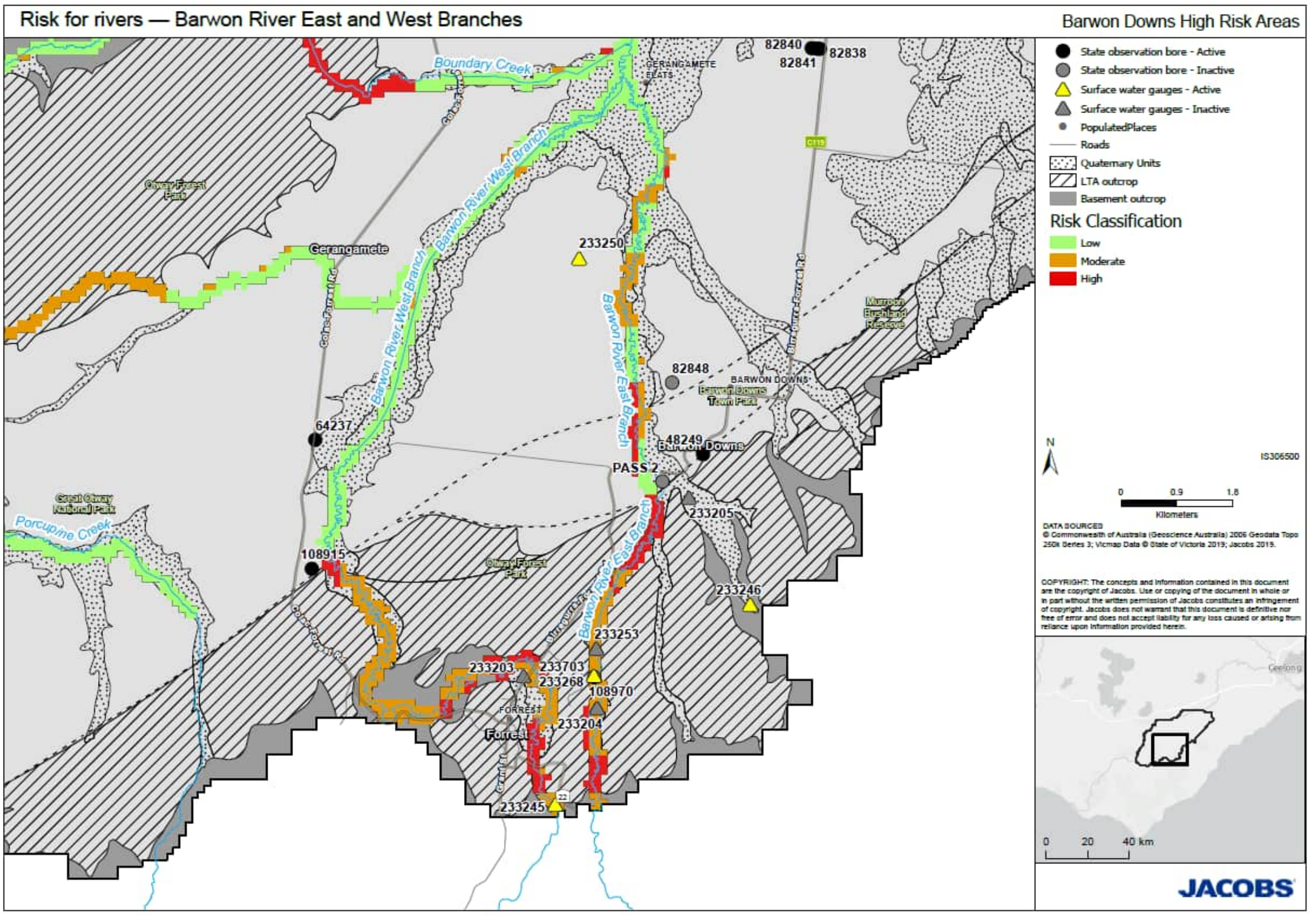
The change in river flux was calculated for reaches that flow over the LTA and the MTD. This shows that the maximum impact predicted by the model is 1.5 L/sec for both reaches (0.1 ML/day). Figure 3.11 shows that the maximum impact predicted by the model is negligible for the West Branch where is flows over the LTA and around 1.5 L/sec where is flows over the MTD. The maximum predicted impact equates to <1% of low flow for the West Branch where it flows over the LTA and 2% of low flow where it flows over the MTD.

Based on the likelihood and consequence classifications (based on change in river flux), both river reaches are classified as moderate risk (see Table 3.2). Small areas of potential high risk are identified when the consequence classification is defined by drawdown, therefore further work is recommended on the Barwon River West Branch to confirm the impacts and risk. It should be noted that there is limited monitoring data to confirm this drawdown impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.2: Risk assessment results for Barwon River West Branch

River Reach	Likelihood	Consequence	Risk
Barwon River West Branch LTA	Certain	Minor	Moderate
Barwon River West Branch MTD	Possible	Moderate	Moderate

Figure 3-12 Location of areas of potential high risk along the Barwon River East (and West) Branches using drawdown to define the consequence



3.2.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River West Branch and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River West Branch gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix C.

The primary data gaps identified for the Barwon River West Branch relate to information that can be used to determine if the rivers are gaining or losing to groundwater, and how drawdown propagates through the LTA (especially across the Bambra Fault) and the potential impact this has on groundwater levels in the shallow LTA, the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above.

<u>Additional Groundwater Monitoring</u>

- Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Bores should be located on the south eastern side of the Bambra Fault.
- Monitoring bores to be installed with a data logger, with a monitoring frequency of at least daily readings. Quarterly manual water level readings are also recommended for a minimum period of 5 years. The datalogger is recommended to be downloaded on a quarterly basis, when the manual readings are collected.
- Ongoing monitoring of existing bores 64237 and 108915.

<u>Additional Surface water monitoring</u>

- Install one stream gauge on the West Branch near Boundary Road to record all flows (with a priority to accurately measure low flows) and level. Collect a survey level of the base of the river at the gauge location.
- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

3.3 Barwon River downstream confluence with Boundary Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Barwon River downstream of the confluence with Boundary Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

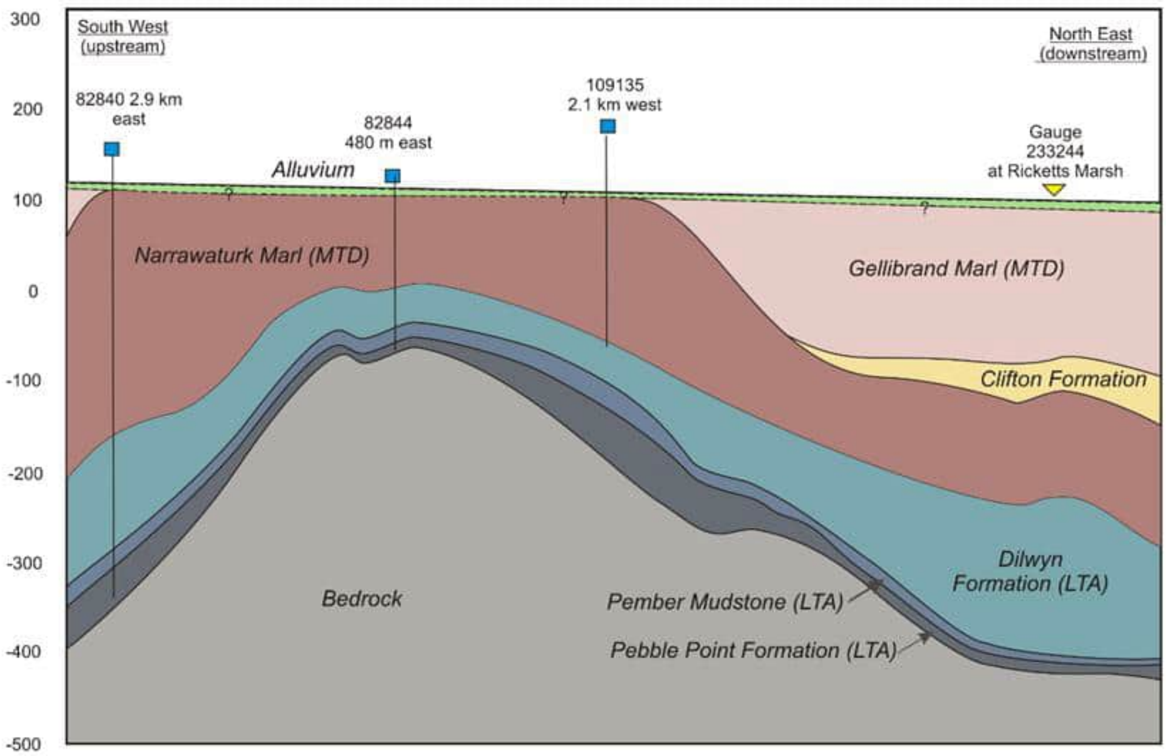
3.3.1 Why it was classified high risk

The Barwon River downstream of the confluence is classified as high risk as there is a small reach considered to have a moderate likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 3.13 shows a long section along the Barwon River downstream of the confluence with Boundary Creek, which shows the stratigraphy as presented in the regional groundwater model. The Barwon River flows through the centre of the graben over alluvial sediments, which in turn, overlie the regional Mid Tertiary Aquitard (MTD), which confines the LTA. The alluvial sediments are more extensive downstream (to the north) as the floodplain widens, however the thickness of the alluvium is not known. The MTD is reasonably thick in the centre of the graben, up to 300 meters thick.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 3.13: Long section along Barwon River downstream of the confluence



Regional groundwater model results

Figure 3.14 shows the estimate of river seepage calculated by the model for the Barwon River downstream of the confluence. The Barwon River downstream of the confluence is represented generally as a gaining river with seasonal variability. During summer months (low flows), the river is predicted to be gaining and during the winter months (high flows), the river is predicted to become losing.

Figure 3.14 also shows there is declining trend in groundwater contributions to baseflow over the years. The decline in more pronounced in the pumping scenario, with longer periods of losing conditions predicted in response to pumping. The regional groundwater model predicts there is a potential peak impact of around 7.5 L/sec in response to pumping.

Figure 3.15 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model change in river flux of around 7.5 L/sec, experienced at the end of the Millennium Drought.

Figure 3.14: River seepage to/from the Barwon River downstream of the confluence

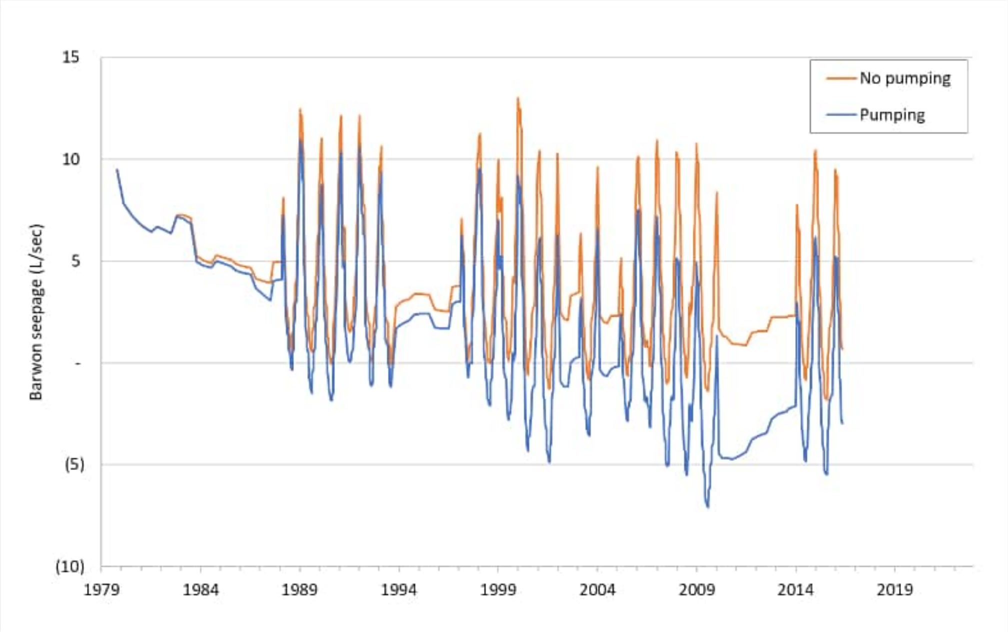


Figure 3.15: Change in river flux between no pumping and pumping

Risk assessment results

Areas of potential high risk are shown in Figure 3-16. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 3.2 and the consequence defined by drawdown predicted in the model.

Figure 3-16 shows the spatial distribution of risk to Barwon River, which has one small area of potential high risk within the model boundary (based on drawdown). The potential high risk area is located downstream of the confluence with Boundary Creek. In other areas, the risk to the Barwon River is moderate to low due to the predicted drawdown being much less at this risk location.

Along this reach, the Barwon River flows over the regional aquitard (MTD). The likelihood of the river being connected to the regional groundwater system is classified as possible.

The risk outcome is high when the consequence is based on the change in flux to rivers (shown in Figure 3.11) estimated by the groundwater model.

There is currently only one surface water gauge located downstream and near the edge of the model domain at Ricketts Marsh (site 23324). The 10th percentile of flow (Q90) from this gauge is 4.9 ML/day based on monitoring data collected between 1971 – 2017.

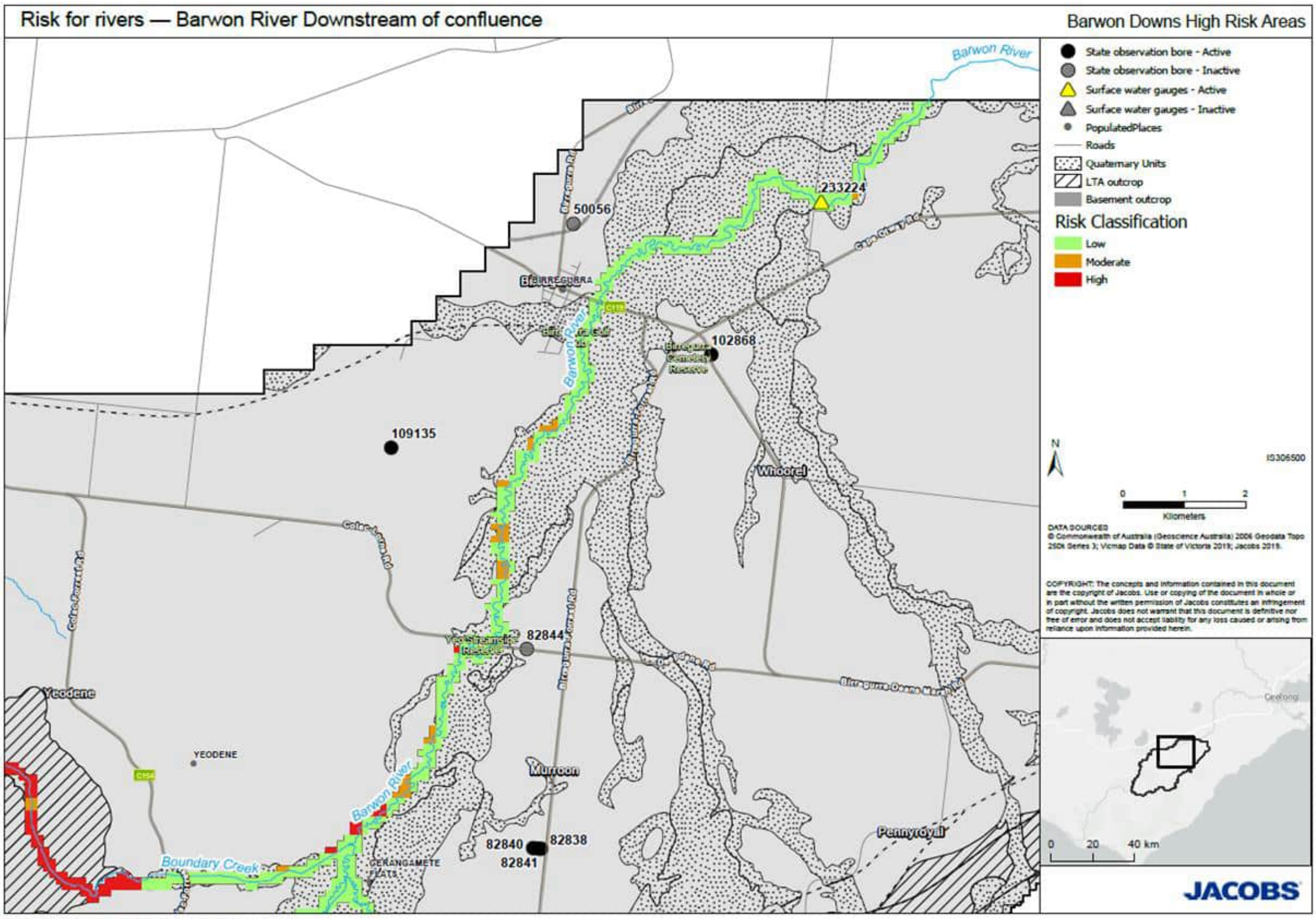
The change in river flux was calculated along the entire reach. This shows that the maximum impact predicted by the model is 7.5 L/sec for both reaches (0.7 ML/day) or 14% of low flow.

Based on the likelihood and consequence classifications (based on change in river flux), the Barwon River downstream of Boundary Creek is classified as high risk (see Table 3.3). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 3.3: Risk assessment results for Barwon River downstream of Boundary Creek

River Reach	Likelihood	Consequence	Risk
Barwon River downstream confluence	Possible	Significant	High

Figure 3-16 Location of areas of potential high risk along the Barwon River downstream of the confluence with Boundary Creek using drawdown to define the consequence



3.3.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Barwon River, the alluvial aquifer and regional groundwater system in LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. is the Barwon River gaining flow or losing flow to groundwater);
- if there is baseflow contribution from the LTA;
- and if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix D.

The primary data gaps identified for the Barwon River relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the overlying MTD, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer
- Surface water flows and levels in the river
- Groundwater levels in the alluvial aquifer and overlying MTD
- Vertical gradients between aquifers and rivers

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

3.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).

- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

- Ongoing monitoring of existing bores 82838.

Additional Surface water monitoring

- Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level.

- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring will initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

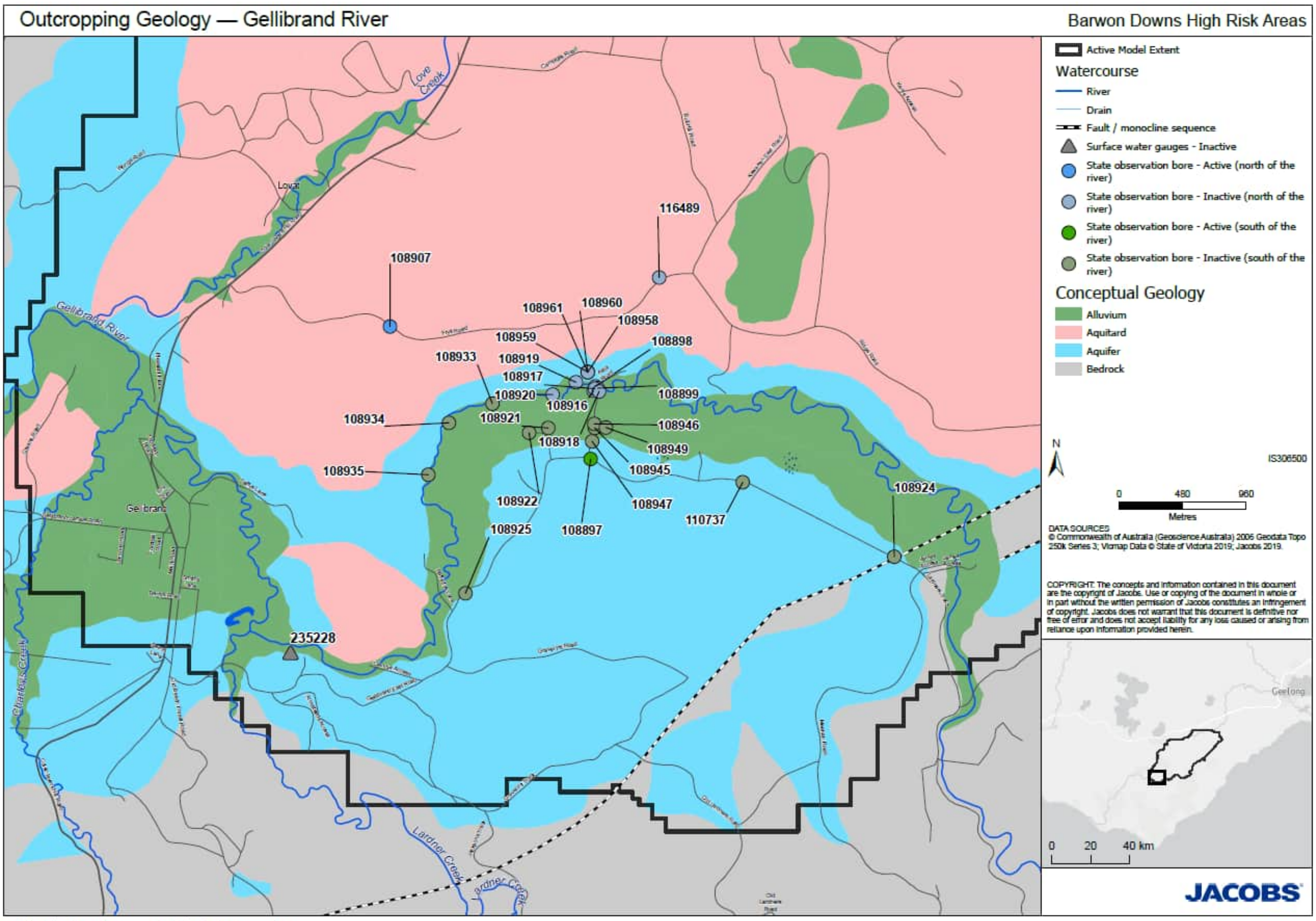
4. Gellibrand River Catchment

The Gellibrand River is located in the south western corner of the LTA extent with tributaries rising in the Otway Ranges and the Barongarook High. Tributaries include Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren. Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

The Gellibrand River is located to the south west of the Barwon Downs bore field and a small section of the river flows through the south western boundary of the groundwater model. The outcropping geology and the regional groundwater model extent are shown in Figure 4-1. The LTA outcrops along the Gellibrand River and because this is a key discharge area for the LTA, the river is gaining in this area (SKM, 2012). The LTA outcrop area is more extensive south of the Gellibrand River, with only a reasonably thin section outcropping north of the river at the southern extent of the regional aquitard.

The alluvial aquifer is also quite extensive in this area, however, its thickness is not known in detail. In most of the focus areas for risk, the river is located near the northern extent of the alluvial sediments where these sediments are likely to be thinner and potentially more hydraulically connected to the underlying LTA. This means that drawdown in the LTA at this location has the potential to influence groundwater levels in the alluvial aquifer.

Figure 4-1 Outcropping geology around Gellibrand River



4.1 Gellibrand River

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on the Gellibrand River. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.1.1 Why it was classified high risk

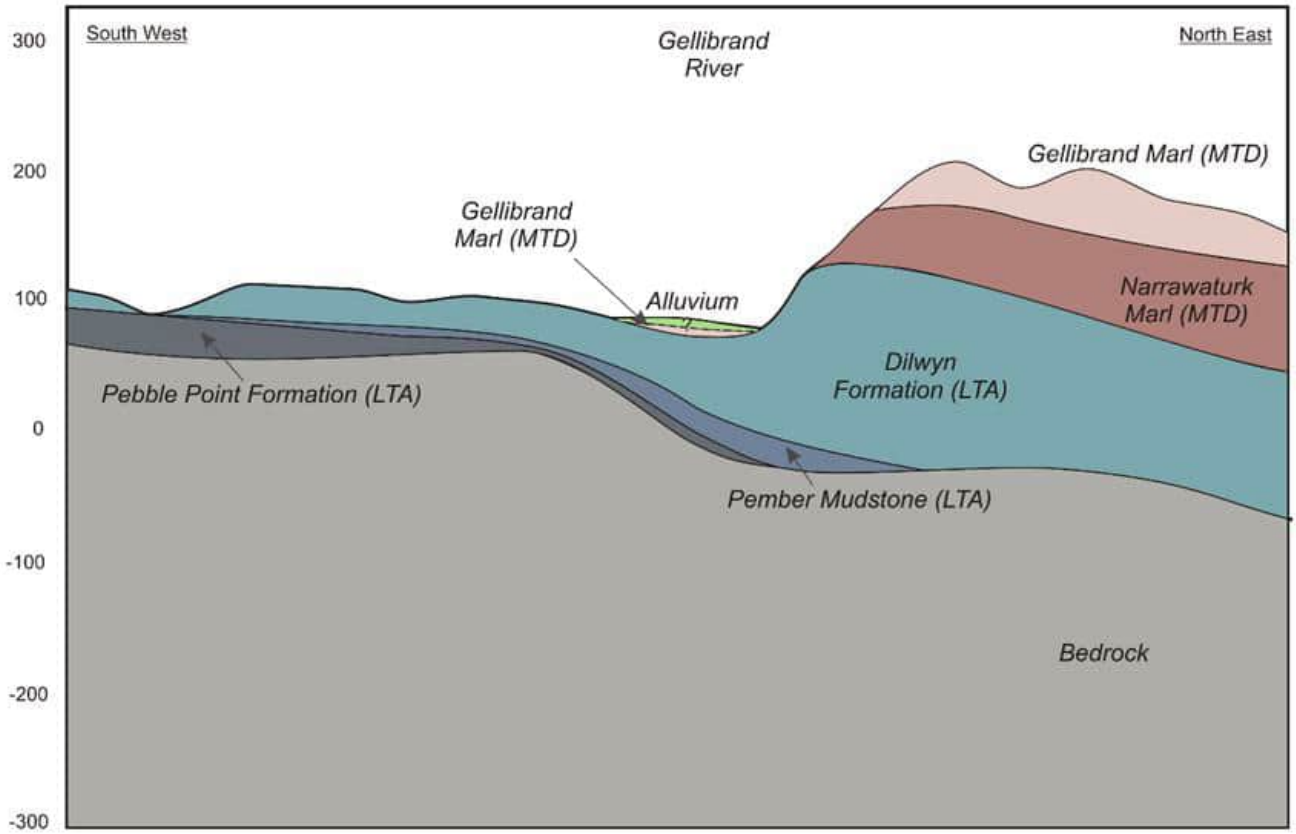
The Gellibrand River is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and to form the basis for further actions.

Figure 4.2 shows a cross section (north east to south west) across the Gellibrand River, which shows the stratigraphy as reflected in the regional groundwater model. This shows that the topography declines significantly in the south of the Barwon Downs graben and drops into the floodplain of the Gellibrand River. The LTA outcrops at the surface through the floodplain and extends south of the river. It is expected that this outcrop area is a key discharge feature of the LTA. The overlying MTD does not extend south into the floodplain of the Gellibrand River.

Alluvial sediments are present beneath the river, and the regional groundwater model also shows a very thin layer of Gellibrand Marl present beneath the alluvial sediments.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4.2: Cross section across the Gellibrand River



Regional groundwater model results

Figure 4.3 shows the estimate of groundwater flux/river seepage calculated by the model for the Gellibrand River. The Gellibrand River is represented as a gaining river and the volumes of groundwater flux to the river are reasonably large ranging between 50 to 80 L/sec. This is consistent with the conceptualisation that the Gellibrand River is a key discharge site. The regional groundwater model predicts that the groundwater contribution to the river declines over the model period (1979 to 2016), however most of this decline is the result of climate. The difference between the pumping and no pumping scenarios is around 5 L/sec.

Figure 4.4 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 4 L/sec in each river reach, at the end of the Millennium Drought.

Figure 4.3: Groundwater flux to Gellibrand River

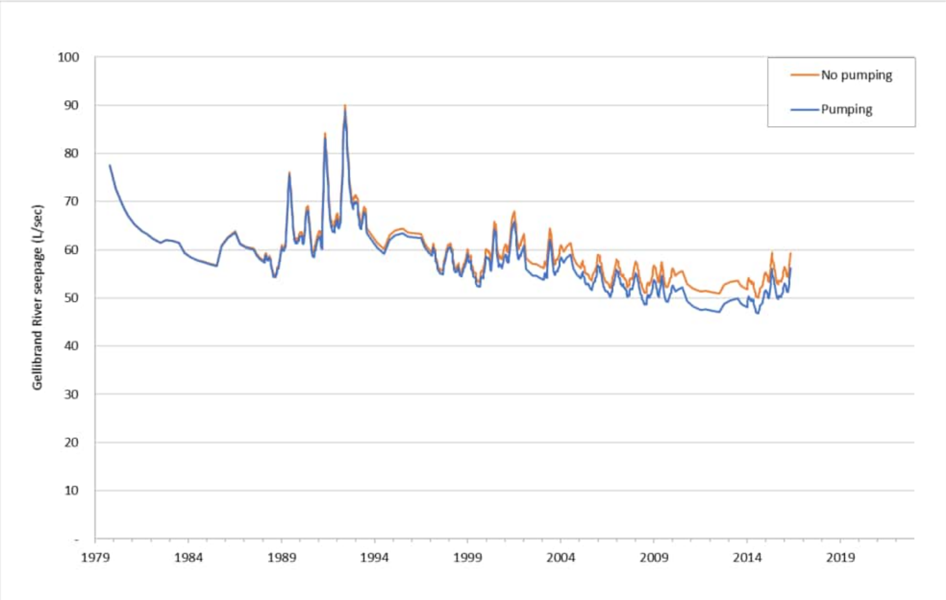
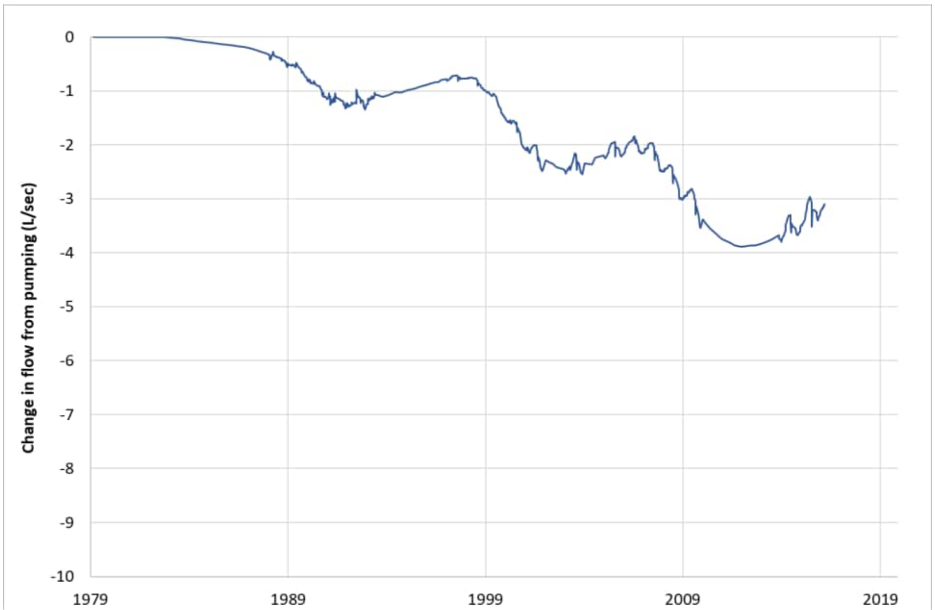


Figure 4.4: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 4-5. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.1 and the drawdown predicted in the model. The Gellibrand River flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-5 shows the spatial distribution of risk to the Gellibrand River, which has three areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the Bambra Fault zone, further downstream in the middle of the model and near the southern boundary of the model. The risk to the river is moderate in other areas.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.4).

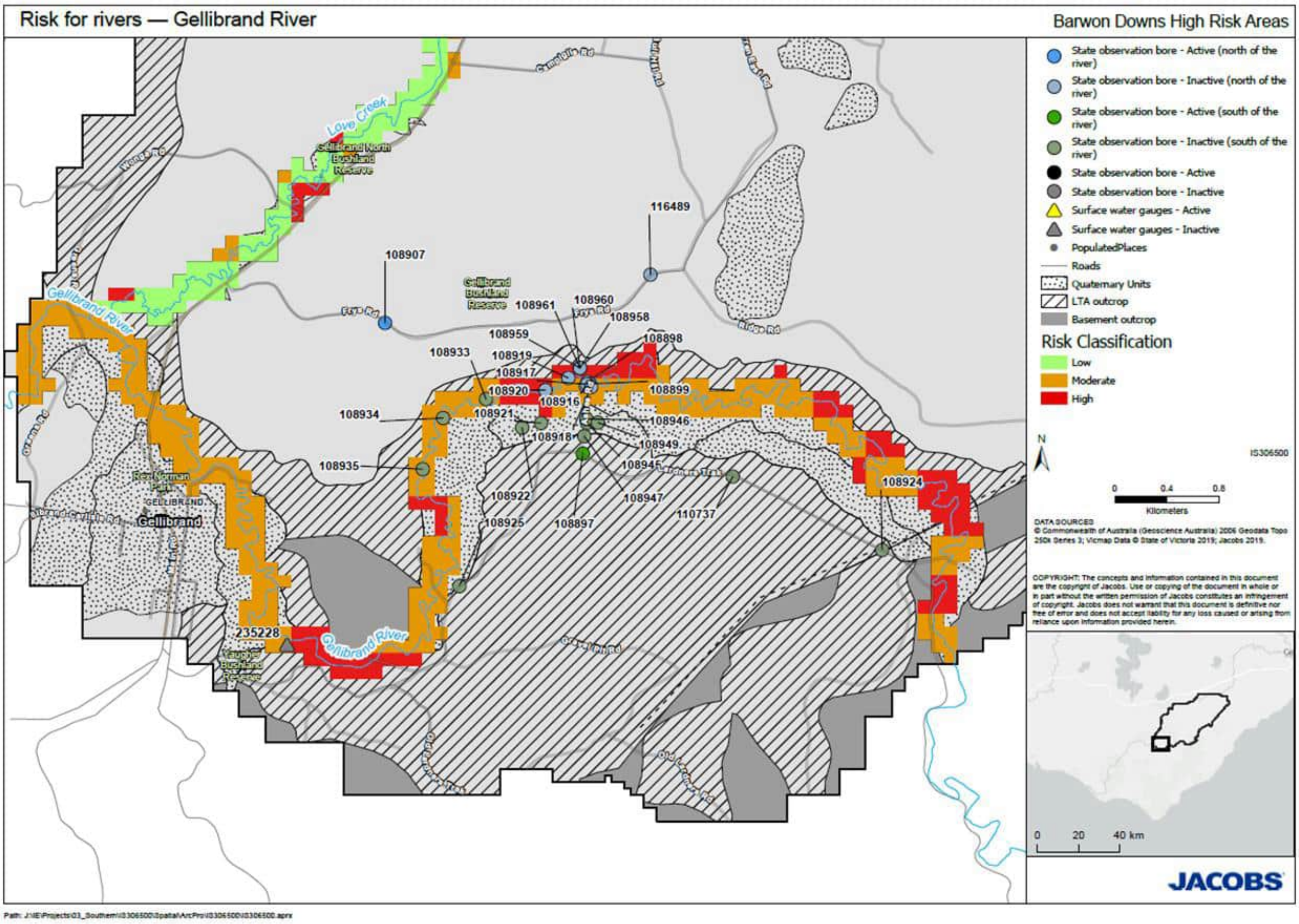
The Gellibrand River is monitored by two active surface water gauges 235227 (Bunkers Hill) and 235202 (Upper Gellibrand) which are located upstream and downstream of the model domain. There is one surface water gauge located in the model domain (235228 at Gellibrand), however monitoring ceased in 1989. The 10th percentile of flow (Q90) from gauge at Bunkers Hill is 12.2 ML/day based on monitoring data collected between 1970 – 2017. The location of these gauges is shown in Figure 4-1.

The change in river flux shows that the maximum impact predicted by the model is almost 4 L/sec (0.3 ML/day). The maximum predicted impact equates to 2% of low flow for the Gellibrand River. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.1). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.1: Risk assessment results for Gellibrand River

River Reach	Likelihood	Consequence	Risk
Gellibrand River	Certain	Moderate	High

Figure 4-5 Location of areas of potential high risk along the Gellibrand River using drawdown to define the consequence



4.1.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Gellibrand River and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Gellibrand River is gaining flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix E.

The primary data gaps identified for the Gellibrand River relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,

- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or when manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level.

- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

4.2 Ten Mile Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on Ten Mile Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.2.1 Why it was classified high risk

Ten Mile Creek is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 4-6 shows the outcropping geology along Ten Mile Creek and Figure 4.7 shows a long section along the creek. Both figures show the stratigraphy as presented in the regional groundwater model, which highlights that the LTA outcrops in the upper reaches of the creek and further downstream, the MTD overlies the LTA. Although there is a thin sequence of MTD shown in Figure 4-6 in the upper reaches of the creek, the creek is incised into the LTA, so the MTD doesn't extend beneath the creek at this location. This area is marked by a question mark (?) in Figure 4.7.

Alluvial sediments are not expected to be present beneath the creek (based on regional mapping).

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4-6 Outcropping geology around Ten Mile Creek

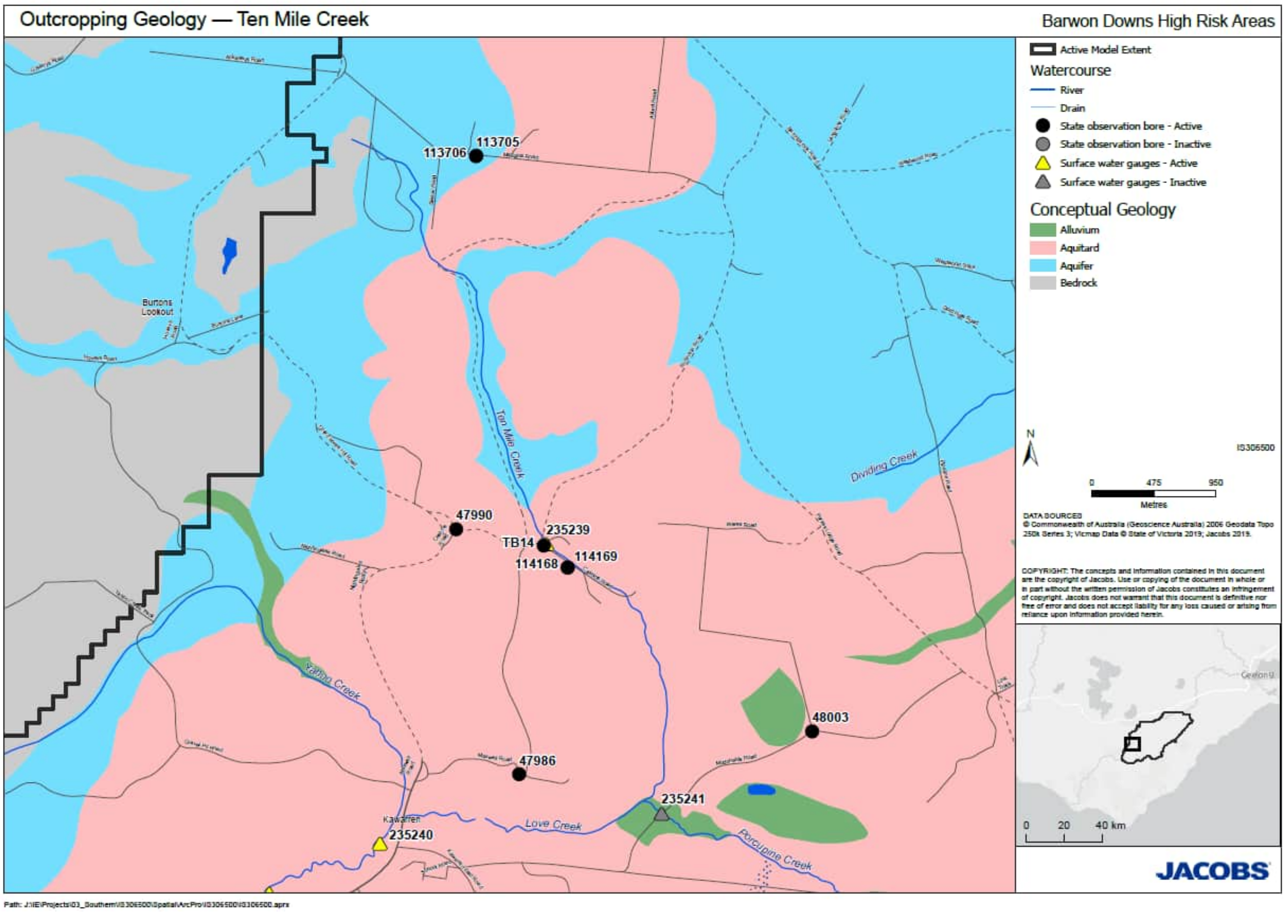
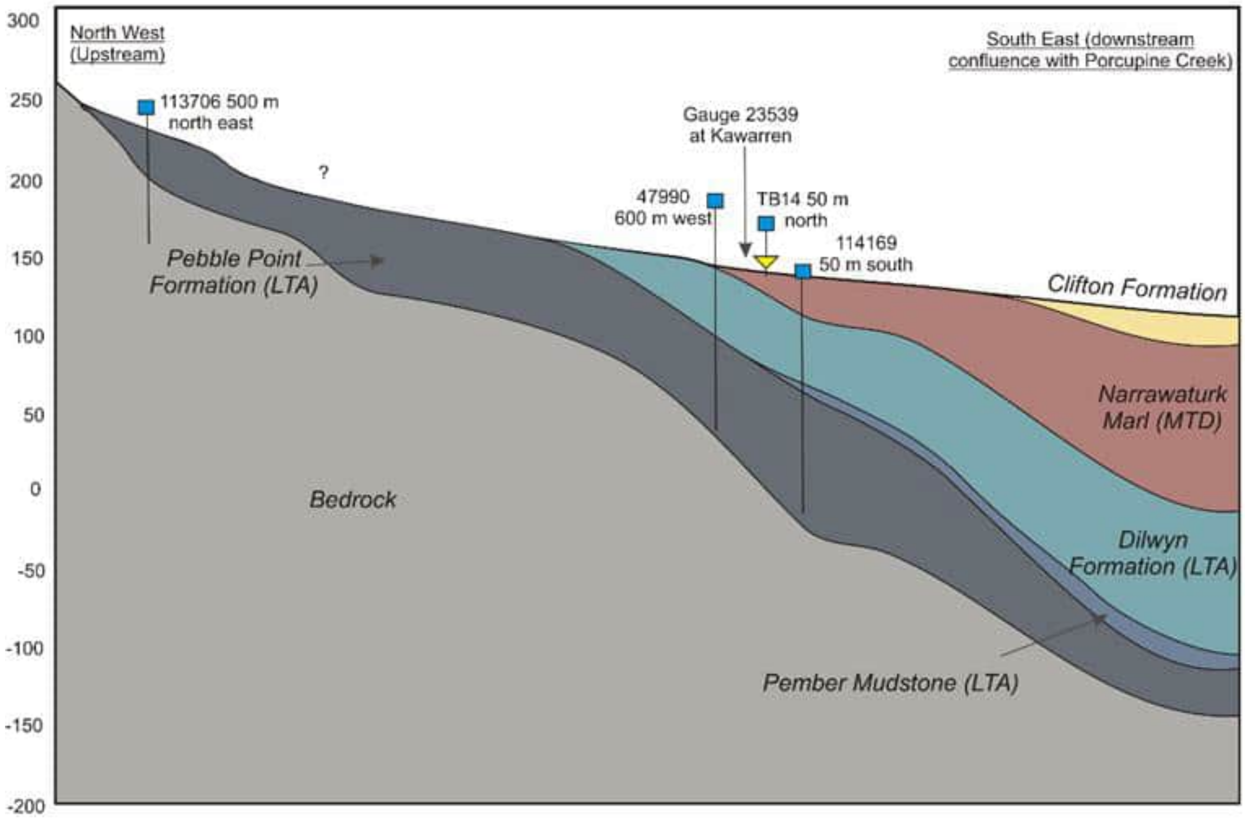


Figure 4.7: Long section along Ten Mile Creek (area marked with a question mark is where the creek is likely incised into LTA through thin MTD).



Regional groundwater model results

Figure 4.8 shows the estimate of groundwater flux/river seepage calculated by the model for Ten Mile Creek. Ten Mile Creek is represented as a gaining river and the volumes of groundwater flux to the river is typically less than 10 L/sec. The regional groundwater model predicts that the groundwater contribution to the river declines marginally over the model period (1979 to 2016) in response to climate. However there is also a noticeable difference in groundwater flux to the river predicted between the pumping and no pumping scenarios.

Figure 4.9 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model was a baseflow reduction of around 2.5 L/sec, at the end of the Millennium Drought.

Figure 4.8: Groundwater flux to Ten Mile Creek

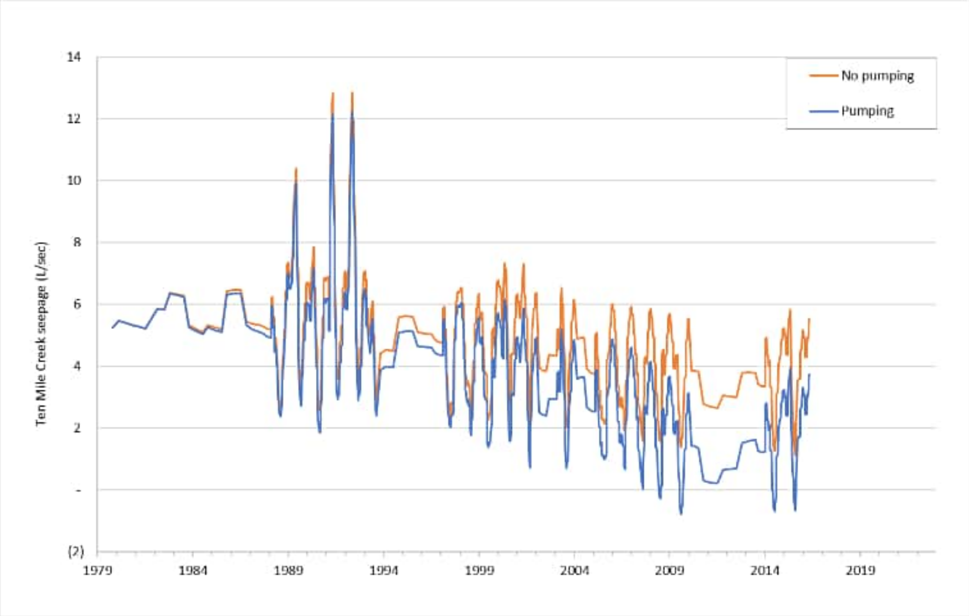
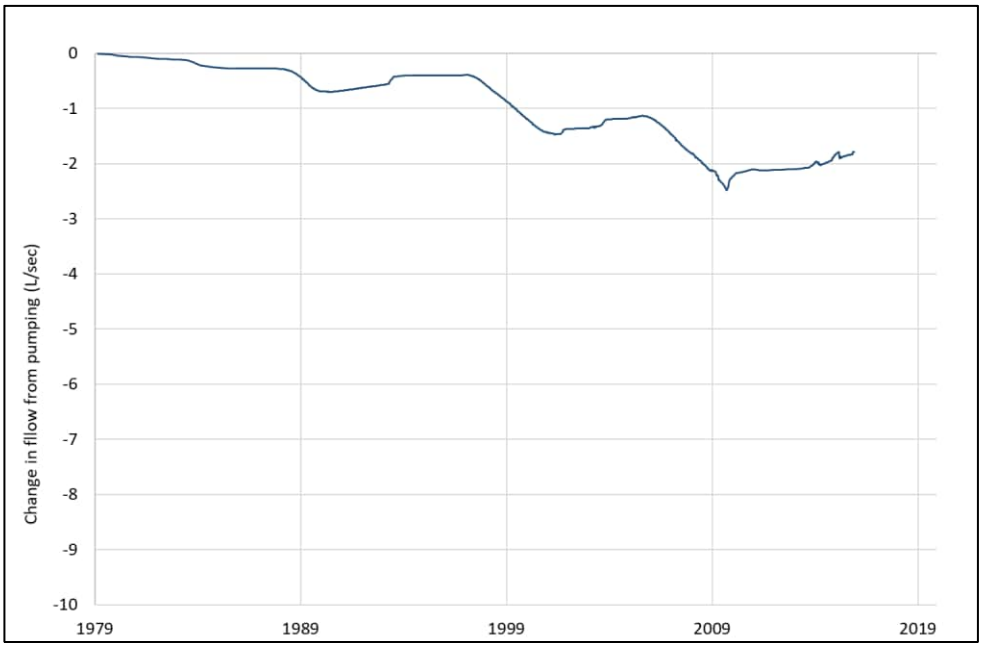


Figure 4.9: Change in river flux between no pumping and pumping



Risk assessment results

Areas of potential high risk are shown in Figure 4-10. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.2 and the drawdown predicted in the model. Ten Mile Creek flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-10 shows the spatial distribution of risk to the creek, which has roughly two areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the headwaters of the creek and further downstream on the LTA outcrop. The risk to the river is low to moderate in other areas.

The risk outcomes remain high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.8).

There is one active surface water gauge (235239) monitoring flow in Ten Mile Creek, however the flow record is intermittent. Monitoring commenced in 1985 and continued until 1995. The gauge was monitored again in 2008-2009 and has recommenced again in 2018. Intermittent monitoring periods since the mid-1990s show a very different flow regime, with flow not recorded above 5 ML/day during the winter months of 2008 or 2019. More detail on the surface water monitoring is provided in Appendix F. The 10^{th} percentile of flow (Q90) from this gauge is 1.3 ML/day based on the available monitoring data.

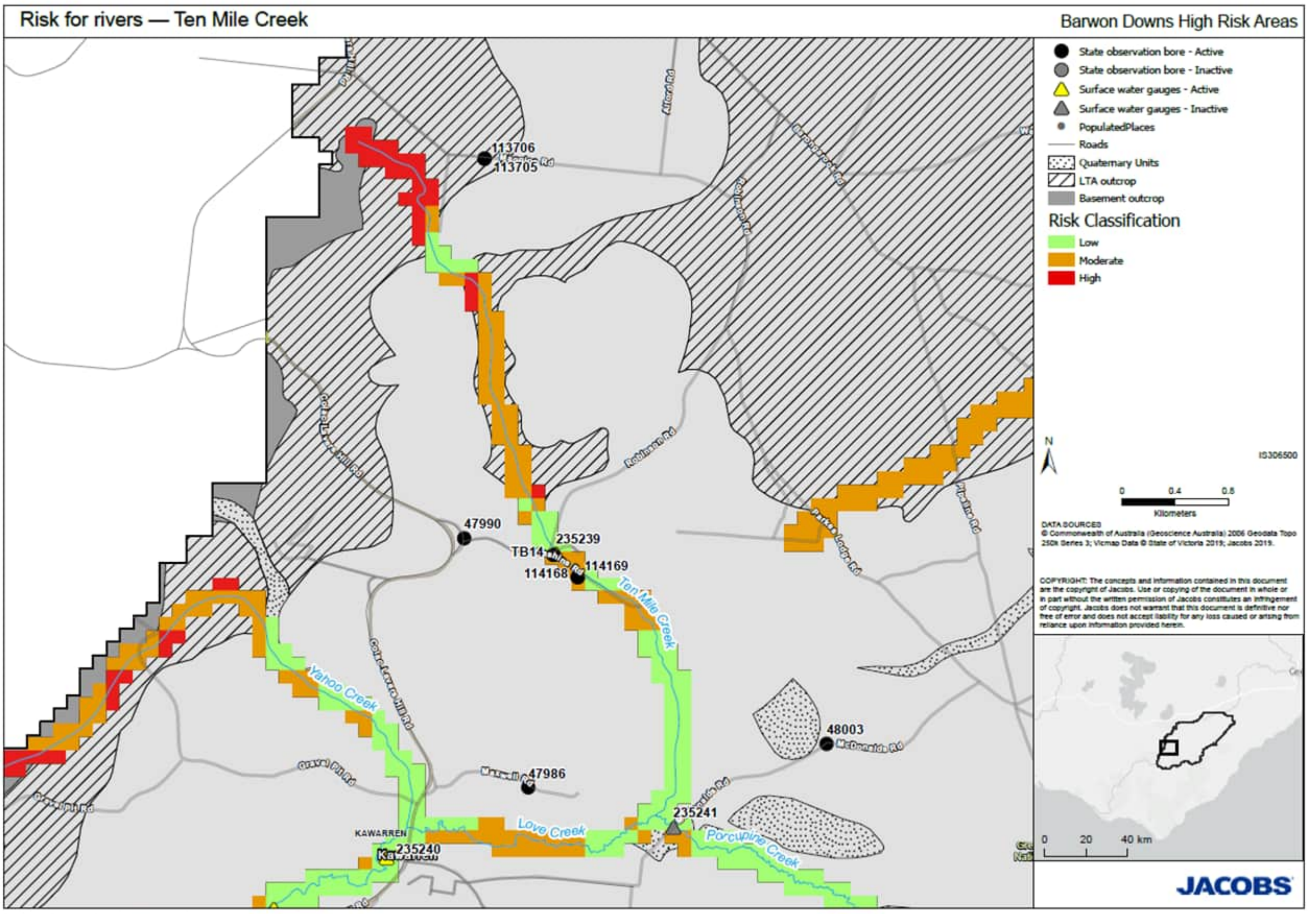
The location of these gauges is shown in Figure 4-6.

The change in river flux shows that the maximum impact predicted by the model is almost 2.5 L/sec (0.2 ML/day). The maximum predicted impact equates to 15% of low flow for Ten Mile Creek. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.2). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.2: Risk assessment results for Ten Mile Creek

River Reach	Likelihood	Consequence	Risk
Ten Mile Creek	Certain	Significant	High

Figure 4-10 Location of areas of potential high risk along Ten Mile Creek using drawdown to define the consequence



4.2.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Ten Mile Creek is gaining flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix F.

The primary data gaps identified for the Ten Mile Creek relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or when manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Continue monitoring at existing stream gauge;
- Survey the stream bed elevation in the vicinity of the gauge and the bores.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

4.3 Yahoo Creek

The regional groundwater model was used to predict the impacts of pumping from the Barwon Downs borefield on Yahoo Creek. The model results informed the risk assessment and the outcomes of this are discussed in the following sections.

4.3.1 Why it was classified high risk

Yahoo Creek is classified as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

Figure 4-11 shows the outcropping geology along Yahoo Creek and Figure 4.12 shows a long section along the creek. Both figures show the stratigraphy as it is represented in the regional groundwater model, which highlights that the LTA outcrops in the upper reaches of the creek and further downstream, the MTD overlies the LTA. Alluvial sediments are present in a small area where the outcropping geology changes from LTA to MTD, however these are not present in the regional groundwater model.

The regional groundwater model results and the risk assessment outcomes are outlined below.

Figure 4-11 Outcropping geology around Yahoo Creek

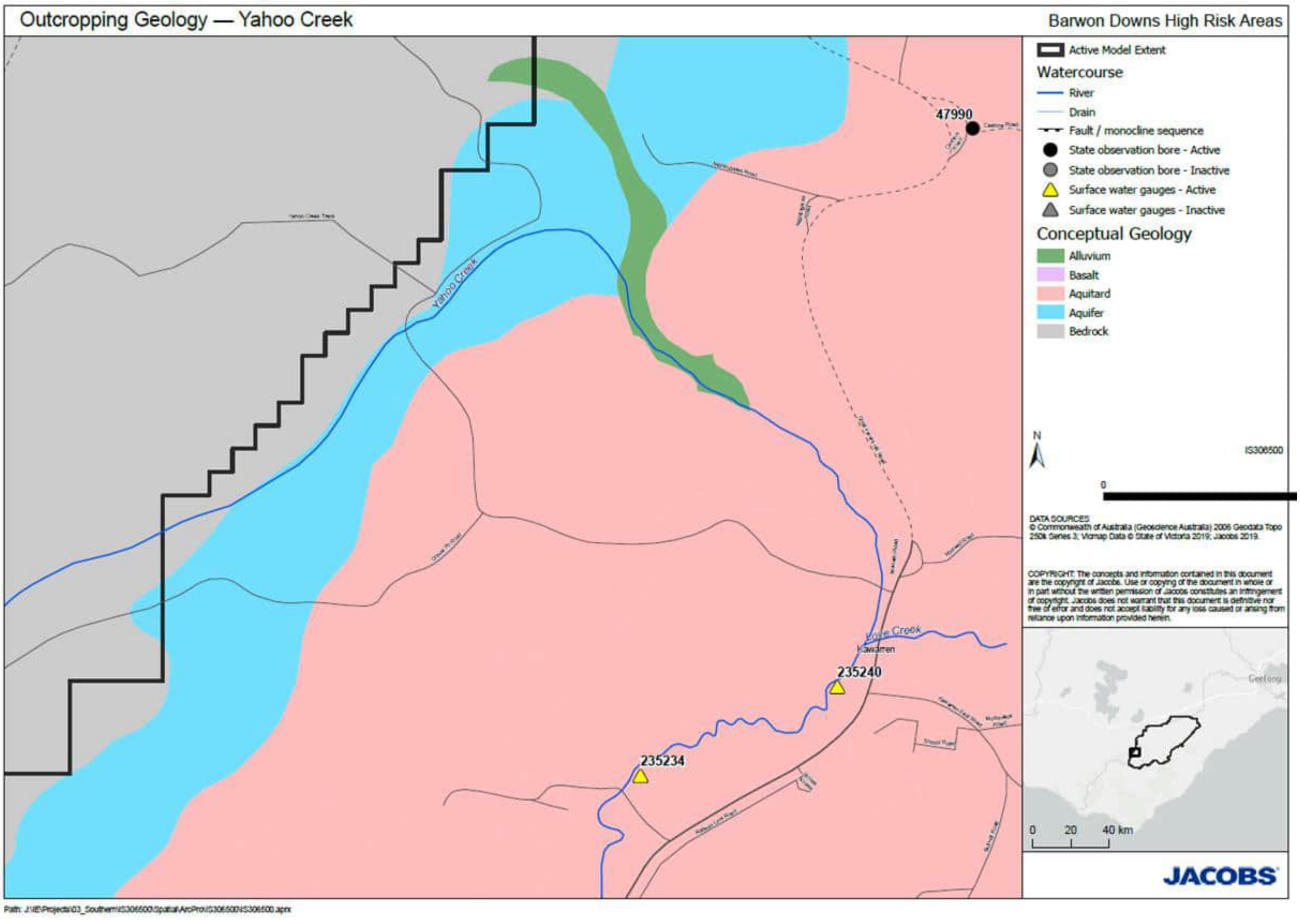
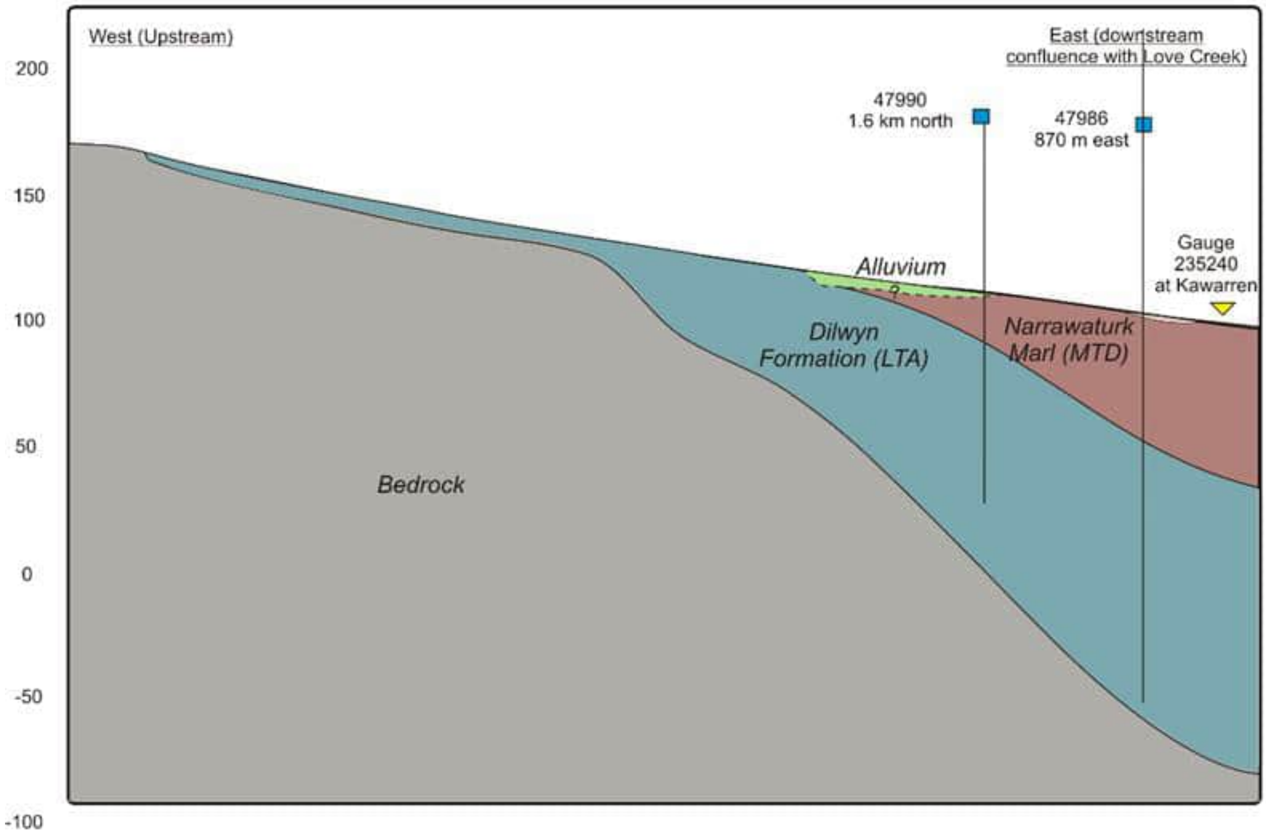


Figure 4.12: Long section along Yahoo Creek



Regional groundwater model results

Figure 4.13 shows the estimate of groundwater flux/river seepage calculated by the model for Yahoo Creek. Yahoo Creek is represented as a losing river (represented by negative seepage rates) and the volumes of river seepage to groundwater is typically less than 8 L/sec. After an initial rise which is likely to be a response to the model initial conditions, the regional groundwater model predicts that seepage from the river to marginally increase over the model period (1979 to 2016) in response to climate. However, there is also a noticeable difference in groundwater flux from the river predicted between the pumping and no pumping scenarios.

Figure 4.14 shows the change in river flux, calculated as the difference between the no pumping and pumping scenarios. This shows that the maximum impact predicted by the regional groundwater model is an increase in seepage from the river of around 1 L/sec, at the end of the Millennium Drought.

Figure 4.13: Groundwater flux to Yahoo Creek (the y-axis of this graph is negative, so this graph indicates seepage from the creek into the model at all times)

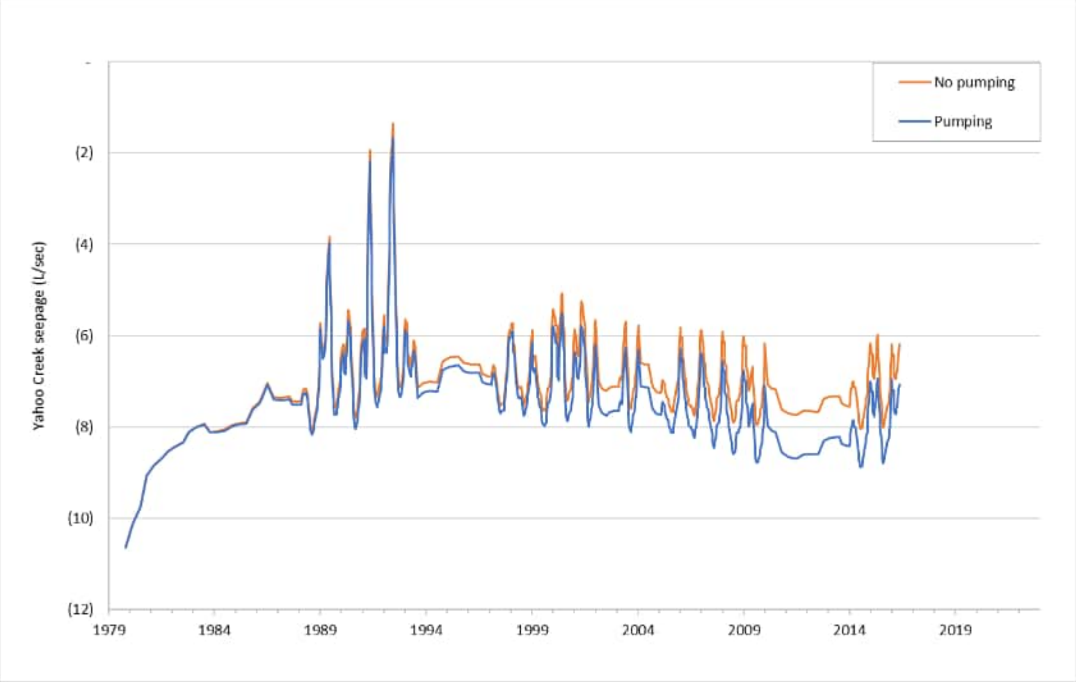
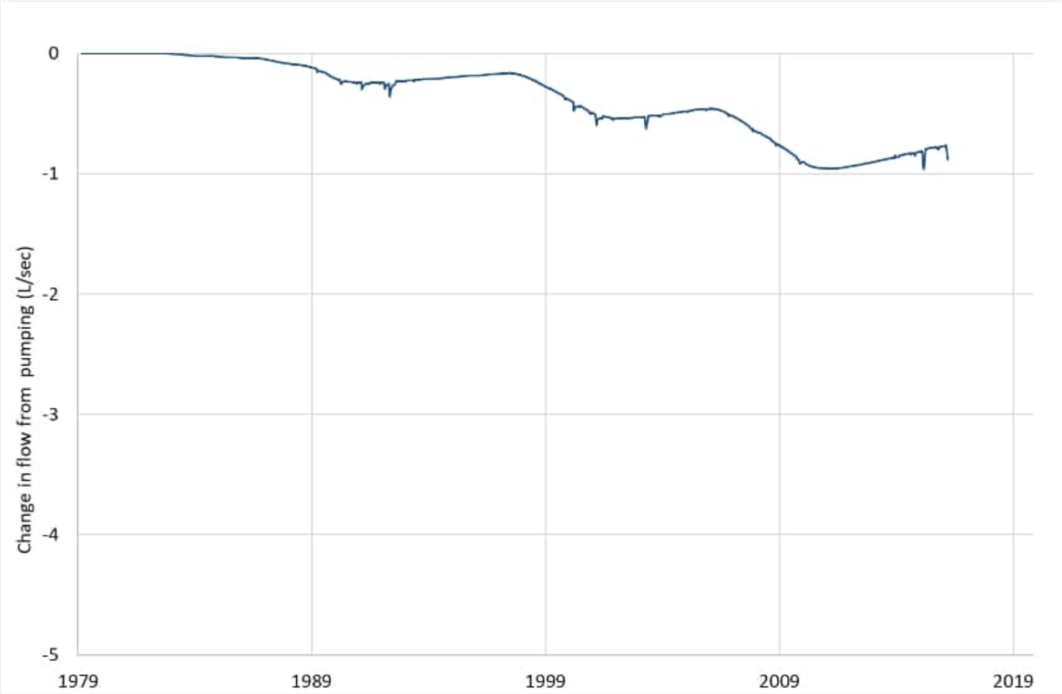


Figure 4.14: Change in river flux between no pumping and pumping (negative numbers indicate seepage from the river to the aquifer).



Risk assessment results

Areas of potential high risk are shown in Figure 4-10. This was calculated using the risk assessment framework outlined in Appendix A, using the likelihood defined in Figure A.1 and Table 4.2 and the drawdown predicted in the model. Yahoo Creek flows across outcropping LTA so the likelihood of the river being connected to the regional groundwater system is classified as certain.

Figure 4-15 shows the spatial distribution of risk to the creek, which shows isolated areas of potential high risk within the model boundary (based on predicted drawdown). The potential high risk areas are located near the headwaters of the creek where the LTA outcrops. The risk to the river is low to moderate in other areas.

The risk outcomes remains high, when the consequence is based on the change in flux to rivers estimated by the groundwater model (shown in Figure 4.14).

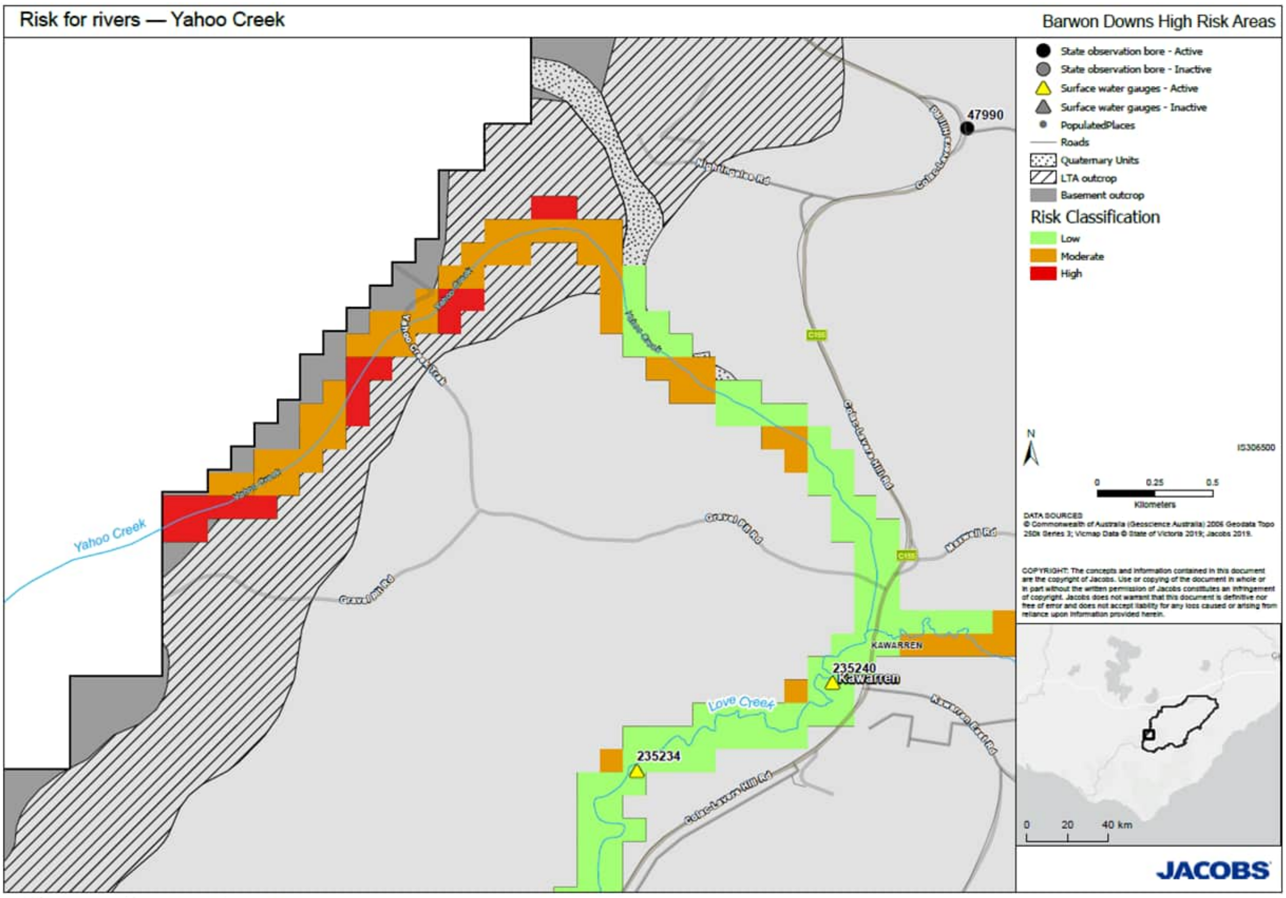
There is currently one surface water gauge located on Yahoo Creek upstream at Kawarren (235240). The location of these gauges is shown in Figure 4-11. The gauge was monitored between 1985 and 1995, and has recently been reactivated. The flow record in the 1980s shows seasonal variations in flow, with flow frequently dropping below 5 ML/day. Flow in 2019 has not been reported above 2 ML/day. More detail on the surface water monitoring is provided in Appendix G. The 10th percentile of flow (Q90) from this gauge is 1.0 ML/day based on the available monitoring data.

The change in river flux shows that the maximum impact predicted by the model is approximately 1 L/sec (<0.1 ML/day). The maximum predicted impact equates to 8% of low flow for Yahoo Creek. Based on the likelihood and consequence (based on change in river flux) classifications, the river is classified as high risk (see Table 4.2). It should be noted that there is limited monitoring data to confirm this impact and additional on-ground data is required to validate the model predictions and confirm the level of risk to environmental receptors at the surface.

Table 4.3: Risk assessment results for Yahoo Creek

River Reach	Likelihood	Consequence	Risk
Yahoo Creek	Certain	Moderate	High

Figure 4-15 Location of areas of potential high risk along Yahoo Creek using drawdown to define the consequence



4.3.2 Current information gaps

Currently there is limited data to confirm surface water groundwater connection between Yahoo Creek and regional groundwater system / outcropping LTA. This data is required to improve understanding of:

- the nature of groundwater-surface water interactions (i.e. confirm that the Yahoo Creek is losing flow from groundwater);
- if there is baseflow contribution from the LTA; and,
- if impacts on baseflow from drawdown are buffered by the presence of alluvial aquifers.

The surface water and groundwater monitoring data that is currently available is provided in Appendix G.

The primary data gaps identified for Yahoo Creek relate to information that can be used to determine if the river is gaining or losing to groundwater, and how drawdown propagates through the LTA and the potential impact this has on groundwater levels in the shallow LTA, alluvial aquifer and river. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer and LTA;
- Vertical gradients between aquifers and rivers; and,
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers).

4.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above.

Additional Groundwater Monitoring

- Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Continue monitoring at existing stream gauge.

Survey data

- Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5. Vegetation and PASS investigation areas

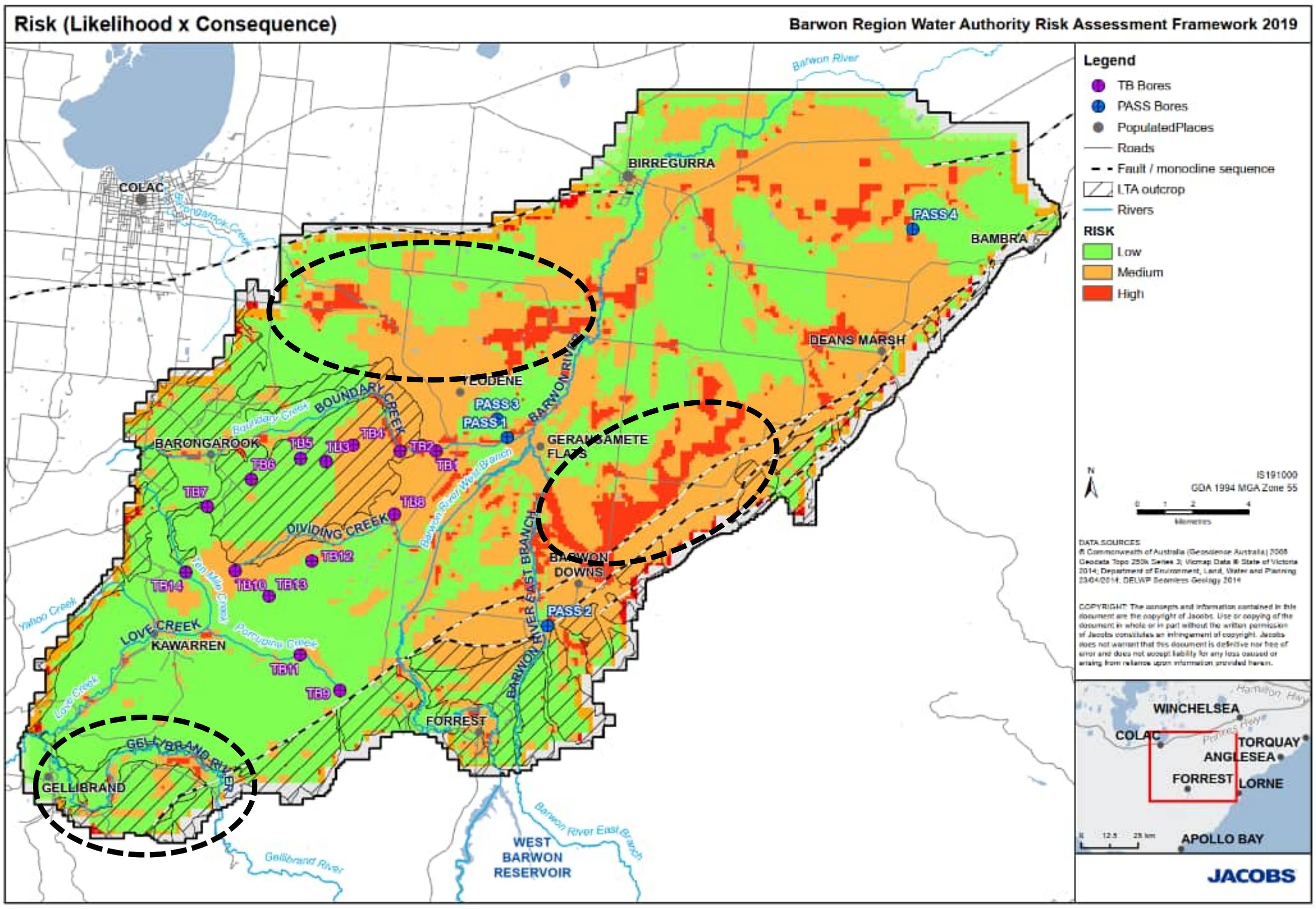
The risk to groundwater dependent vegetation across the catchment was determined using the depth to water table from the regional groundwater model and the drawdown predicted in the water table aquifer as a result of historical groundwater extraction. More detail on the risk assessment framework is provided in Appendix A.

The risk to groundwater dependent vegetation is presented in Figure 5-1. This shows that there are three key (largest) areas the model estimates the risk to be high:

- West of the Barwon River to the north of Yeodene;
- East of the Barwon River between Barwon Downs and Yeodene; and,
- Along the Gellibrand River.

These are the largest areas of potential high risk. Further investigations may be recommended in other isolated areas of potential high based on the outcomes of the investigation plan. These are discussed in the following sections.

Figure 5-1: Historical risk across the study area based on modelled drawdown (consequence) and modelled depth to watertable (likelihood)



5.1 North of Yeodene

The area is bounded by Boundary Creek to the south, Barwon River to the east and Colac Fault to the north west. The Colac Fault represents the edge of the model domain. Barongarook Creek is also located in this area. The headwaters of Barongarook Creek are located in the centre of the area and the creek flows in a north westerly direction towards Lake Colac.

5.1.1 Why it was classified as high risk

Vegetation and PASS in some areas north of Yeodene is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area west of Barwon River is shown with the outcropping geology in Figure 5-2. The regional aquitard (MTD) outcrops across most of the area. The LTA outcrops on the Barongarook High located in the south of this area, and this is the key recharge area for the aquifer. North of the Barongarook High, the LTA is confined by the MTD which is 70-100 m thick.

Alluvial sediments are present along the Barwon River and although there are no bores located in the alluvial sediments, it's likely that the alluvial sediments form the water table aquifer. The alluvial aquifer is expected to be hydraulically isolated from the LTA by a thick sequence of MTD. It should be noted that the alluvial aquifer is not included in the groundwater model as the aquifers are localised and not continuous across the model domain.

Error! Reference source not found. shows the spatial distribution of risk across the area. Areas of potential h igh risk are located around Barongarook Creek and north east of Yeodene. There is limited information to inform the accuracy of the assigned risk in these areas. Information on groundwater monitoring in the area is limited to the deeper formations. More detail is provided in Appendix H.

Figure 5-2 Outcropping geology – vegetation west of Barwon River to the north of Yeodene

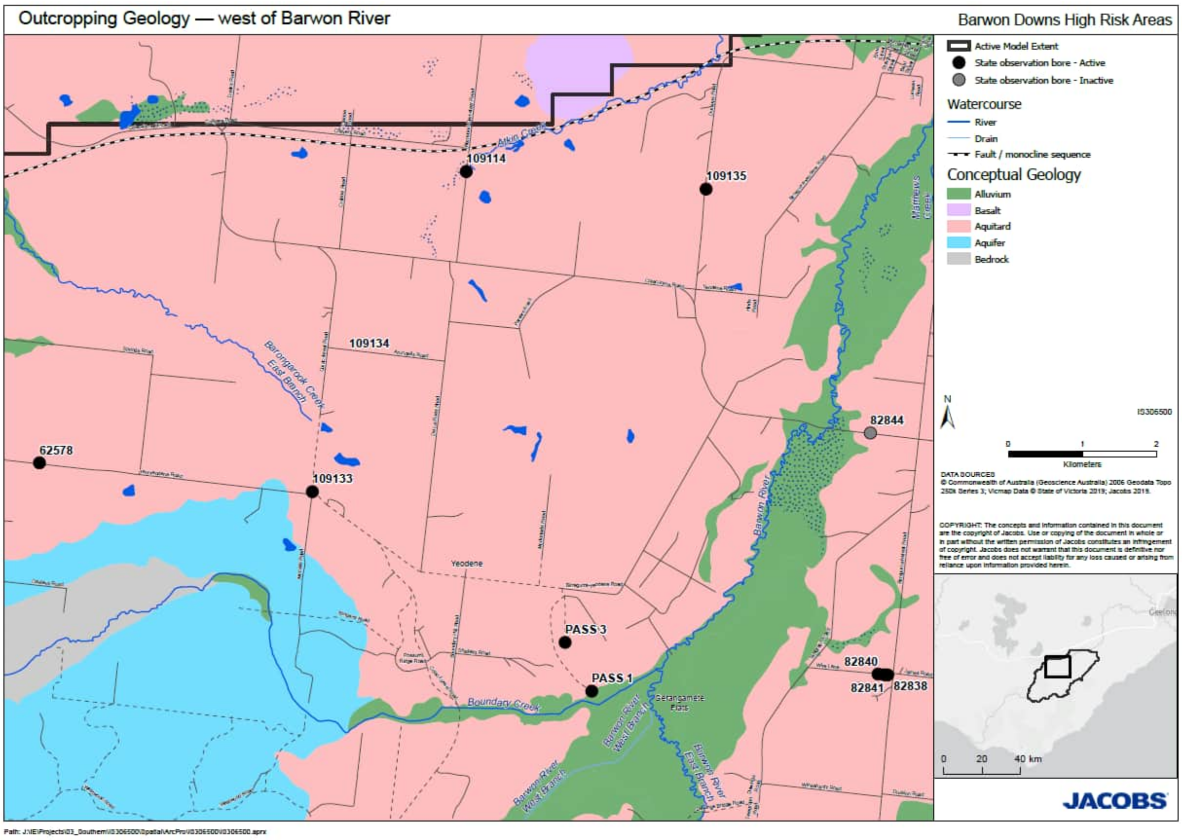
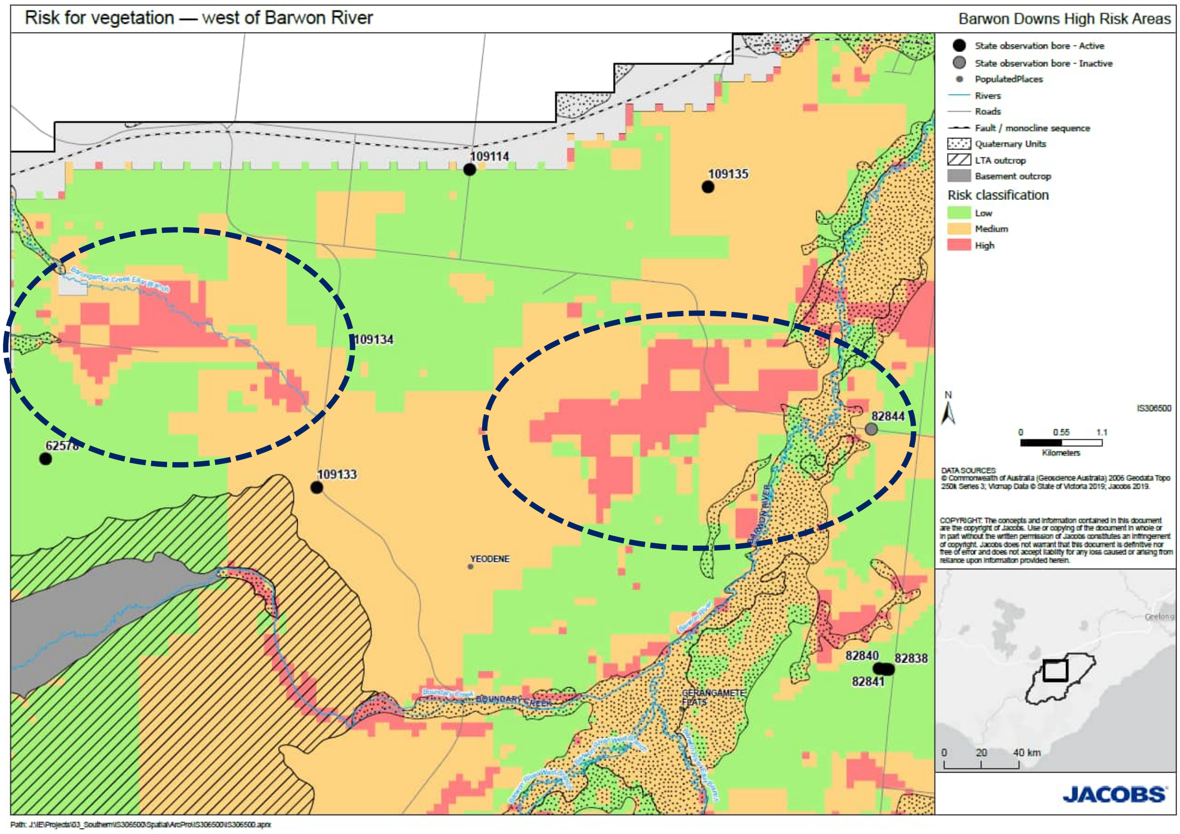


Figure 5-3: Risk to vegetation – vegetation west of Barwon River to the north of Yeodene



5.1.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve understanding of:

- the depth to watertable;
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and,
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers; and,
- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.1.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis, or whenever manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Surface water monitoring

- Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level.
- Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
- Survey the elevation of the creek bed close to the bores and at any gauge locations.

Additional Vegetation monitoring

- Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5.2 Deans Marsh

The area around Deans Marsh is bounded by the Bambra Fault to the south east and the Barwon River to the north west. Several tributaries of the Barwon River flow in a north westerly direction from the Otway ranges to the Barwon River, including Mathews Creek, Deans Marsh Creek and Yan Yan Gurt Creek.

5.2.1 Why it was classified as high risk

Vegetation and PASS in some areas around Deans Marsh is classified as high risk as there are particular sections considered to have a possible or certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area east of the graben is shown with the outcropping geology in Figure 5-4. The regional aquitard (MTD) outcrops across most of the area. The LTA outcrops on the south eastern side of the Bambra Fault, and this is the minor recharge area for the aquifer. North west of the Bambra Fault, the LTA is confined by the MTD which is up to 100 m thick.

Alluvial sediments are present along the tributaries and the Barwon River and although there are no bores located in the alluvial sediments, these are likely to contain the water table aquifer. The alluvial aquifer is expected to be hydraulically isolated from the LTA by a thick sequence of MTD. It should be noted that the alluvial aquifer is not included in the groundwater model as the aquifers are localised and not continuous across the model domain.

Figure 5-4 Outcropping geology – vegetation east of Barwon River around Deans Marsh

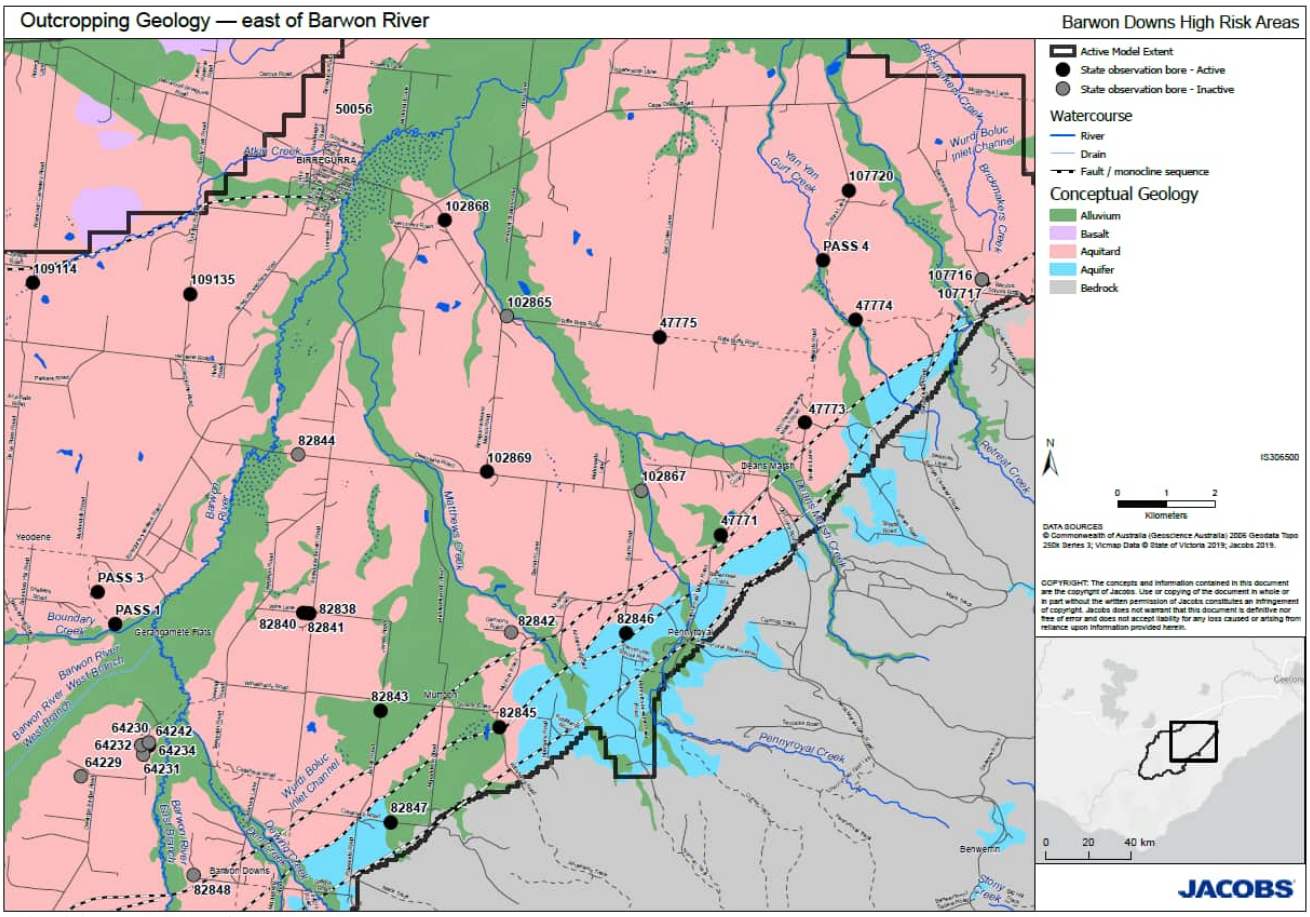
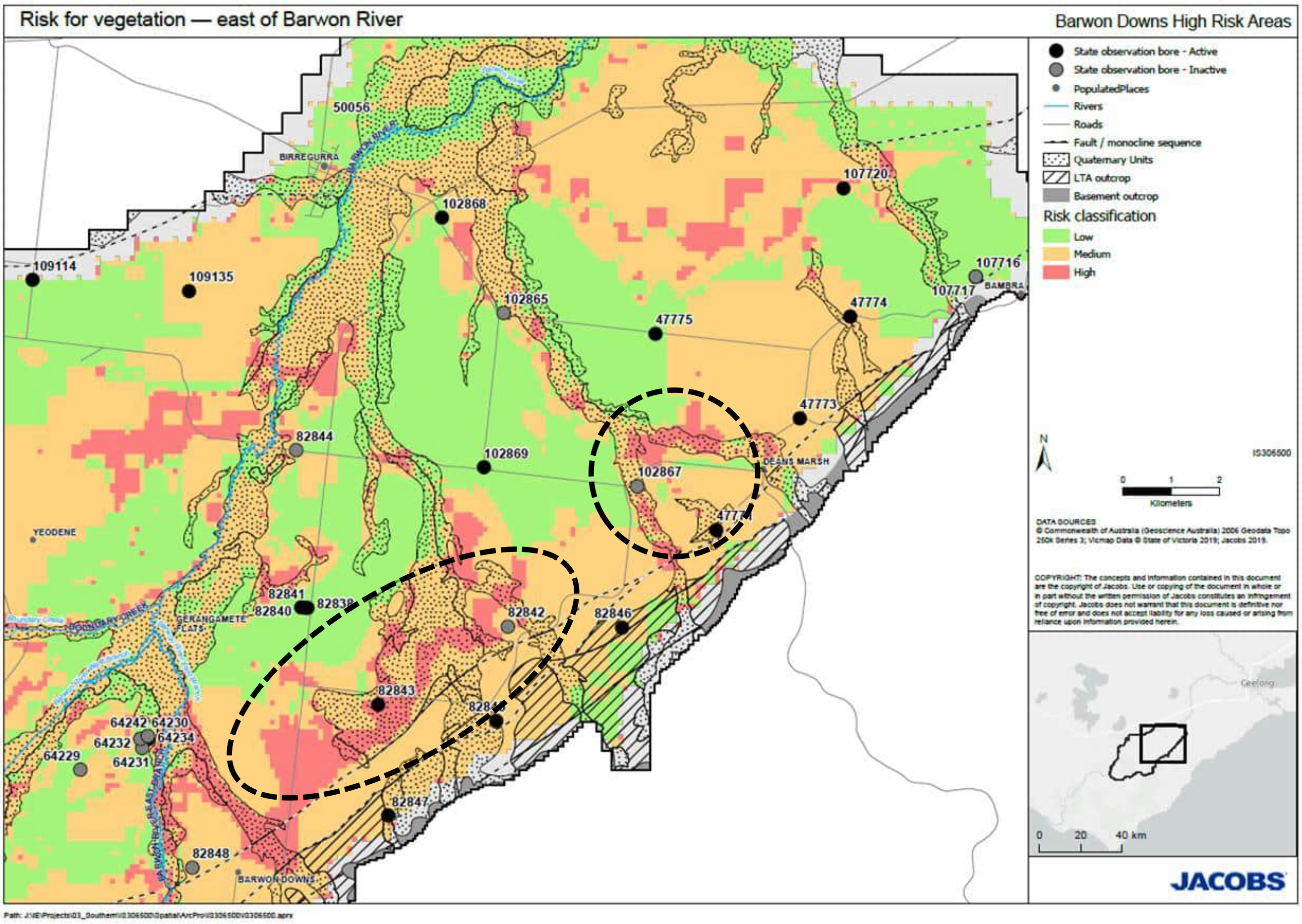


Figure 5-5 shows the risk to the groundwater dependent vegetation in this area of the catchment is focussed in areas where there are alluvial sediments, for example, around Mathews Creek and Deans Marsh Creek. Other areas of high risk are located in the north east of the area.

Figure 5-5: Risk to vegetation – vegetation east of Barwon River around Deans Marsh



5.2.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve the understanding of:

- the depth to watertable
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer;
- Groundwater levels in the alluvial aquifer and MTD;
- Vertical gradients between aquifers; and,

- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.2.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep).
- Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual readings are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years.

Additional Vegetation monitoring

- Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition.
- Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

5.3 Gellibrand River

The area along the Gellibrand River is the same area covered in Section 4.1, however the focus is on vegetation in the area, rather the groundwater contributions to the river.

5.3.1 Why it was classified as high risk

Vegetation and PASS in some areas around the Gellibrand River is classified as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to water table as a result of historic groundwater pumping. This has the potential to adversely impact on GDEs & PASS. However, given there is limited on-ground data in this area to inform the model predictions, additional on-ground data is required to validate the predicted impact and inform further actions.

The area along the Gellibrand River is shown with the outcropping geology in Figure 5-6. As described in Section 4.1, the LTA outcrops near the Gellibrand River and alluvial sediments are also present. The alluvial sediments are expected to form water table aquifer where present.

Figure 5-7 shows the risk to the groundwater dependent vegetation around the Gellibrand River using depth to watertable (likelihood) and drawdown (consequence). This shows the highest risks are expected to be in the areas to the east and close to the Bambra Fault. The risk across the remainder of the area is considered to be moderate and low.

Figure 5-6 Outcropping geology – vegetation around Gellibrand River

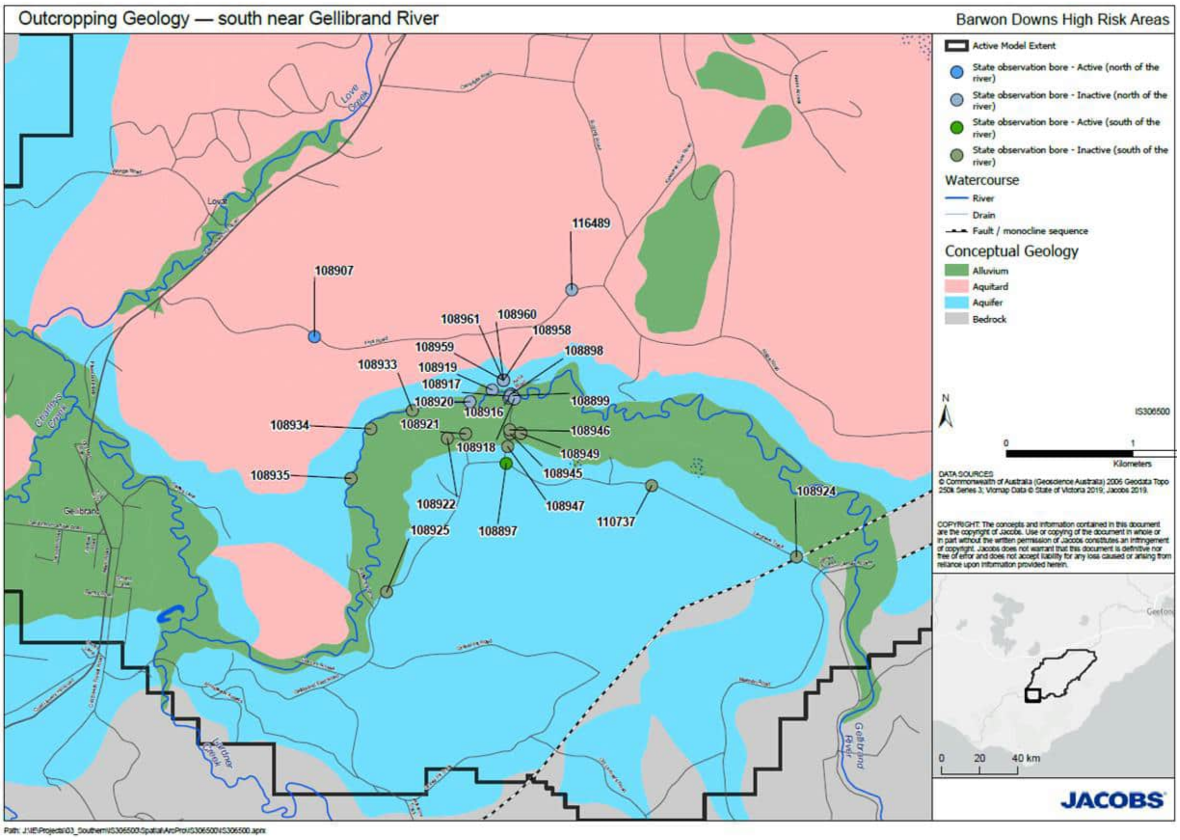
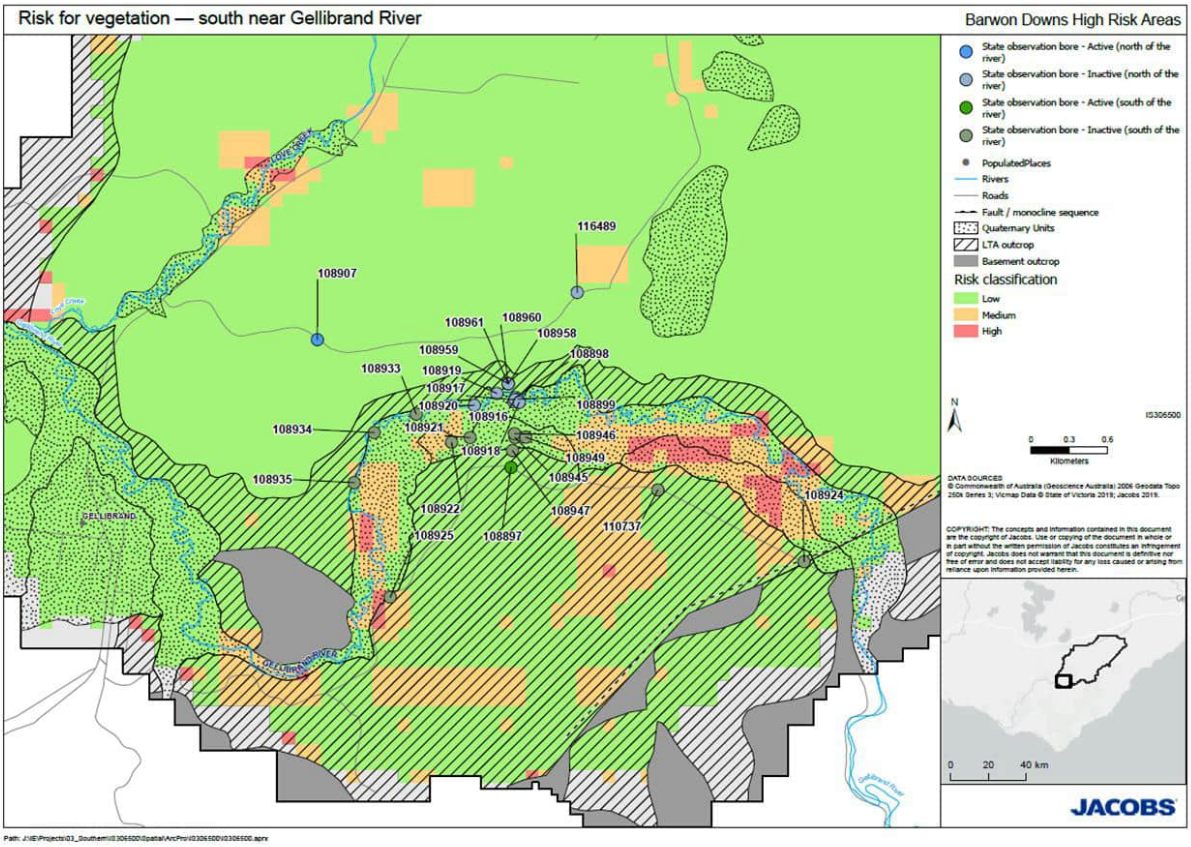


Figure 5-7: Risk to vegetation – vegetation around Gellibrand River



5.3.2 Current information gaps

Currently there is limited data to confirm the depth to watertable and connection between the watertable aquifer and the regional groundwater system. This data is required to improve the understanding of:

- the depth to watertable
- the level of connection between the watertable aquifer and the underlying MTD or LTA; and
- if drawdown impacts at the watertable are buffered by the presence of alluvial aquifers.

The groundwater monitoring data that is currently available is provided in Appendix H.

The primary data gaps identified for vegetation in this area relate to information that can be used to determine if the vegetation is dependent on groundwater, how drawdown propagates through the LTA and overlying MTD and the potential impact this has on groundwater levels in the watertable aquifer. This includes information on:

- Presence and thickness of an alluvial aquifer
- Groundwater levels in the alluvial aquifer and MTD
- Vertical gradients between aquifers
- Absolute groundwater level predicted in water table aquifer and drawdown predicted by the regional groundwater model.

5.3.3 Additional monitoring recommended to address information gaps

The following additional monitoring assets are recommended to address the information gaps outlined above:

Additional Groundwater Monitoring

- See recommendations for Gellibrand River in Section 4.1.3

Additional Vegetation monitoring

- Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

Data collected from this additional monitoring should be initially be reviewed after a period of 12 months as outlined in more detail in Chapter 6.

6. Recommendations for the Surrounding Environment investigation plan

This report outlines the rationale and recommendations for additional monitoring assets and an associated monitoring program where areas of potential high risk have been identified by the regional groundwater model. Adverse impacts in these areas of potential high risk have not been confirmed due to insufficient monitoring to validate groundwater model predictions. Further work involving the installation of new monitoring assets, together with review of the data and possible development of local groundwater models, is recommended for Surrounding Environment investigation plan.

An overview of the recommendations for additional monitoring assets to install as part of the investigation plan, together with the rationale, is outlined in Table 6.1.

After 12 months of data has been collected, it is recommended that the data is reviewed and the risk re-evaluated. The review would confirm the following:

- Presence and thickness of an alluvial aquifer;
- Surface water flows and levels in the river;
- Groundwater levels in the alluvial aquifer, LTA or MTD;
- Vertical gradients between aquifers and rivers;
- Absolute groundwater level predicted in water table aquifer and change in river flux predicted by the regional groundwater model (for rivers); and,
- Absolute groundwater level predicted in water table aquifer and change in water table predicted by the regional groundwater model (for GDEs and PASS).

The review of the additional data and hydrological conceptual model could result in one of the following three scenarios:

1. Site specific monitoring data confirms a lower risk than that predicted by the regional groundwater model, presumably based on the following criteria:
    - Regional groundwater model over-predicts impact;
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed upward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or water table decline predicted by model with the observed flow data confirms low risk.
2. Site specific monitoring data confirms the high risk predicted by the regional groundwater model, based on the following criteria:
    - Confirmed absence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer consistent with regional groundwater model predictions; and,
    - Groundwater flux predicted by model confirmed with observed data.

3. Site specific monitoring data confirms a high risk, based on the following criteria:
    - Confirmed presence of alluvial aquifer;
    - Observed groundwater levels in water table aquifer higher than model water levels;
    - Observed downward gradient exists between LTA and alluvial aquifer; and,
    - Comparison of groundwater flux or watertable flux predicted by regional model with the observed flow data confirms high risk.

If scenario 1 occurs – no further action is required, results presented to Southern Rural Water for consideration

If scenario 2 occurs – it is recommended that the regional groundwater model is used to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for any further action.

If scenario 3 occurs – recommended that a local groundwater model(s) is/are developed for each location to assess magnitude of impact on groundwater levels and any subsequent reductions in baseflow. Results presented to SRW for consideration with regard to requirements for further action.

Table 6.1: Rationale and recommendations for additional monitoring

Area	Why	What is the information gap	Recommended additional monitoring assets
BARWON RIVER CATCHMENT			
Barwon River east branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River east branch and regional groundwater system / outcropping LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing), if there is baseflow contribution from the LTA and if borefield impacts on baseflow are buffered by the presence of alluvial aquifers.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the East Branch near Seven Bridges Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores PASS 2 and 48249 **Additional Surface water monitoring** Install one stream gauge on the East Branch near Seven Bridges Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. **Survey data** Survey elevation of the base of the river near PASS2 to confirm potential for groundwater surface water interaction. Survey existing stream gauges 233214 and 233268 to collect data on surface water level to inform groundwater surface water interactions.
Barwon River west branch	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact	Currently there is limited data to confirm surface water groundwater connection between Barwon River west branch and regional groundwater system / outcropping LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores along the West Branch near Seven Bridges Road or Boundary Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 64237 and 108915. **Additional Surface water monitoring** Install one stream gauge on the West Branch near Boundary Road to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Barwon River downstream of confluence	Rated as high risk as there are particular sections considered to have a possible likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Barwon River downstream of the confluence and the regional groundwater system / MTD. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the MTD.	**Additional Groundwater Monitoring** Install 2 monitoring bores in close proximity to existing bore 82838 along James Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. Ongoing monitoring of existing bores 82838. **Additional Surface water monitoring** Install one stream gauge on the Barwon River downstream of the confluence with Boundary Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
GELLIBRAND CATCHMENT			

Gellibrand River	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between the Gellibrand River and the regional groundwater system / LTA. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores on track off Lardners Road before Meehan Road or tracks of Gravel Pit Road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Gellibrand River (235228) to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals.
Ten Mile Creek	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a significant impact on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm surface water groundwater connection between Ten Mile Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e. gaining/losing) and if there is baseflow contribution from the LTA.	**Additional Groundwater Monitoring** Install 2 monitoring bores close to existing stream gauge to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. Survey the stream bed elevation in the vicinity of the gauge and the bores.
Yahoo	Rated as high risk as there are particular sections considered to have a certain likelihood of connection to the regional groundwater system and modelling indicates a moderate impact	Currently there is limited data to confirm surface water groundwater connection between Yahoo Creek and the regional groundwater system where the LTA outcrops. This data is required to understand the nature of groundwater surface water interaction (i.e.	**Additional Groundwater Monitoring** Install 2 monitoring bores where the LTA outcrops near Gravel Pit road to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow LTA (approximately 30 m deep).

	on baseflow as a result of groundwater extraction. Additional on-ground data is required to validate the predicted impact and inform further actions	gaining/losing) and if there is baseflow contribution from the LTA.	Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Continue monitoring at existing stream gauge. **Survey data** Survey elevation of the base of the river near new bores to confirm potential for groundwater surface water interaction as the existing stream gauge is located too far from the LTA outcrop area.
Vegetation and PASS investigations			
Yeodene	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA).	**Additional Groundwater Monitoring** Install 2 monitoring bores in upper Barongarook Creek catchment to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores in along Colac-Lorne Road, north east of Yeodene, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Surface water monitoring** Re-instate stream gauge on the Barongarook Creek to record all flows (low and high flows) and level. Gauge will need to be monitored for a period of 5 years with readings at minimum daily intervals. Survey the elevation of the creek bed close to the bores and at any gauge locations.

			Additional Vegetation monitoring Establish two vegetation monitoring sites in Barongarook Catchment and north east of Yeodene and monitor vegetation condition and reliance on groundwater.
Deans Marsh	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS. Additional on-ground data is required to validate the predicted impact and inform further actions	Currently there is limited data to confirm the depth to watertable and connection with the regional groundwater system. This data is required to understand the nature of groundwater dependence from the regional groundwater system (MTD or LTA). Vegetation assessments are required to confirm vegetation types and their reliance groundwater.	**Additional Groundwater Monitoring** Install 2 monitoring bores along Bambra Fault near existing bore 82843 to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Install 2 monitoring bores east of Deans Marsh near existing bore 102867, to monitor groundwater levels in the alluvial aquifer (approximately 10 m deep) and the shallow MTD (approximately 30 m deep). Monitoring bores to be installed with a data logger, which should be downloaded on an annual basis or whenever manual reading are taken. Quarterly manual water level readings are also recommended for a minimum period of 5 years. **Additional Vegetation monitoring** Establish two vegetation monitoring sites close to new groundwater bores to confirm vegetation types and their reliance on groundwater and monitor vegetation condition. Establish another vegetation monitoring site close to existing bores 82838, 82840 and 82841.
Gellibrand	Rated as high risk as there are particular sections considered to have a high likelihood of connection to the regional groundwater system and modelling indicates a significant impact on depth to watertable as a result of historic groundwater pumping adversely impacting GDEs & PASS.	Currently there is limited data to confirm the depth to watertable and connection with the LTA. This data is required to understand the nature of groundwater dependence from the LTA.	**Additional Groundwater Monitoring** See recommendations for Gellibrand River **Additional Vegetation monitoring** Establish one vegetation monitoring site close to new groundwater bores to monitor vegetation condition and reliance on groundwater.

	Additional on-ground data is required to validate the predicted impact and inform further actions		

7. References

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SKM, (2001) Barwon Downs Groundwater Flow and Subsidence Modelling Project. Report on the Groundwater Flow Model, Draft D, May 2001. Prepared by Sinclair Knight Merz for Barwon Region Water Authority.

SKM, (2011) Climate Change Modelling for the Barwon Downs Aquifers. Draft 1, May 2011. Prepared by Sinclair Knight Merz for Barwon Region Water Authority.

SKM (2012) Newlingrook Groundwater Investigation - Gellibrand springs assessment. File note to Barwon Water 25 October 2007.

Appendix A. Risk Assessment Framework

The Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (GDEs) (DELWP, 2015) have been used to identify areas of potential high risk that may require further investigations to validate the model results and confirm the presence of high value GDEs. The guidelines have been used to assess the potential risk to vegetation and rivers and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The guidelines outline a risk assessment process involving seven steps:

1. Determine the licence application area and identify high value ecosystems. Determine that the aquifer is unconfined and identify any features within that area, such as river, springs, soaks or terrestrial vegetation containing high value ecosystems. If the aquifer if unconfined and high value ecosystems are identified, go to step 2, otherwise assess the risk as low.

2. Determine the likelihood that the proposed groundwater extraction will interact with the feature.

3. Determine the consequence of the proposed groundwater extraction on the features.

4. Determine the risk to the high value ecosystems dependent on groundwater.

5. Determine how risk will be managed for groundwater licence application with a risk assessment of medium or high.

6. Consult with relevant Catchment Management Authority

7. Make a final decision.

This report is limited to steps 1 through to 5. It is envisaged that Steps 6 and 7 will be undertaken by Southern Rural Water in consultation with DELWP.

During Step 1, all features within the study area were assessed, regardless of whether they were situated where the regional aquifer is unconfined or identified as a high value GDE. The reason for this is that the location of all high value GDEs across the whole study area is not known. Consequently, the guidelines were adapted to understand the potential areas at high risk and allow for a more targeted assessed to identify potential high value GDEs. In addition to this, drawdown from the regional aquifer has the potential to propagate through the overlying hydrogeological units, especially where the overlying aquitard is thin, therefore areas where the aquitard is present were also considered in the first instance.

The Guidelines state that:

- If the risk is low, the groundwater extraction licence application can be approved.

- If the risk is moderate, risk treatment options would be developed to manage risk and the groundwater licence can be approved with conditions.

- If the risk is high, risk treatment options to reduce the risk to medium or decide to accept the risk and fully document the reason, or the groundwater licence application many be refused.

For sites classified as medium and high risk, risk treatment options would be developed.

Areas classified as medium or high risk will require further work to improve the understanding of the local hydrogeological conceptual model and validate the model predictions. The presence of high value GDEs would also need to be confirmed as well as the potential impact of groundwater extraction on the identified GDEs. It is envisaged that any potential further work would be completed before consultation and final decision is made on the groundwater licence. If necessary, triggers levels would be identified for those areas where high value GDEs were identified and a potential impact was predicted. In the context of the Guidelines, this study presents the additional work that would be expected to support a licence determination.

A.1 Risk assessment framework for rivers

The risk posed to rivers as a result of groundwater extraction from the Barwon Downs borefield was assessed using the risk assessment framework outlined in the Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015).

The risk assessment framework as outlined in the Ministerial Guidelines is:

- **Likelihood** of groundwater-surface water interaction defined by either (see Table A.1):
  - The depth to watertable in the regional aquifer OR
  - The time lag until 60% of extraction comes from the river.
- **Consequence** of the proposed groundwater extraction on the river defined by either (see Table A.2):
  - The drawdown in the regional aquifer OR
  - The percentage reduction in low flow.
- **Risk** is considered in terms of low, medium, high risk using the following equation:
  - Likelihood x Consequence = Risk

A.1.1 Likelihood

The likelihood was defined based on a qualitative assessment of the time lag for a potential impact to reach the river or creek. The likelihood of connection to the regional aquifer and aquitard was defined as (see Figure A.1):

- Unlikely – rivers and creeks known to be disconnected (e.g. Dividing Creek)
- Possible – rivers and creeks where they flow over the regional aquitard, on the basis that the aquitard is a low permeability which increases the time lag for impact of groundwater extraction.
- Certain – rivers and creeks where they flow over the regional aquifer, on the basis that the permeability of the aquifer is high so the time lag for potential impact of groundwater extraction will be less.

Figure A.1 shows the spatial representation of the likelihood of river being connected to the regional groundwater system.

Table A.1: Likelihood of rivers being dependent of groundwater (surface flow)

Likelihood	Description	Ministerial Guidelines		Application for this project
		Measure depth to watertable	Measure surface flow	
Unlikely (low)	A disconnected ecosystem	Depth to watertable > 6 m from surface	>12 months' time lag until 60% of extraction comes from river	River known to be disconnected
Possible (moderate)	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface	Between 3 – 12 months' time lag until 60% of extraction comes from river.	River flows over regional aquitard
Certain (high)	A well-connected ecosystem	Depth to watertable < 2 m from surface	<3 months' time lag until 60% of extraction comes from river	River flows over regional aquifer

A.1.2 Consequence

The **consequence** of pumping has been considered using both measures outlines in Table A.2:

1. Percentage reduction in low flows (10^{th} percentile low flow, or low) defined by the change in river flux. The change in river flux represents the difference in river flux between no pumping (Scenario 0) and the pumping scenarios (Scenarios 2 and 3).
2. Drawdown in the aquifer where the aquifer outcrops near the river.

Two consequence measures have been used because there is limited flow data available for many of the creeks, which introduces uncertainty when comparing the reduction in baseflow predicted by the model. Therefore, drawdown in the regional aquifer was used as another measure. The drawdown in the aquifer, where the aquifer outcrops is provided in Figure A.2.

Table A.2: Consequence classifications for streams (drawdown and reduction in baseflow to river)

Consequence	Description	Measure Drawdown (m)	Measure % Low (low) flow
Minor	Proposed extraction impacts on natural or current streamflow are small	Watertable decline of <0.1 m	Less than 1% reduction in the low flow rate
Moderate	Proposed extraction impacts measurably on natural or current streamflow	Watertable decline of 0.1 - 2 m	Between 1% and 10% reduction in the low flow rate
Significant	Proposed extraction impacts significantly on natural or current streamflow	Watertable decline of > 2 m	More than 10% reduction in the low flow rate.

Figure A.1: Likelihood of surface water connection to groundwater

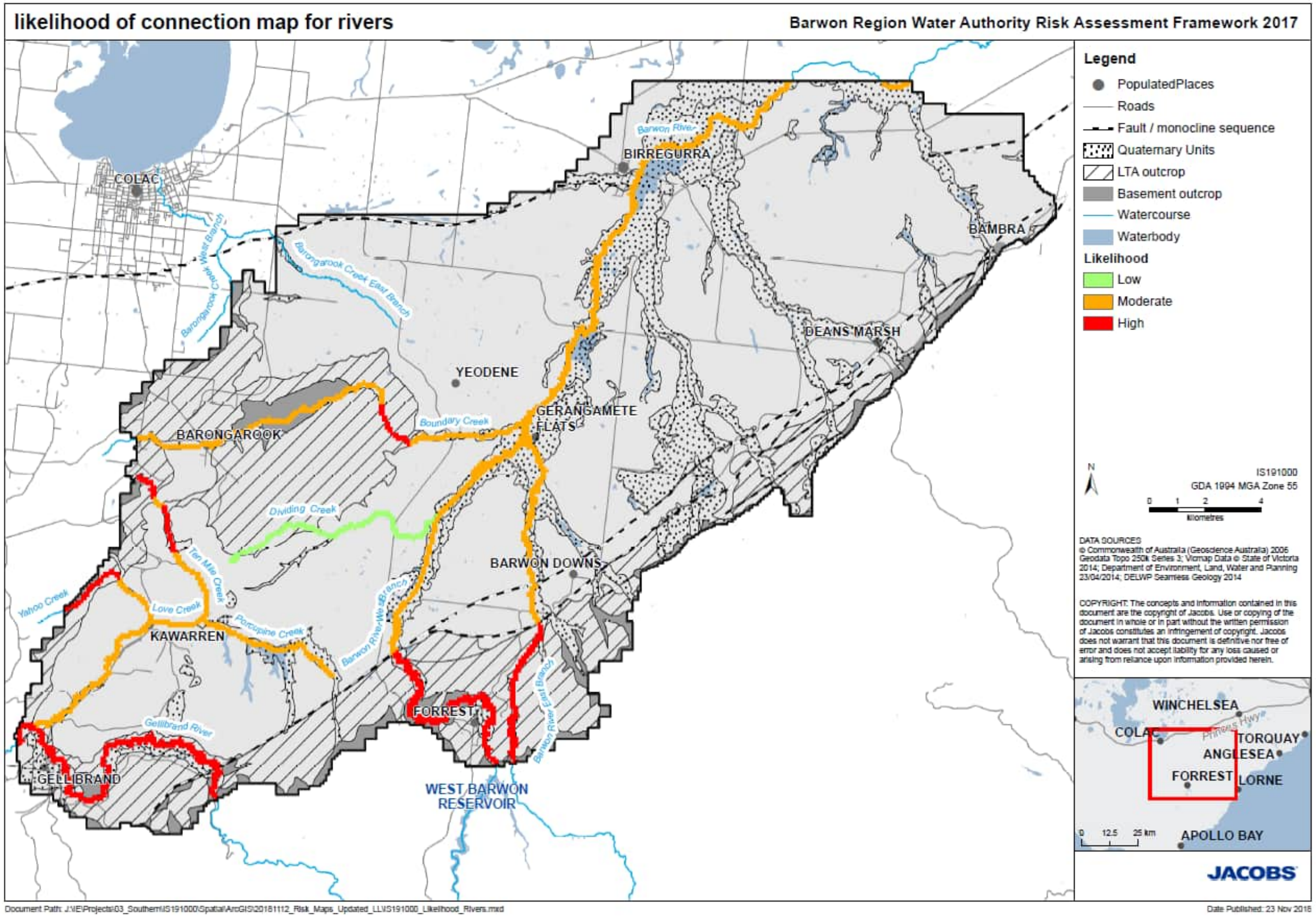
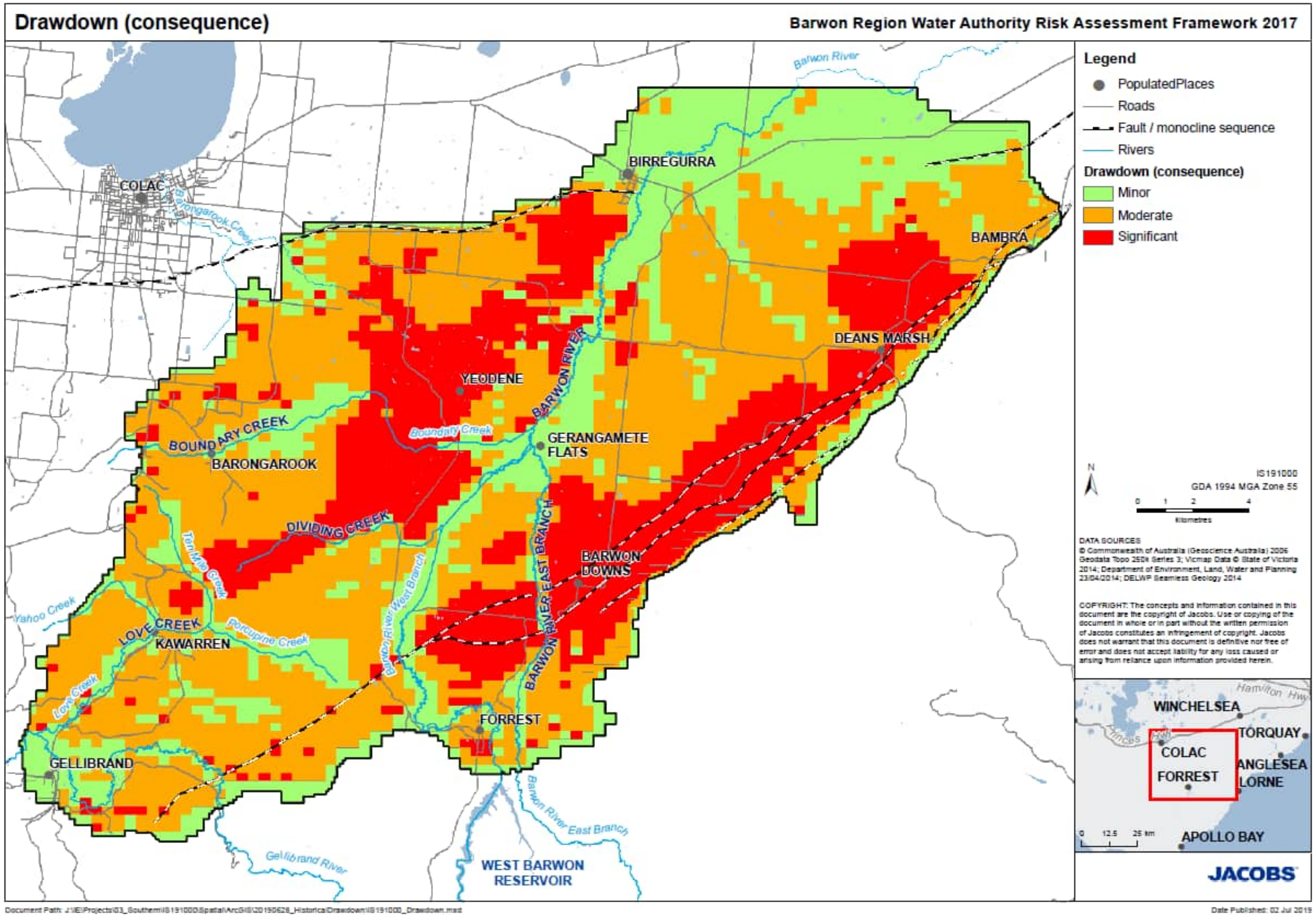


Figure A.2: Drawdown in the model watertable aquifers as a measure of consequence of impact of the borefield



A.1.3 Risk

The risk assessment framework is shown in Figure A.3.

There is limited site specific information along many of creeks and rivers in terms of both streamflow monitoring and groundwater monitoring of both alluvial and regional aquifers. However other site specific studies completed as part of the Technical Works Monitoring Program have highlighted there are physical attributes, such as the presence of a local alluvial quifer and the regional aquitard, that essentially mitigate the risk the drawdown. Consequently, risk of groundwater extraction to creeks and rivers maybe over-estimated.

Figure A.3: Risk assessment framework

Connection between receptor class and groundwater		Reduction in streamflow / Drawdown: Minor	Moderate	Significant
	Unlikely	Low	Low	Medium
	Possible	Low	Medium	High
	Certain	Medium	High	High

A.2 Risk assessment framework for vegetation and PASS

The Ministerial Guidelines have been adopted to assess the potential risk to groundwater dependent vegetation and have also been adapted to assess the risk to potential acid sulfate soils. While these guidelines do not specifically apply to acid sulfate soils, they provide a sound and consistent framework to assess the risk of declining groundwater levels in areas where there are potential acid sulfate soils that are dependent on groundwater to remain saturated.

The risk assessment framework is based on the following:

- **Likelihood** that groundwater will interact with the high value GDE defined by the depth to watertable in the regional aquifer (see Table A.3)
- **Consequence** of the proposed groundwater extraction on the feature defined by the drawdown in the regional aquifer (see Table A.4)
- **Risk** is considered in terms of low, medium, high risk using the following equation:
    - Likelihood x Consequence = Risk

Table A.3: Likelihood of terrestrial vegetation being dependent of groundwater (depth to watertable)

Likelihood	Description	Measure
Unlikely	A disconnected ecosystem	Depth to watertable > 6 m from surface
Possible	A poorly connected ecosystem	Depth to watertable 2 - 6 m from surface
Certain	A well-connected ecosystem	Depth to watertable < 2 m from surface

Table A.4: Consequence (drawdown in watertable level)

Consequence	Description	Measure
Minor	Proposed extraction is small with respect to the aquifer’s ability to supply	Watertable decline of <0.1 m
Moderate	Proposed extraction impacts measurably with respect to the aquifer’s ability to supply	Watertable decline of 0.1 - 2 m
Significant	Proposed extraction impacts is large with respect to the aquifer’s ability to supply	Watertable decline of > 2 m

Figure A.4: Risk assessment framework

Connection between receptor class and groundwater		Groundwater Drawdown: Minor	Moderate	Significant
	Unlikely	Low	Low	Medium
	Possible	Low	Medium	High
	Certain	Medium	High	High

Groundwater Drawdown

Appendix B. Barwon River East Branch Monitoring Data

B.1 Available surface water monitoring data

Flow in the Barwon River East Branch is currently monitored by three surface water gauges – one at Forrest which is located upstream and outside of the model domain (233214); one at Flume located further downstream (233268) and another at the inlet channel which flows to the Wurdee Buloc Reservoir which monitor Barwon Water's diversion channel, not the river itself. The elevation of the surface water gauge is not known, so it is not possible to determine the hydraulic gradient between the surface water and groundwater to inform the nature of the groundwater surface water interactions.

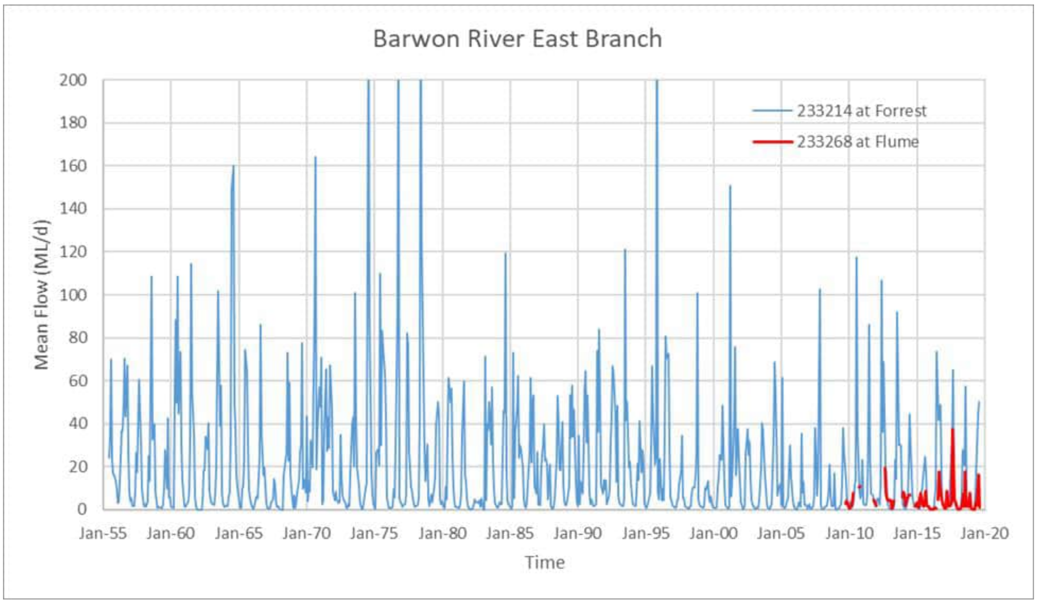
The flow monitoring record at the Forrest and Flume gauges is shown in Figure B.1. This shows that flow is generally higher upstream at Forrest compared to downstream at Flume due to diversions into the Wurdee Boluc Inlet Channel in accordance with the Upper Barwon Bulk Entitlement. The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and at the very edge of the model domain. This gauge measures passing flow, environmental releases and spills from the West Barwon Reservoir.

A summary of the gauges is provided in Table B.1 and the locations are shown in Figure 3-1.

Table B.1: Barwon River East Branch surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233214	(Upstream) Barwon River East Branch at Forrest	June 1955 - Present	Active
233268	(Upstream) East Barwon River at Flume	Jul-2009 to present	Active
233253	(Upstream) East Barwon River at Offtake	May-2002 to Oct-2015	Inactive
233204	(Upstream) Barwon River East Branch at Forrest (Below Tunnel)	Oct-1926 to Oct-1959	Inactive
233703	(Upstream) Wurdiboluc Inlet Channel at East Barwon Offtake	Jul-2000 to present	Active

Figure B.1: Average monthly flow in the Barwon River East Branch



B.2 Available Groundwater monitoring data

There are two active monitoring bores in the vicinity of the Barwon River East Branch – bore 48249 and PASS 2. Another two bores are also present in the area, however these bores are no longer monitored (bores 82848 and 108970). A summary details of these bores are provided in Table B.2 and the locations of the active monitoring bores are shown in Figure 3-1.

The active monitoring bores intersect the confined LTA below the MTD north west of the Bambra Fault. Bore 48249 is located in the confined LTA in the middle of the Bambra Fault zone (between two fault lines) where the MTD confines the LTA. The observed depth to groundwater is around 35 m below ground surface (elevation around 145 mAHD) and groundwater levels have declined approximately 5 m since monitoring commenced in the early 1990s.

Bore PASS 2 is the only bore monitoring the water table aquifer near the Bambra Fault. The observed groundwater level is around 138 mAHD and is marginally artesian at this location. Given the groundwater level in bore 48249 is higher in elevation (145 mAHD), this suggests that the groundwater levels in the watertable aquifer could be supported by an upward gradient from the LTA.

Table B.2: Barwon River East Branch groundwater monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
48249	LTA	136	Oct-1982 - Aug-2019	Active
82848	LTA	353	Jul-1985 - May-1997	Inactive
108970	Not known	30	Aug-1986 - Nov-1988	Inactive
PASS 2	Quaternary Alluvium	9.8	Mar-2015 – Jun-2016	Active

B.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores with long and consistent monitoring trends. The observed and modelled groundwater levels for bores located close to the Barwon River East Branch are outlined below.

East Branch of the Barwon River:

- Bore 48249 monitors the LTA at 136 m depth. The model estimates that the groundwater level in the LTA at this location is influenced by groundwater pumping more than observed and that levels are up to 10 meters lower than observed. In this area the model is over-estimating the drawdown.

- Bore PASS 2 was installed recently and is less than 10 m deep. The observed groundwater level is slightly artesian in this bore (Jacobs, 2017b). Based on the limited observed water levels, the model appears to be representing the groundwater level in the water table aquifer reasonably well at this location.

The groundwater model estimates the groundwater level is around 140 mAHD in both PASS2 and 48249. However, the observed groundwater level is around 137 mAHD in the shallow PASS 2 bore and 145 mAHD in the deeper bore (48249). This indicates there is an upward gradient in the LTA at this location, generating groundwater flow from the LTA to the overlying hydraulic units (MTD and alluvial aquifer) and potentially the Barwon River East Branch of the Barwon River. The model may be over-predicting drawdown and hence risk in this area.

Figure B.2: Groundwater hydrograph – bore 48249

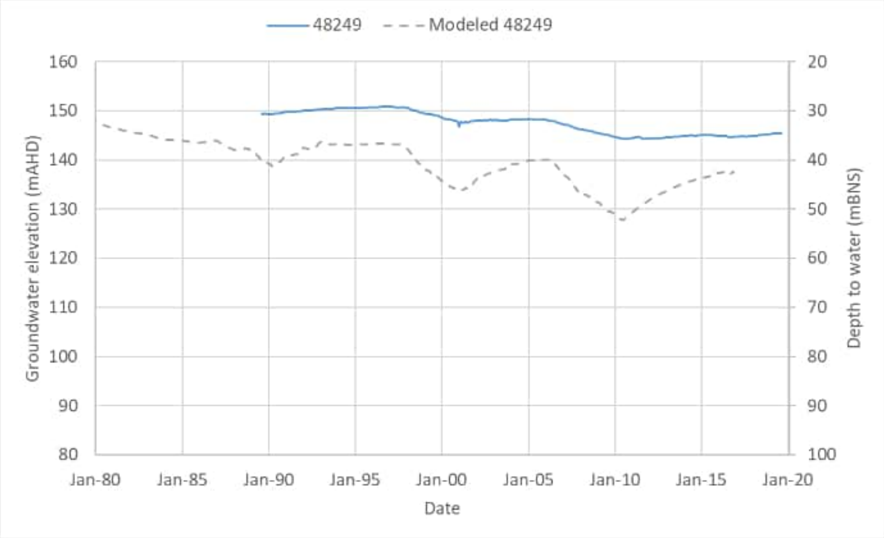
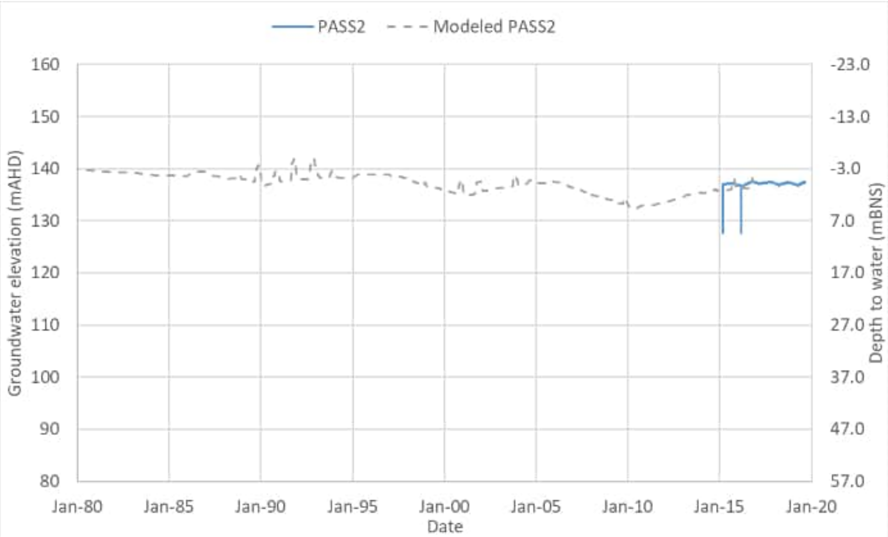


Figure B.3: Groundwater hydrograph – bore PASS 2



Appendix C. Barwon River West Branch Monitoring Data

C.1 Available surface water monitoring data

The West Branch was historically monitored by a gauge at Forrest, however monitoring ceased when the reservoir was constructed. Flow in the West Branch is monitored by one active surface water gauge located at the compensation weir spillway (233245) and the very edge of the model domain.

A summary of the gauges is provided in Table C.1 and the locations are shown in Figure 3-1.

Table C.1: Barwon River West Branch surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233203	(Upstream) Barwon River West Branch at Forrest	Oct-1926 to May-1965	Inactive (no data)
233245	(Upstream) West Barwon River at Compensation Weir Spillway	October 2000 - Present	Active
233244	(Reservoir) West Barwon River at West Barwon Reservoir H.G.	Nov-2001 to present	Active (no data)

C.2 Available groundwater monitoring data

There are two active monitoring bores in the vicinity of the Barwon River West Branch – bores 108915 and 64237. These bores both intersect the confined LTA below the MTD north west of the Bambra Fault.

A summary of the bores is provided in Table C.2 and their locations are shown in Figure 3-1.

Bore 108915 is 209 m deep and is located close to the Bambra Fault. The depth to watertable is this bore is approximately 35 m depth and has declined around 5 m over the monitoring period. The waterlevel in the overlying MTD and alluvial aquifer is not known, so the potential interactions between the regional and local groundwater systems and the West Branch is not clear.

Bore 64237 is located in the centre of the graben and is over 400 m deep. Groundwater levels in the LTA were artesian (10 m above ground surface) prior to pumping from Barwon Downs. The current groundwater level is slightly artesian (around 1 m above ground surface) which suggests there is approximately 10 m residual drawdown in the LTA at this location. The waterlevel in the LTA is heavily influenced by pumping.

There are no bores on the south east side of the Bambra Fault where the LTA outcrops.

Table C.2: Barwon River East groundwater monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
64237	LTA	422	Sep-1985 - Aug-2019	Active
108915	LTA	209	May-1987 - Aug-2019	Active

C.3 Interpretation of groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores with long and consistent monitoring trends. The observed and modelled groundwater levels for bores located close to the Barwon River West Branch are outlined below.

Barwon River West Branch:

- Figure C.1 shows the model estimates the groundwater levels in bore 64237 reasonably well, however in this case the observed groundwater levels are influenced groundwater pumping and the model underestimates the drawdown in the LTA in response to pumping in this location.

- Groundwater level in the model for bore 108915 is slightly higher than the observed groundwater level (see Figure C.2), although the trend appears to be accurate.

- There is an upward gradient in the LTA at this location from the deeper bore (64237) to the shallower bore (108915) and the groundwater model provides a reasonable representation of this.

In summary, a high risk is predicted in this area, where the model indicates a decline in groundwater levels from 148 to 138 mAHD, while the observed groundwater levels is currently around 145 mAHD. To confirm the vertical hydraulic gradients in the vicinity of the high risk areas, it is recommended that river bed elevation be surveyed and ongoing monitoring of existing bores to confirm groundwater levels in relation to the river in this location.

Figure C.1: Groundwater hydrograph – bore 64237

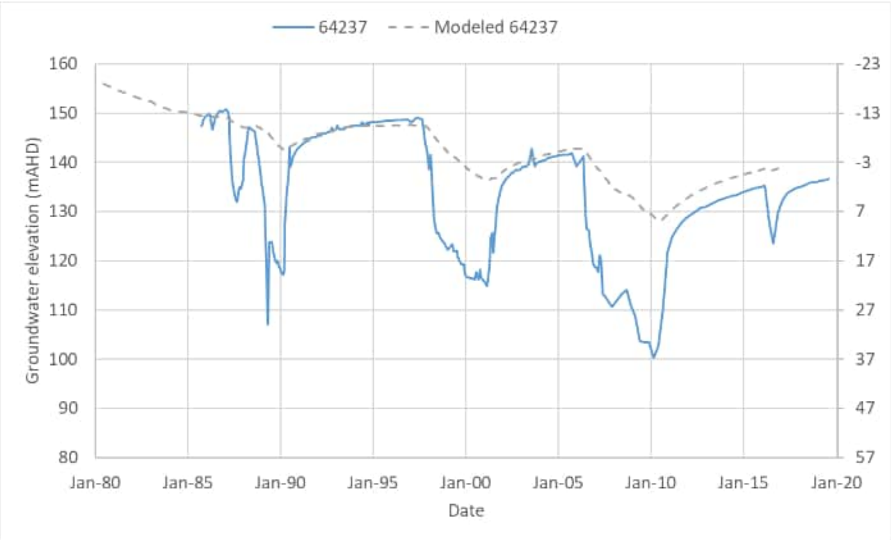
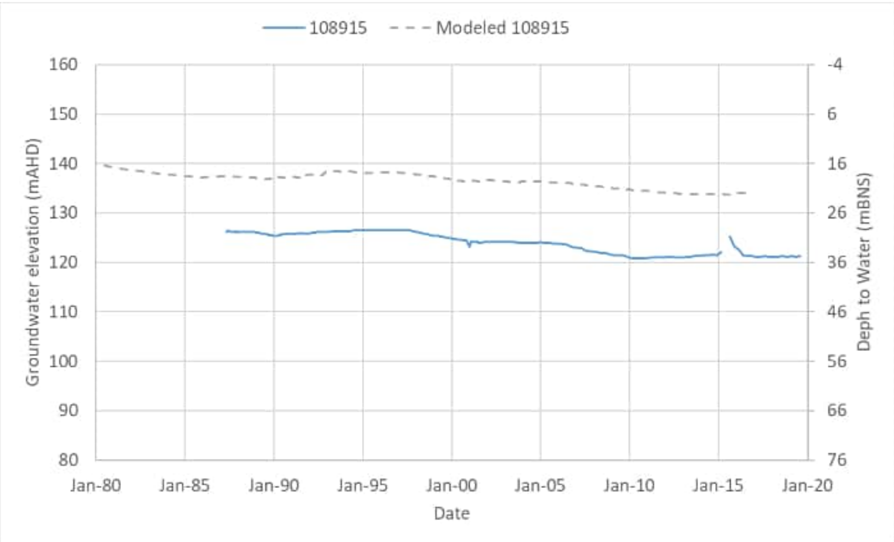


Figure C.2: Groundwater hydrograph – bore 108915



Appendix D. Barwon River downstream of Boundary Creek

D.1 Available surface water data

There is currently only one surface water gauge located downstream and near the edge of the model domain (23324).

The flow monitoring record at the Ricketts Marsh gauge is shown in Figure D.1, which highlights that there has been a decline in flow over the monitoring record (since 1971). Flow in the 1970s was often recorded above 1000 ML/day during the winter months, however since the mid 1990s, flow has only exceeded 1000 ML/day on one occasion (during the winter 2013). Very low flows (10 ML/day) were often recorded during summer months, although again since mid 1990s, these low flow periods appear to be pronounced and longer. It should be noted that this is consistent with rainfall in the region. Rainfall was typically above average between 1970 and 1995 before the Millennium Drought commenced in mid to late 1990s.

The surface water elevation at this location is shown in Figure D.2. This indicates the surface water level typically ranges between 97 and 98 mAHD at this location. The shift in surface water levels in the late 1970s is likely due to the gauge being replaced and re-surveyed.

A summary of the gauges is provided in Table D.1 and the locations are shown in Figure 3-2.

Table D.1: Barwon River Downstream of Confluence surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
233224	Barwon river at Ricketts Marsh	1971 to 2019	Active

Figure D.1: Monthly mean flow - 233224 at Rickets Marsh

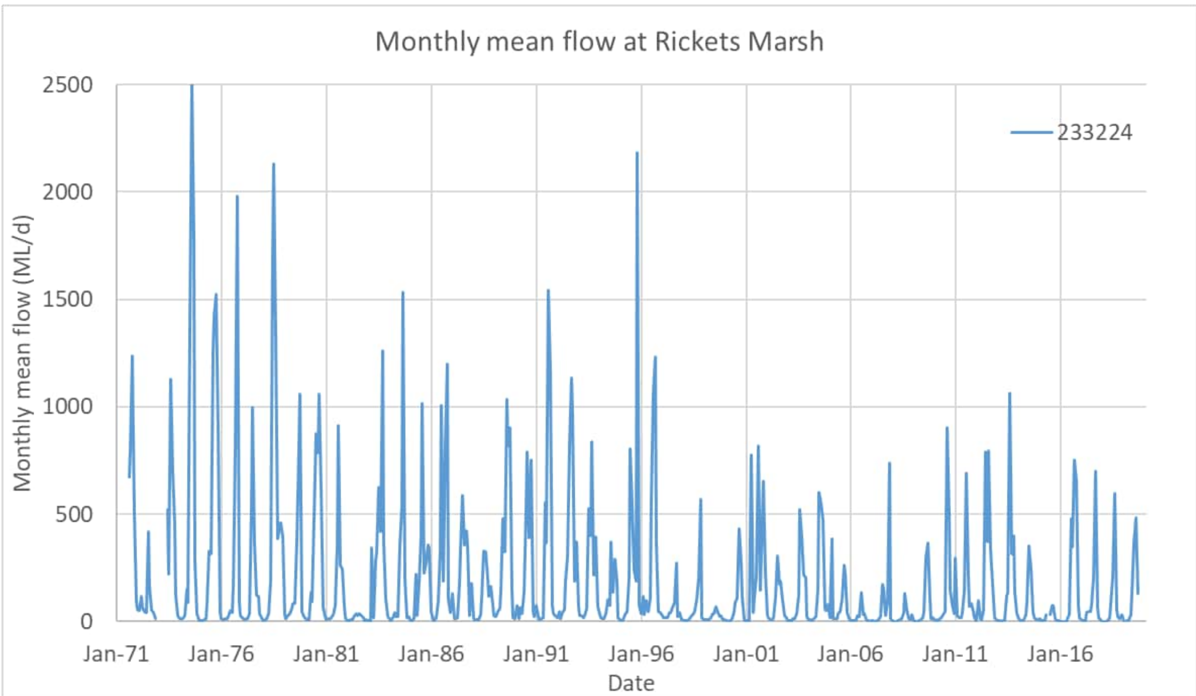
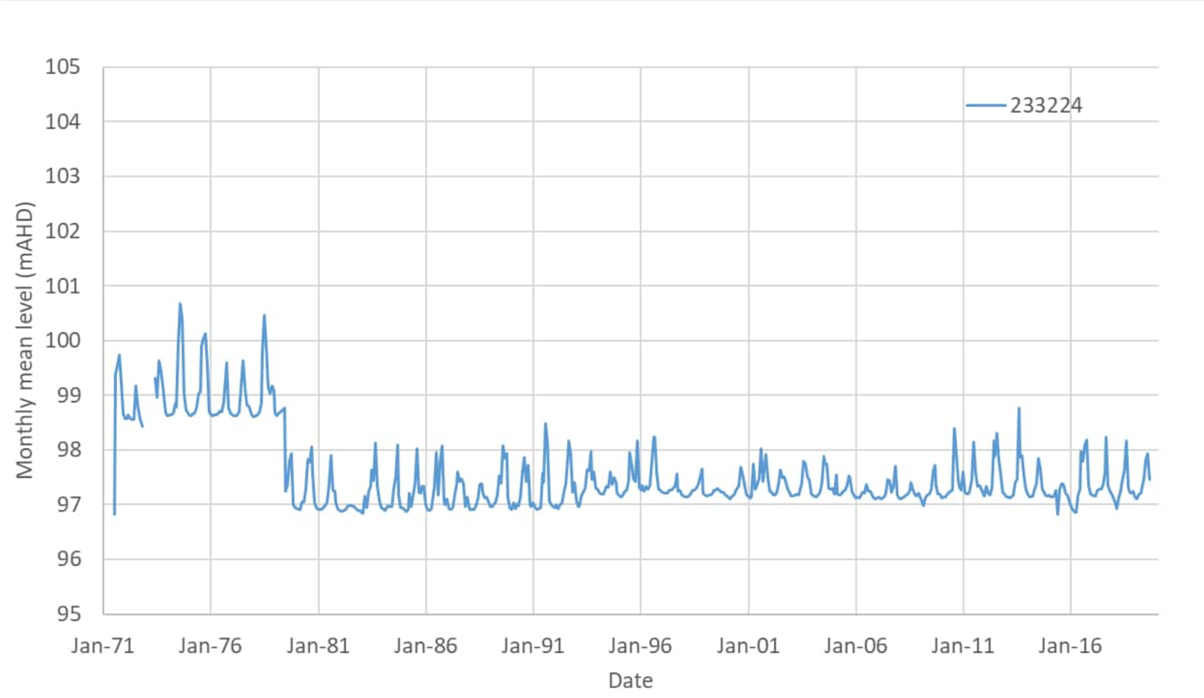


Figure D.2: Monthly mean level - 233224 at Rickets Marsh



D.2 Available groundwater monitoring data

There are five active monitoring bores in the vicinity of Barwon River Downstream of confluence – three bores are located to the east of Gerangmete Flats (82838, 82840 and 82841) and two located downstream (109135 and 102868). Another bore is located further downstream; however it is no longer active (82814).

A summary of the bores is provided in Table D.2 and hydrographs are shown in **Error! Reference source not found.** to Figure D.7. The bores monitor the regional aquifer (LTA) at depths ranging between 233 and 422 m depth. Bores 82838, 82840 and 82841 are located in the centre of graben at different depths, so can be used to inform the groundwater trends in different levels in the LTA. Groundwater levels in the deeper bores (82840 and 82841) are strongly influenced by pumping, while the shallower bore (82838) shows a stronger seasonal response and much less drawdown. The most recent readings from the shallow bore (82838) indicate that the condition of the bore could be compromised and should be assessed.

Groundwater levels in many of the deeper LTA bores were artesian prior to pumping, and now currently 10-20 m below ground level. With the exception of bore 109135 and 82838, water levels are 10-20 meters lower than the pre-pumping groundwater level. Both these bores are shallower bores and 109315 is also located further from the bore field.

Additional shallow bores are recommended along the Barwon River downstream of the confluence to confirm the groundwater levels in the alluvial aquifer and thickness.

Table D.2: Barwon River Downstream of confluence monitoring bores

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
82838	MTD	285.1	1974 - 2019	Active
82840	LTA	610.8	1973 - 2019	Active
82841	LTA	484.6	1974 - 2019	Active
82844	LTA	233.0	1985 - 2007	Inactive

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
109135	LTA	237.0	1986 - 2019	Active
102868	LTA	577.0	1984 - 2019	Active
50056	NKN	336.2	1986 - 1992	Inactive

D.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores and the observed and modelled groundwater levels is shown in Figure D.3 to Figure D.7. The groundwater level in the LTA in the centre of the model is typically underestimated in the groundwater model. For example:

- Model estimates the groundwater levels in bore 82838 are lower than the observed water level. Model also estimates impacts from pumping, however observed data is more influenced by seasonal variations.
- Groundwater level in the model for bore 82840 is generally lower than the observed groundwater level. However the model predicts less drawdown than observed at this location. The trend is reasonably accurate.
- Groundwater level in the model for bore 82841 is lower than the observed groundwater level. The predicted drawdown and the trends appear accurate.
- Model estimates the groundwater levels in bore 109135 are lower than observed groundwater level. The trend appears to be accurate until most recent predictions, where a significant recovery in water level has been observed at the bore, although there has been a sharp decline in waterlevels in 2019 and the reason for this is not known. Given observed groundwater levels are much higher than modelled, this is likely to influence the drawdown predictions and risk assessment.
- Groundwater level in the model for bore 102868 is lower than the observed groundwater level. The modelled trends appear accurate.
- There is a downward gradient in the LTA in the centre of the graben. Its likely that groundwater levels would have been similar at different levels in the aquifer prior to groundwater pumping and pumping and drought have induced a downward gradient in the aquifer.

In summary, although the model under predicts groundwater levels, the calibration appears to be fairly accurate in the LTA. Given observed groundwater levels are higher than modelled, this is likely to impact on the drawdown estimates in the model and subsequent risk assessment.

Figure D.3: Groundwater hydrograph – bore 82838

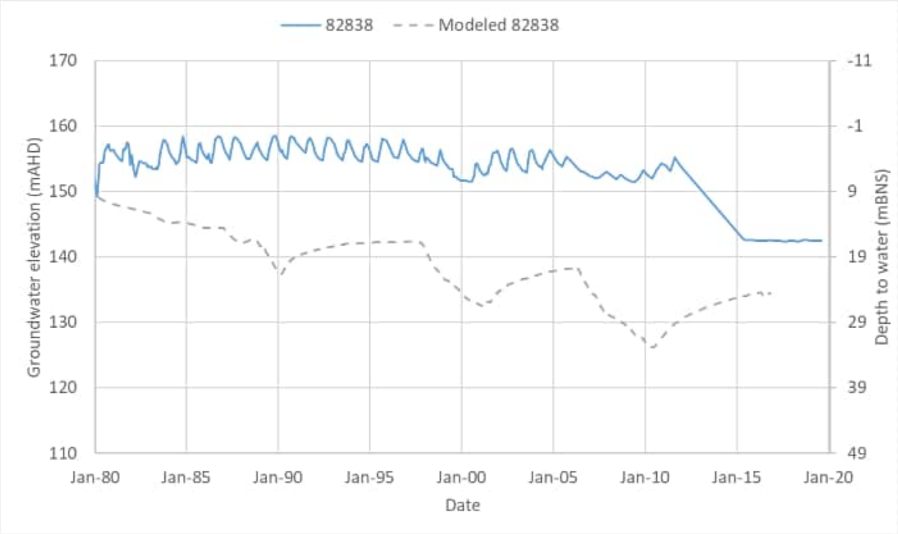


Figure D.4: Groundwater hydrograph – bore 82840

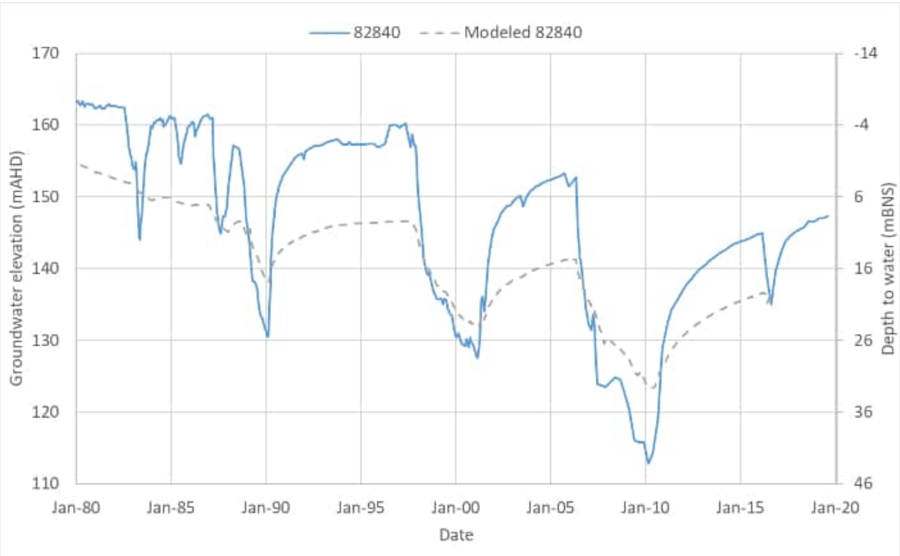


Figure D.5: Groundwater hydrograph – bore 82841

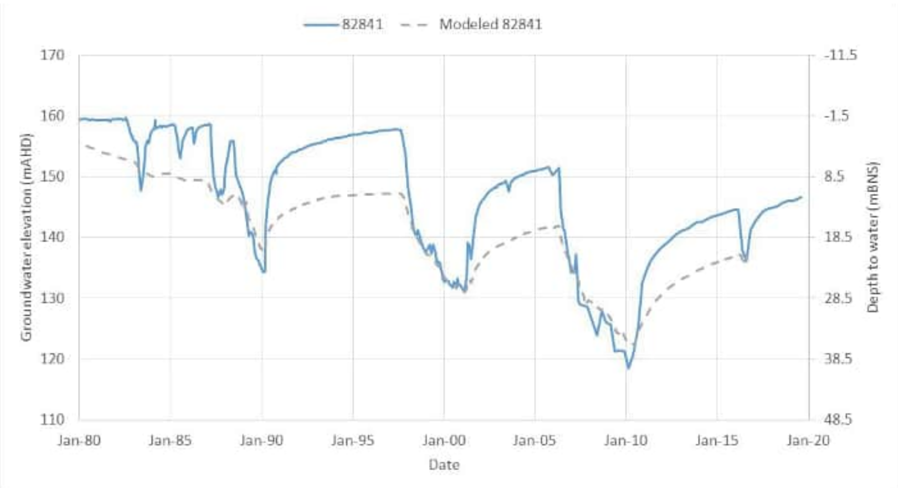


Figure D.6: Groundwater hydrograph – bore 82844

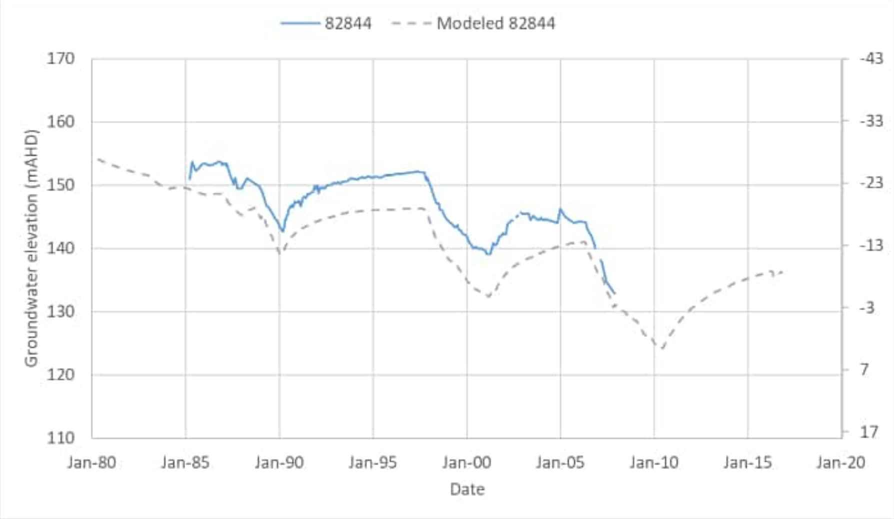
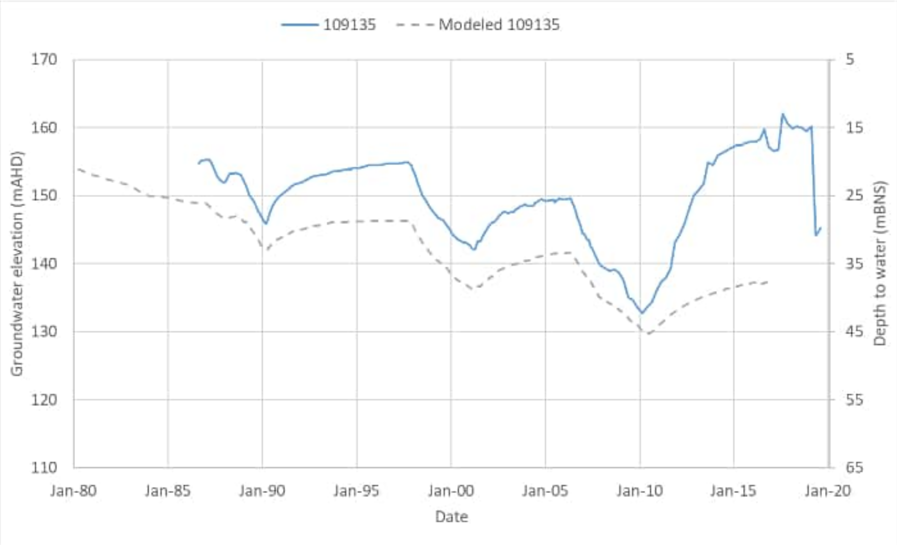


Figure D.7: Groundwater hydrograph – bore 109135



Appendix E. Gellibrand River

E.1 Surface water monitoring data

The Gellibrand River is monitored by two active surface water gauges 235227 (Bunkers Hill) and 235202 (Upper Gellibrand) which are located upstream and downstream of the model domain. There is one surface water gauge located in the model domain (235228 at Gellibrand), however monitoring ceased in 1989. The location of these gauges is shown in Figure 4-1.

The flow in the Upper Gellibrand is typically up to 250 ML/day during high flow periods, with short periods of very low flow (<1 ML/day) during the summer months (see Figure E.1). In contrast, the flow downstream at Bunkers Hill often exceeds 750 ML/day and appears to have a reasonable baseflow maintaining flow during the summer months. The river is considered to be a key discharge area for the LTA, and Loves Creek and its associated tributaries also join the Gellibrand between the two gauges.

There is no information on the elevation of the surface water at Upper Gellibrand (235202), however there is elevation data at the downstream gauge at Bunkers Hill shown in Figure E.2. The elevation of the surface water ranges between 50 and 51 mAHD at this location, which is downstream of the model domain.

Table E.1: Gellibrand River surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235202	Gellibrand River at Upper Gellibrand	1949 to 2019	Active
235228	Gellibrand River at Gellibrand	1970 to 1989	Inactive
235227	Gellibrand River at Bunkers Hill	1970 to 2019	Active

Figure E.1: Monthly mean flow Gellibrand River

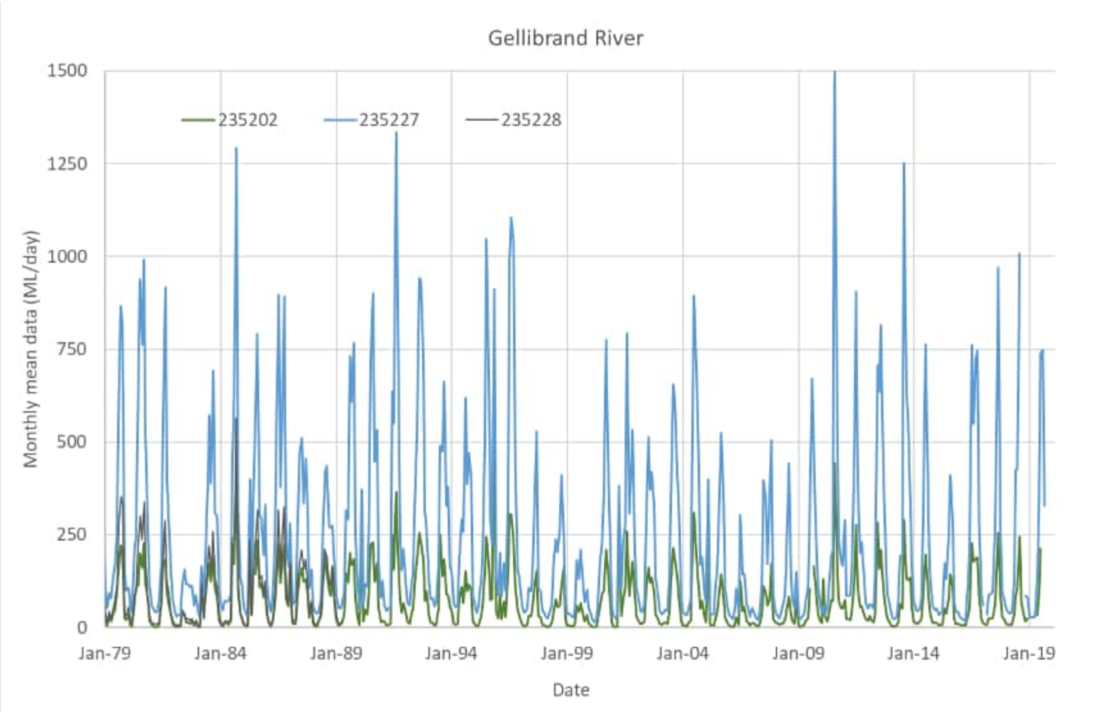
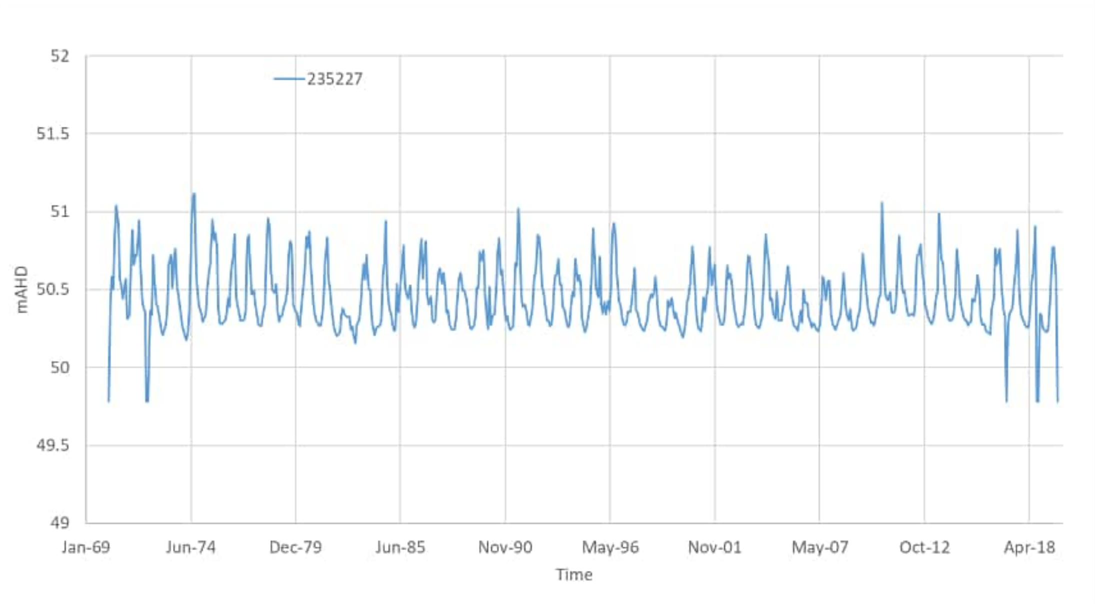


Figure E.2: Monthly mean level – 235227 Gellibrand River at Bunkers Hill



E.2 Groundwater monitoring data

Figure 4-1 shows all the groundwater monitoring bores in the areas. The majority of the existing groundwater monitoring bores are located south of the Gellibrand River where the effects of the bore field are reduced. Bores located on the northern side of the river were reviewed to determine if impacts from groundwater pumping have been observed.

Only one groundwater bore is currently monitored on the northern side of the river (108907) and this is located at some distance from the Gellibrand River. Monitoring has ceased in the other groundwater bores.

There are no existing bores located on the north side of the river in the area of high risk identified. The closest existing bores located along the northern side near this section of the Gellibrand River are listed in Table C.2 and are described below.

- Bores 108958, 108959, 108960 and 108961 have no information on depth, formation monitored or groundwater levels.
- Bores 108916, 108917, 108918, 108919 and 108920 are all shallow bores between 15 and 20 meters deep and are likely to be screened in the shallow regional aquifer (LTA).
- Bores 108898 and 108899 are deeper bores also screened the regional aquifer (LTA).

Bores 108917 and 108919 show steady seasonal fluctuations in the shallow LTA, with groundwater levels around 78 mAHD.

Bore 108899 is slightly deeper in the LTA (34 m deep) and shows a similar steady seasonal trend with waterlevels around 82 mAHD, indicating an upward gradient. Bore 108919 intersects the LTA at a depth of 272 mAHD. The groundwater level trend shows a similar steady seasonal trend over the monitoring record, with groundwater levels at around 82 mAHD, further supporting that there is an upward hydraulic gradient from the LTA to the shallow aquifer.

Groundwater levels in these bores do not appear to be influenced by pumping from Barwon Downs.

Table E.2: Groundwater bores on the northern side of the Gellibrand River

Bore	Aquifer monitored	Bore depth	Monitoring record	Current status
108916	Shallow LTA*	14.9	1981 to 2011	Inactive
108917	Shallow LTA*	15.0	1981 to 2013	Inactive
108918	Shallow LTA*	15.3	1981 to 1994	Inactive
108919	Shallow LTA*	16.6	1981 to 2011	Inactive
108920	Shallow LTA*	18.0	1981 to 1998	Inactive
108898	LTA	272.0	1981 to 2013	Inactive
108899	LTA	34.0	1981 to 2013	Inactive
108958	Unknown	N/A	1979 to 1985	Inactive
108959	Unknown	N/A	1979 to 1983	Inactive
108960	Unknown	N/A	1979 to 1985	Inactive
108961	Unknown	N/A	1979 to 1985	Inactive

E.3 Interpretation of the groundwater model results

The hydrographs with observed monitoring data and the water level predicted by the calibration model are shown in Figure E.3 to Figure E.6.

Monitoring ceased in 2014 for bores 108917, 108919 and 108899, so while they are not currently monitored, a reasonable groundwater trend is available. Bores 1089717 and 108919 both intersect the shallow LTA and show a steady seasonal trend over the monitoring record (1991 – 2014). Groundwater levels are 78 mAHD at this location and the model represents this reasonably well.

Bore 108899 is slightly deeper at 34 m depth and was monitored between 1981 and 2014. The groundwater level is around 82 mAHD, which suggests there is an upward gradient in the vicinity when compared to bores 108917 and 108918. The water level in the groundwater model is less than observed and more consistent with bores 108917 and 108918 (around 78 mAHD). The observed upward gradient is not represented in the groundwater model and this is likely to influence the representation of the groundwater baseflow to the Gellibrand River in the model.

Figure E.3: Groundwater hydrograph – bore 108917

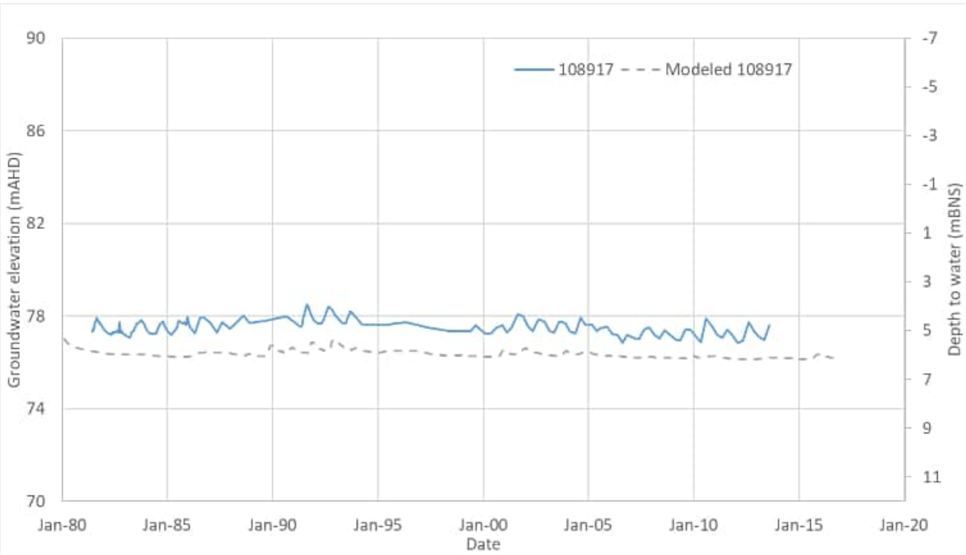


Figure E.4: Groundwater hydrograph – bore 108919

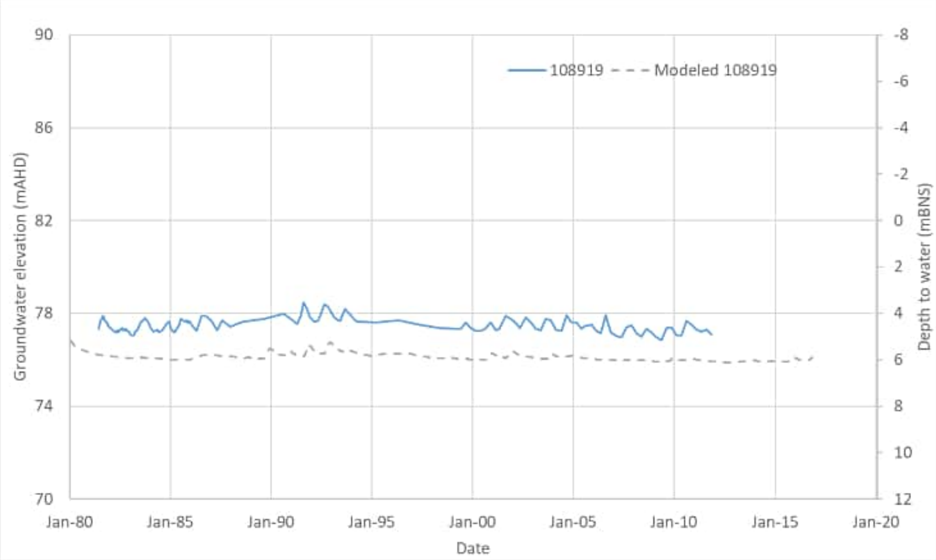


Figure E.5: Groundwater hydrograph – bore 108899

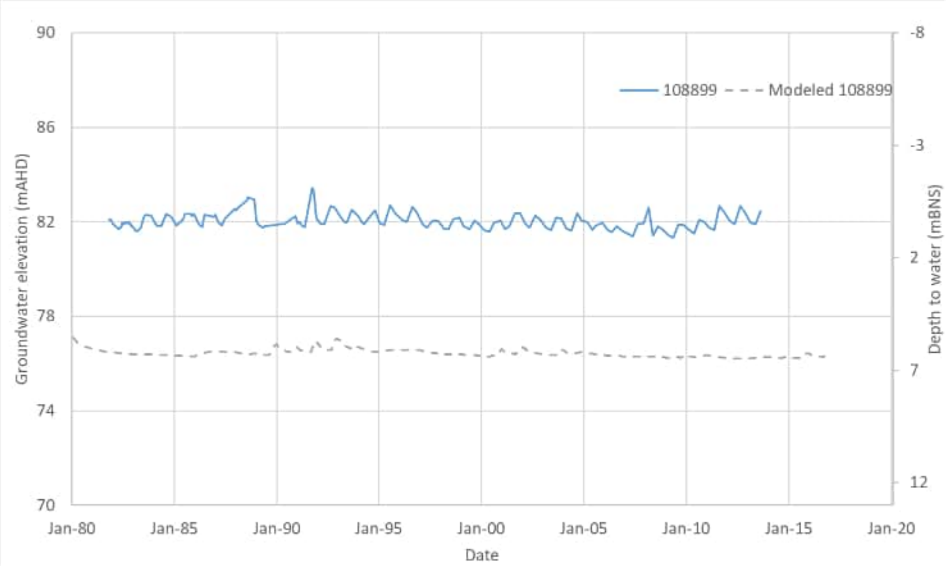
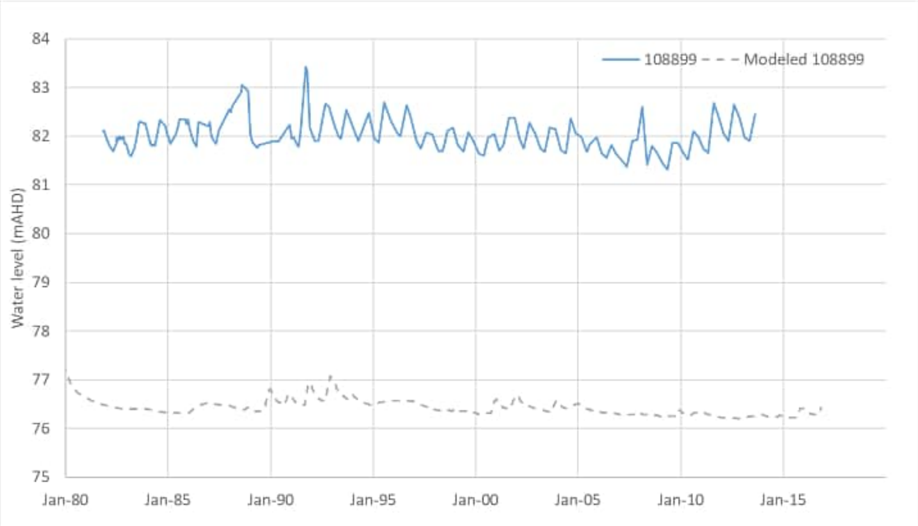


Figure E.6: Groundwater hydrograph – bore 108899



Appendix F. Ten Mile Creek

F.1 Surface water monitoring data

There is one active surface water gauge (235239) monitoring flow in Ten Mile Creek, however the flow record is intermittent. Monitoring commenced in 1985 and continued until 1995. The gauge was monitored again in 2008-2009, and has recommenced again in 2018.

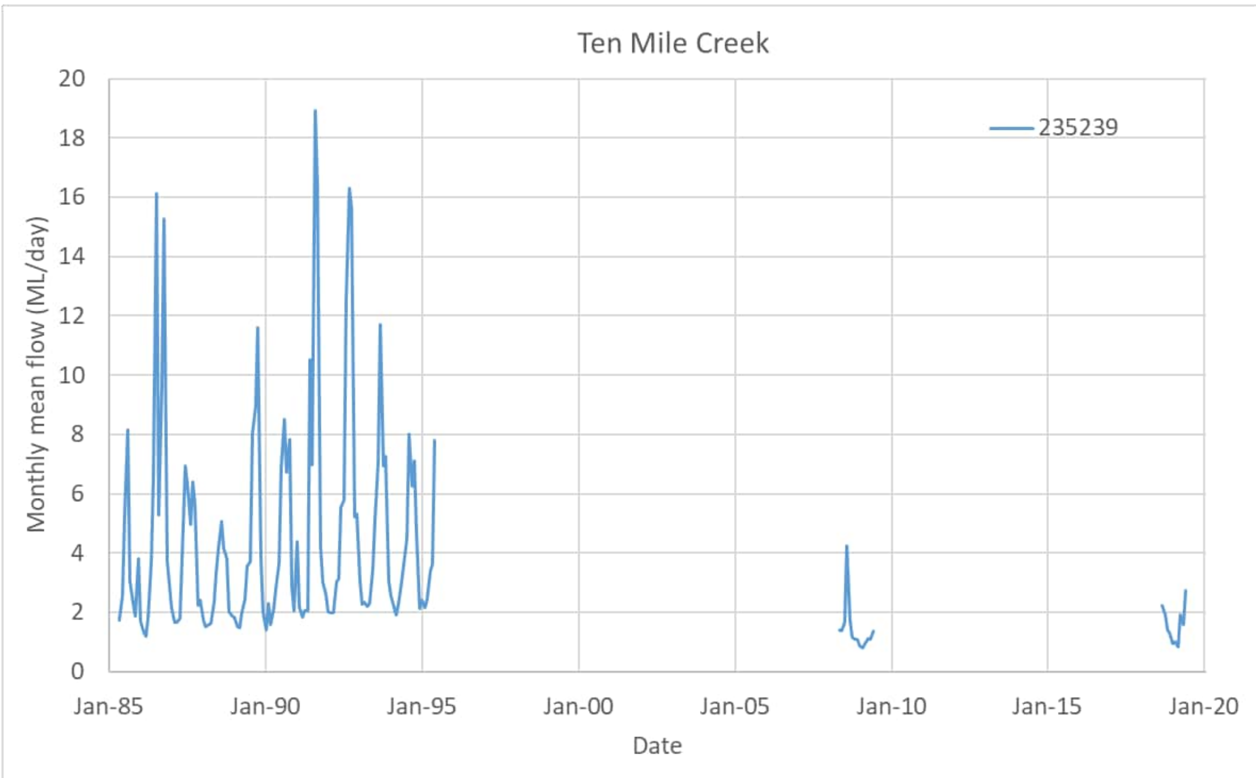
The flow monitoring record at the Kawarren gauge is shown in Figure F.1. This shows that flow during the 1980s and 1990s was typically up to 15-20 ML/day during high flows and during low flow periods flow was around 1-2 ML/day during the summer months. Intermittent monitoring periods since the mid-1990s show a very different flow regime, with flow not recorded above 5 ML/day during the winter months of 2008 or 2019.

A summary of the gauges is provided in Table F.1 and the locations are shown in Figure 4-6. The gauge is not surveyed so the surface water elevation is not known.

Table F.1: Ten Mile Creek surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235239	Ten Mile Creek at Kawarren	1985 – 1995, 2008 – 2009, 2018 to present	Active
235241	Porcupine Creek at Kawarren	1986 to 2009	Inactive

Figure F.1: Monthly mean flow – 235239 at Ten Mile Creek



F.2 Groundwater monitoring data

There are eight active monitoring bores in the vicinity of Ten Mile Creek (see Table F.2). Bores 113705 and 113706 monitor the LTA at different depths (174 m and 90 m respectively). There is a 10 meter difference between the groundwater levels in the bores, highlighting there is an upward gradient in the LTA at this location. Groundwater levels in both bores show a slight downward trend over the monitoring record (1985 – 2019).

Bores 114168 and 114169 also monitor the LTA at different depths (182 m and 82 m respectively), in the middle reaches of Ten Mile Creek. The groundwater levels in these bores are similar, although there is generally a slight upward gradient, but less pronounced compared to bores 113705/113706. Groundwater levels in these bores show a rising trend since monitoring commenced in mid 1990s. These groundwater trends suggest that groundwater levels at this location have not been significantly influenced by climate or pumping.

Bore 48003 monitors the LTA east of Ten Mile Creek, while bores 47990 and 47986 monitor the LTA west of Ten Mile Creek. The groundwater levels are similar and all show a declining trend over the monitoring period with some seasonal fluctuations in bores 48003 and 47990.

Table F.2: Ten Mile Creek groundwater monitoring bores

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
TB14	QA	11.6	2014 to 2015	Inactive
47986	LTA	296.0	1982 to 2019	Active
47990	LTA	153.0	1983 to 2019	Active
48003	LTA	381.4	1987 to 2019	Active
113705	LTA	174.0	1993 to 2019	Active
113706	LTA	90.0	1993 to 2019	Active
114168	LTA	180	1993 to 2016	Inactive
114169	LTA	82.0	1993 to 2019	Active

F.3 Interpretation of the groundwater model results

The groundwater model was calibrated using observed groundwater levels from selected monitoring bores and the observed and modelled groundwater levels are shown in Figure F.2 to Figure F.9. The groundwater level in the LTA in this area is typically underestimated in the groundwater model. The model predicts one groundwater level for the whole LTA aquifer, which is estimate at the centre of the layer. Bores nested in the LTA at different depths highlight that there is upward gradient present in the LTA that is not replicated in the model. This means the groundwater model could be over estimating the impact from pumping on groundwater levels in these areas.

For example, for bores 113705 and 113706, the groundwater levels are 232 and 218 mAHD respectively, and the groundwater model estimates it to be 218 mAHD. The groundwater level is under-estimated and the upward gradient cannot be represented in the model as the LTA is a single layer. For bores 114168 and 114169, the groundwater level is reasonably well represented, however the model indicates the water level trend should be declining instead of the while rising groundwater trend that has been recorded.

Figure F.2: Groundwater hydrograph – bore 113705

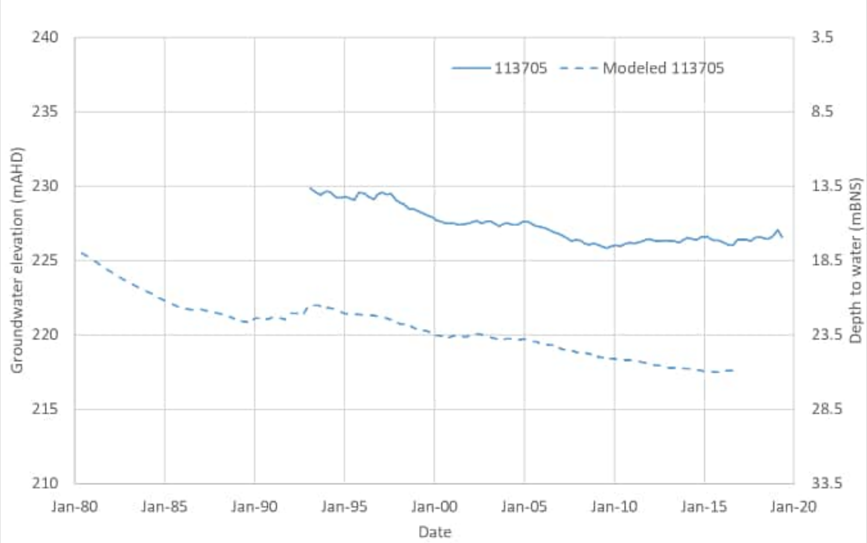


Figure F.3: Groundwater hydrograph – bore 113706

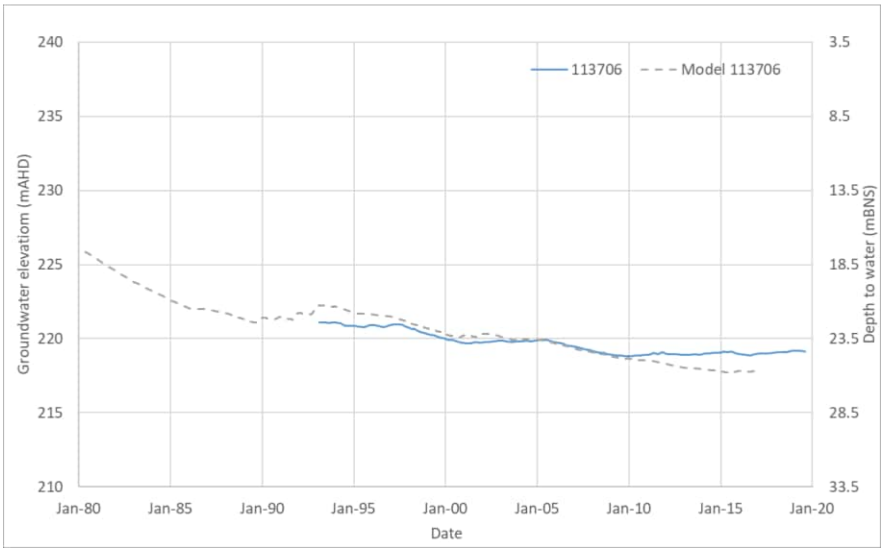


Figure F.4: Groundwater hydrograph – bore 114168

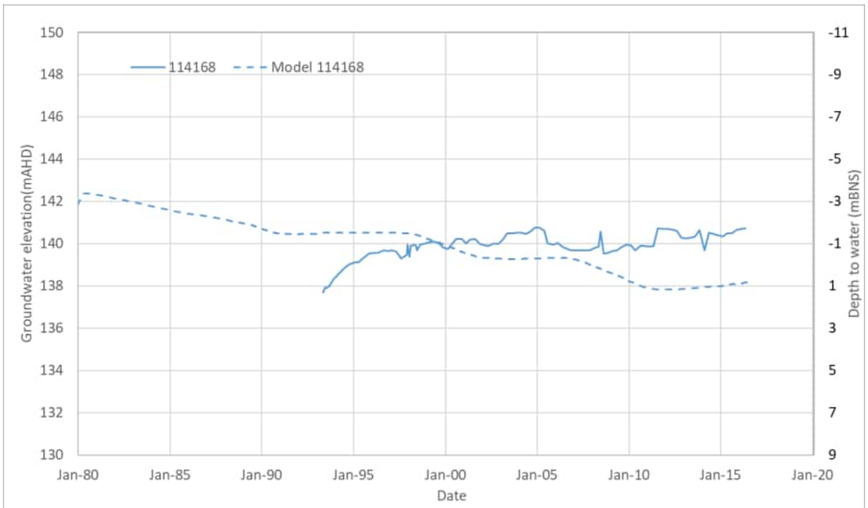


Figure F.5: Groundwater hydrograph – bore 114169

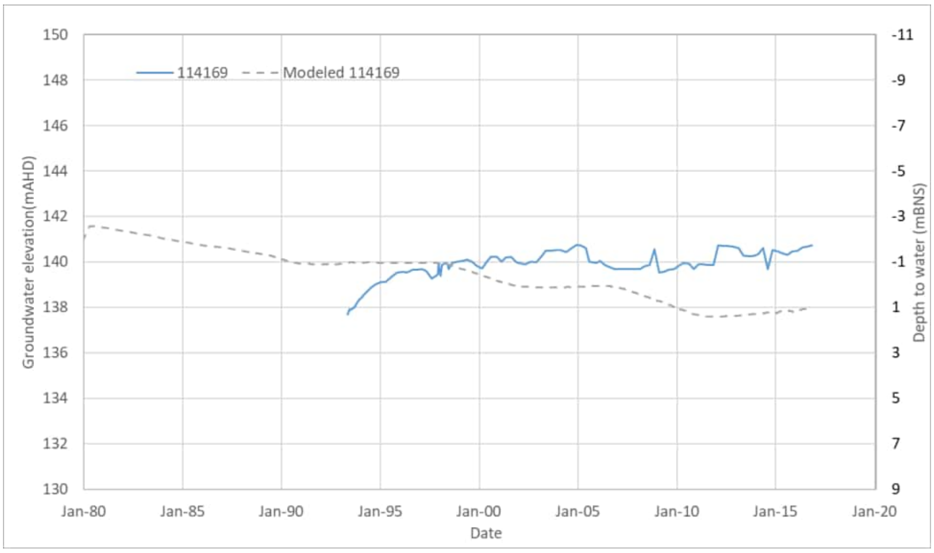


Figure F.6: Groundwater hydrograph – bore 47986

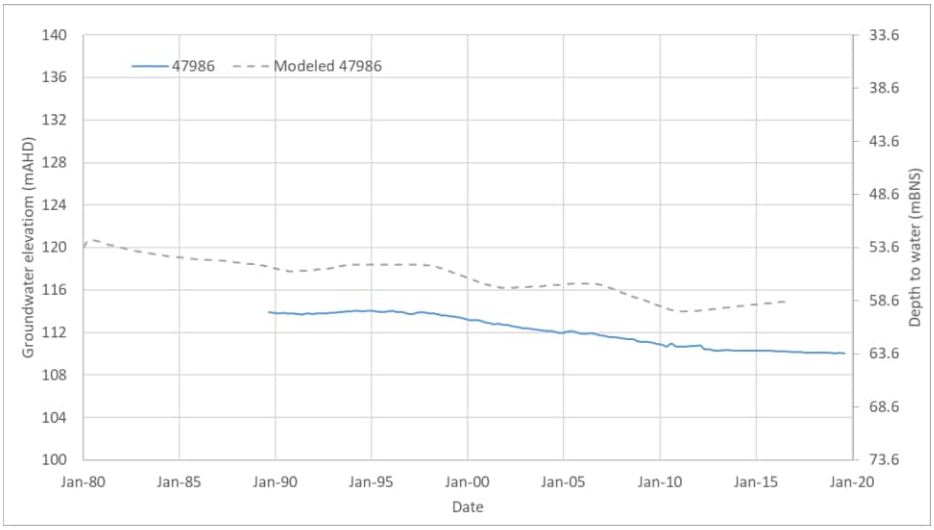


Figure F.7: Groundwater hydrograph – bore 47990

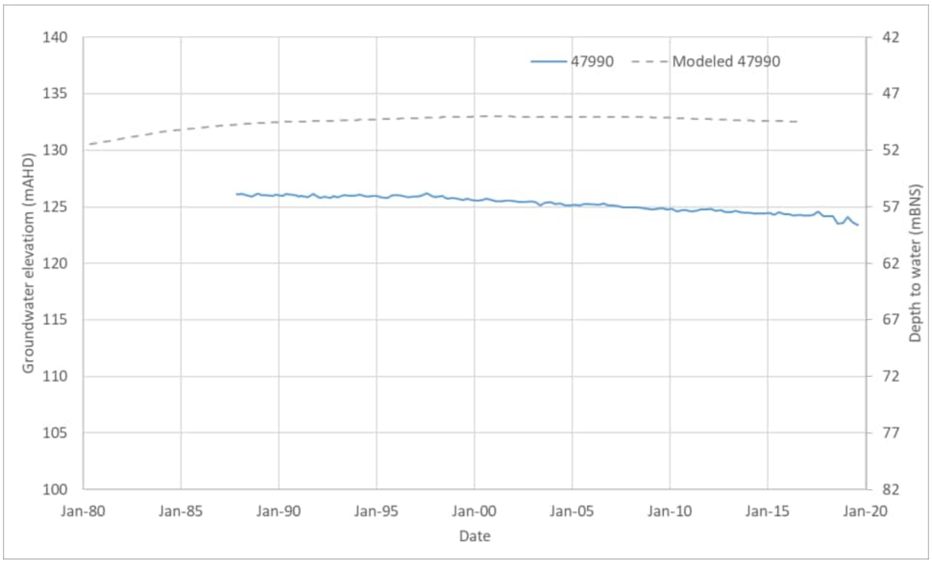


Figure F.8: Groundwater hydrograph – bore 48003

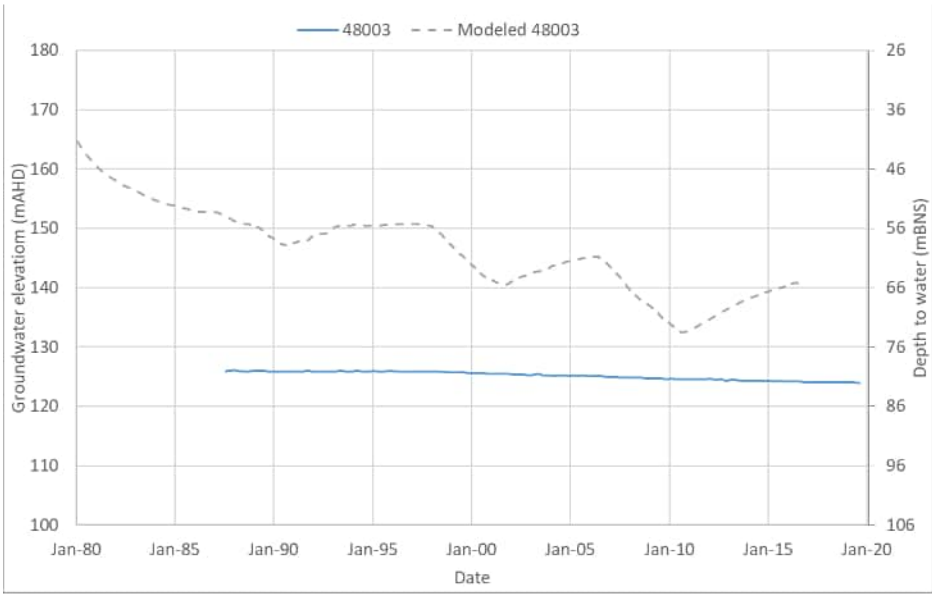
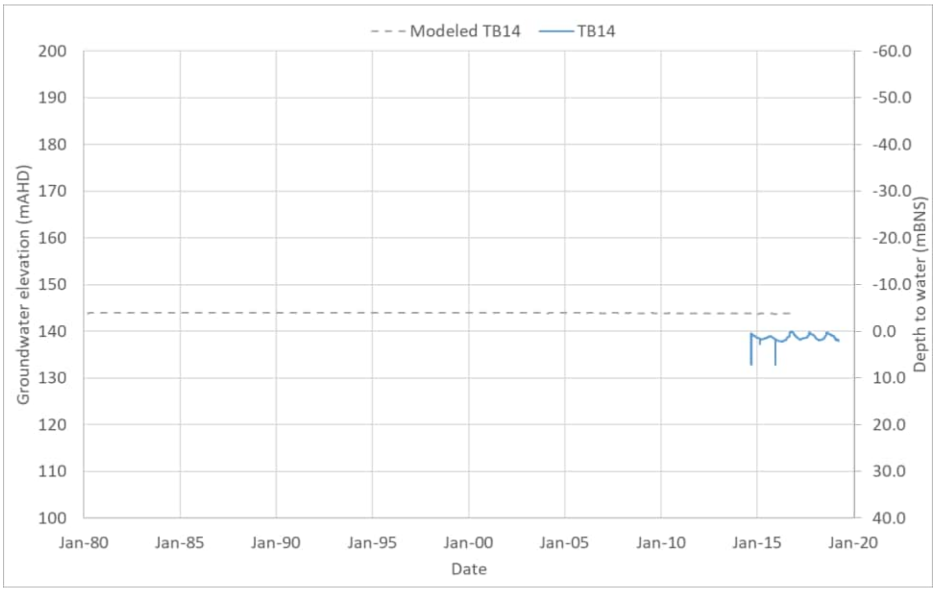


Figure F.9: Groundwater hydrograph – bore TB14



Appendix G. Yahoo Creek

G.1 Surface monitoring data

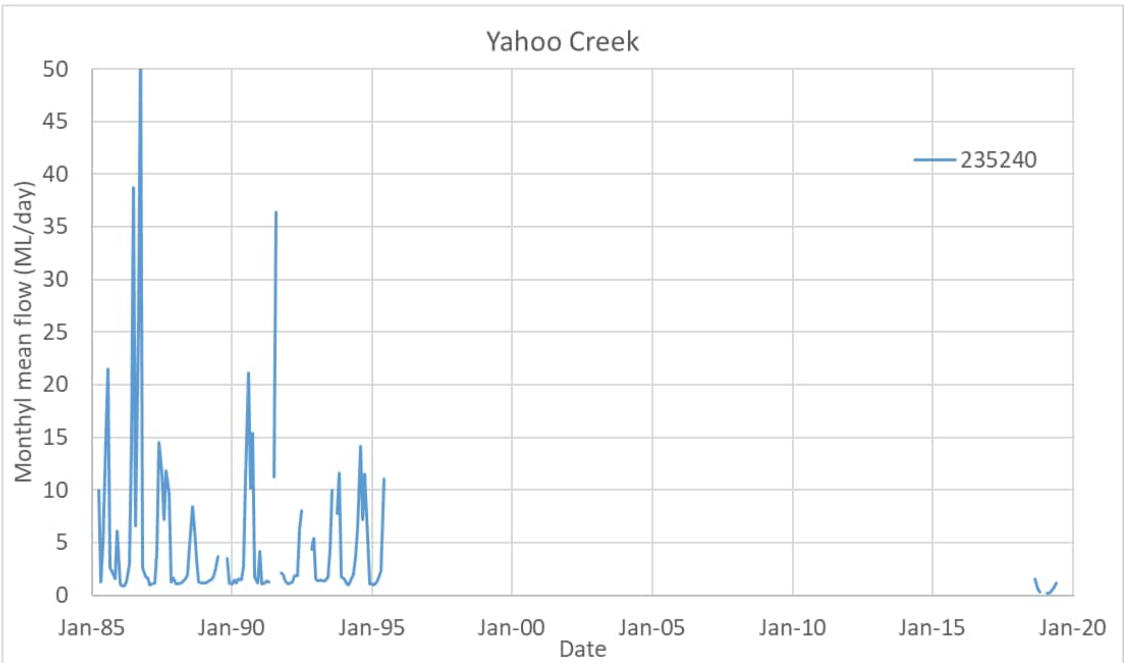
There is currently one surface water gauge located on Yahoo Creek upstream at Kawarren (235240). The flow monitoring record is intermittent (see Figure G.1). The gauge was monitored between 1985 and 1995, and has recently been reactivated. The flow record in the 1980s shows seasonal variations in flow, with flow frequently dropping below 5 ML/day. Flow in 2019 has not been reported above 2 ML/day.

A summary of the gauges is provided in Table G.1 and the locations are shown in Figure 4-11.

Table G.1: Yahoo Creek surface water monitoring gauges

Surface water gauge	Location	Monitoring record	Current status
235240	Yahoo Creek at Kawarren	1985 to 1995, 2018 to present	Active
235234	Loves Creek at Gellibrand	1979 to present	Active

Figure G.1: Monthly mean flow - 235240 at Yahoo Creek



G.2 Groundwater monitoring data

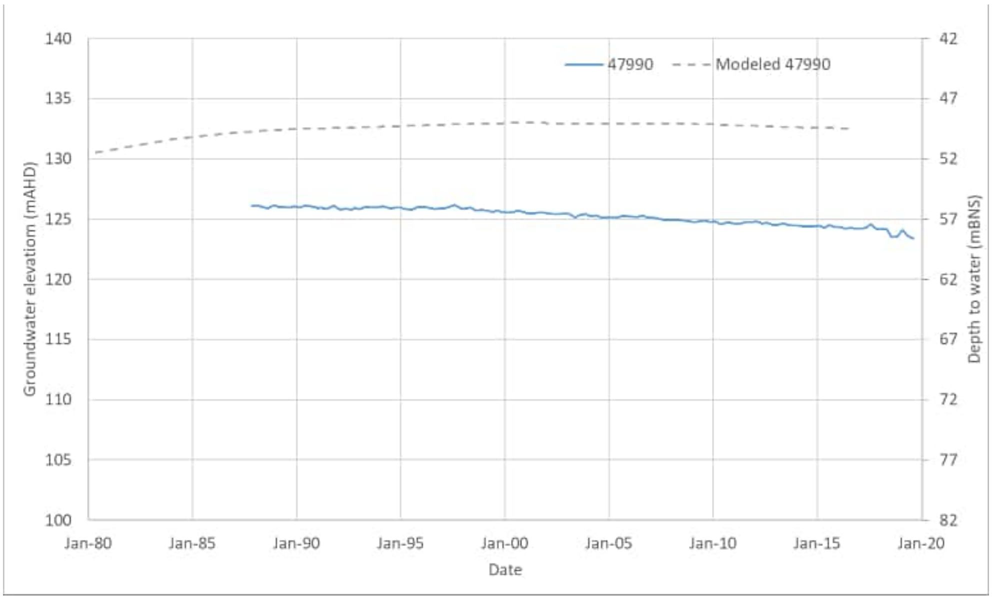
There is one bore located in this part of the study area. Bore 47990 is located north west of the creek and has a monitoring record from 1983 to present. The groundwater level is around 125 mAHD and the depth to water table is around 57 m. The water level trend shows a marginal declining trend.

A summary of bore 47990 is provided in Table G.2 and a hydrograph is provided in Figure G.2. The hydrograph shows that the regional groundwater model predicts the groundwater levels to be 7 m higher at this location and waterlevels are predicted to have risen.

Table G.2: Yahoo Creek groundwater monitoring data

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
47990	LTA	153.0	1983 to 2019	Active

Figure G.2: Groundwater hydrograph – bore 47990



Appendix H. Vegetation

H.1 West of the graben

There are no groundwater monitoring bores located in the areas of high risk, however there are five bores monitoring the LTA at depths ranging between 85 and 306 m around the area. The are no bores monitoring the watertable aquifer. The locations of all groundwater monitoring bores are shown in Figure 5-2.

Bore 62578 is located in the south west and is the shallowest bore at 85 m deep. The bore shows a subdued response to pumping from Barwon Downs and groundwater levels are currently 2 m lower than groundwater levels in the mid-1990s. The depth to water table is around 25 m.

Bore 109133 is also located in the south and monitors the LTA at around 221 m depth. Groundwater levels in the LTA at this location have declined in response to pumping and are currently 10 m lower than groundwater levels in the late 1980s. The depth to water table is around 60 m.

Bores 109134 and 109135 are located in the middle of the area of interest. Bore 109134 is 156 m deep and no longer monitored. Bore 10195 is 237 m deep and shows an interesting groundwater trend that warrants further investigation. The groundwater levels declined in response to pumping but showed a strong recovery and in 2018 groundwater levels were above their pre-pumping levels. However groundwater levels recorded in 2019 have shown a sharp decline and the accuracy of these measurements will need further investigation.

Bore 109114 is located close to the north western boundary of the model and monitors the LTA at a depth of around 300 m. Groundwater levels in the LTA show a strong response to pumping and are currently 10 m lower than their pre-pumping levels.

Bores PASS1 and PASS3 are located in the Boundary Creek catchment. PASS1 is a shallow bore monitoring the alluvial aquifer, located on the northern floodplain of Boundary Creek approximately 1 km upstream of its confluence with the Barwon River (Jacobs, 2017b). The depth to water is shallow (within 2 m of the surface) and groundwater levels show seasonal fluctuations. The regional groundwater model predicts groundwater level are almost 10 m higher than observed with no seasonal fluctuations.

PASS3 monitors the alluvial aquifer along a tributary to Boundary Creek (Jacobs, 2017b). The depth to water is shallow (within 2 m of the surface) and groundwater levels show seasonal fluctuations. While the regional groundwater model predicts groundwater level are with 2 m of the observed levels, the observed seasonal fluctuations are not represented in the model.

This monitoring highlights that groundwater levels in the LTA across this area are influenced by pumping from Barwon Downs. However there is no information to understand the impacts on groundwater levels in the MTD and limited information on the alluvial aquifers. PASS monitoring bores indicate that the groundwater level in the alluvial aquifer is shallow which suggest this alluvial aquifer has not been influence by pumping.

Table H.1: Groundwater bores – West of the graben

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Status
PASS 1	Quaternary alluvium	10.0	2015 – 2017	Active
PASS 3	Quaternary alluvium	10.0	2015 - 2016	Active
62578	LTA	85.0	1986 - 2019	Active
109114	LTA	308.5	1984 - 2019	Active
109133	LTA	211.5	1986 - 2019	Active
109134	LTA	156.0	1986 - 2008	Inactive
109135	LTA	237.0	1986 - 2019	Active

Figure H.1: Groundwater hydrograph – bore 62578

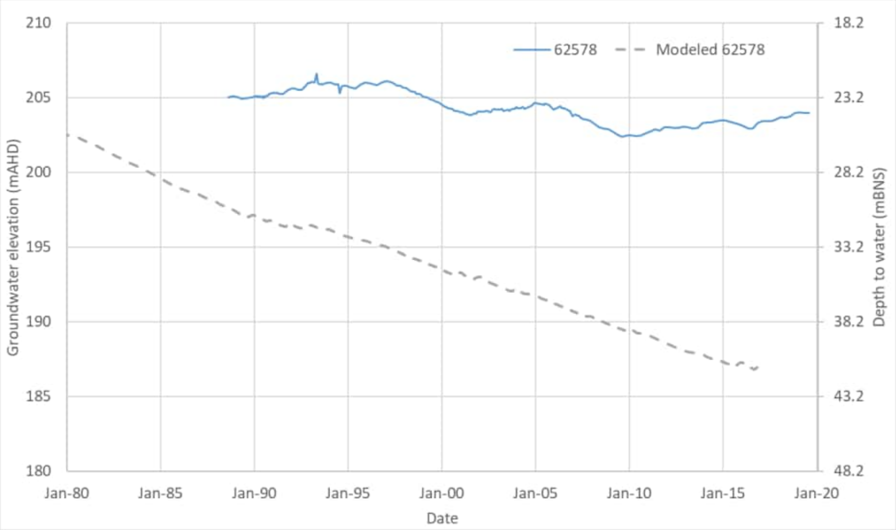


Figure H.2: Groundwater hydrograph – bore 109114

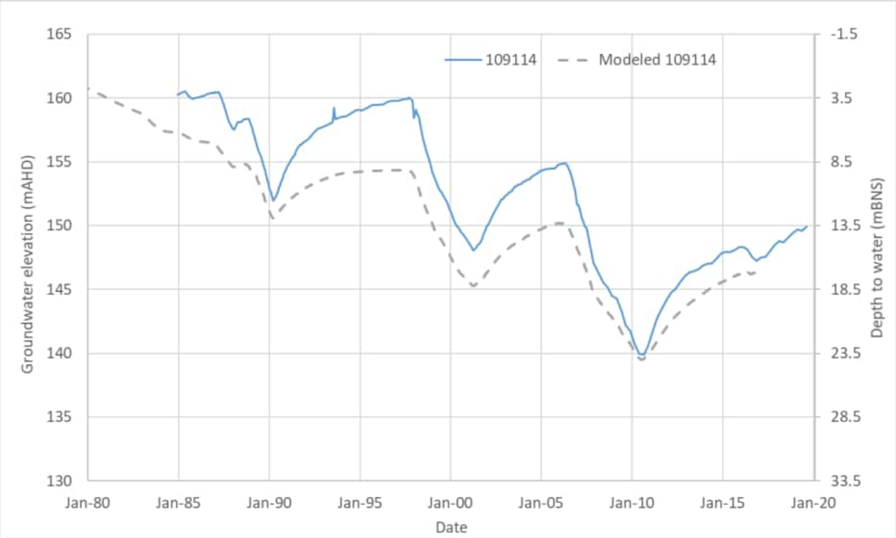


Figure H.3: Groundwater hydrograph – bore 109133

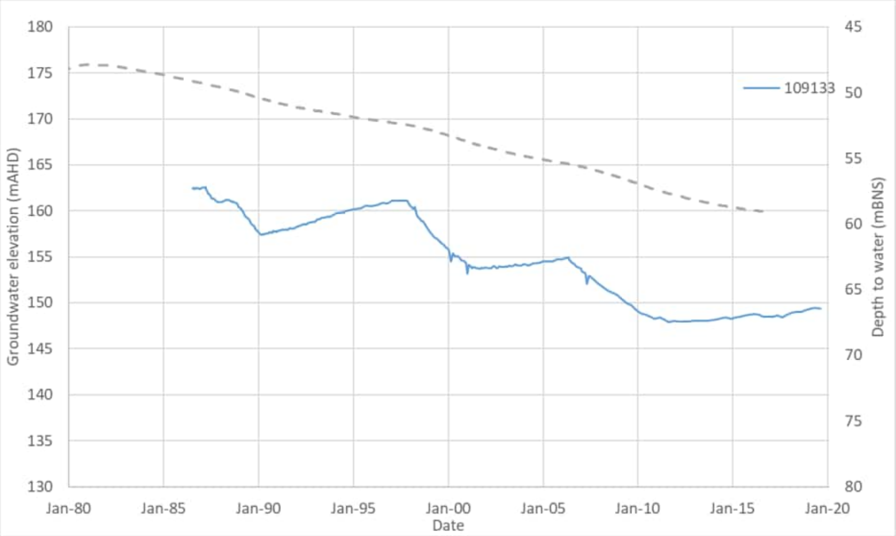


Figure H.4: Groundwater hydrograph – bore 109135

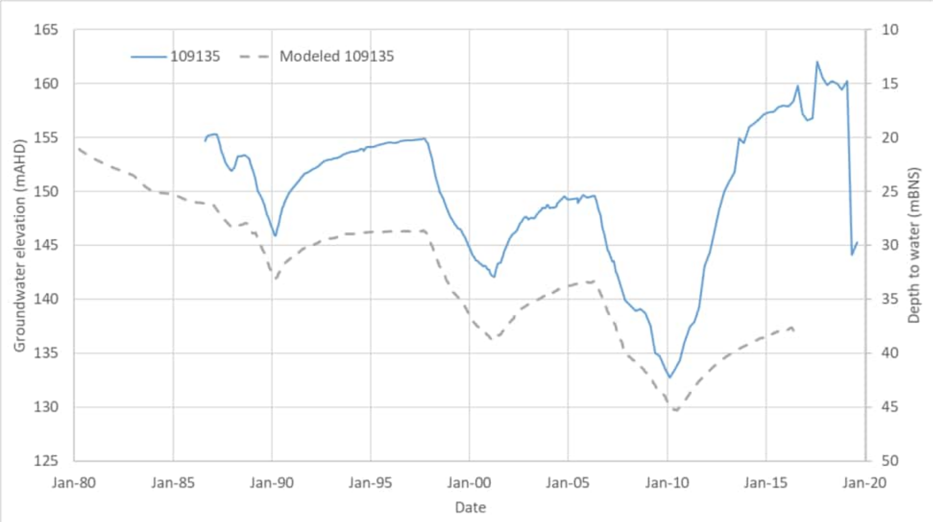


Figure H.5: Groundwater hydrograph – bore PASS 1

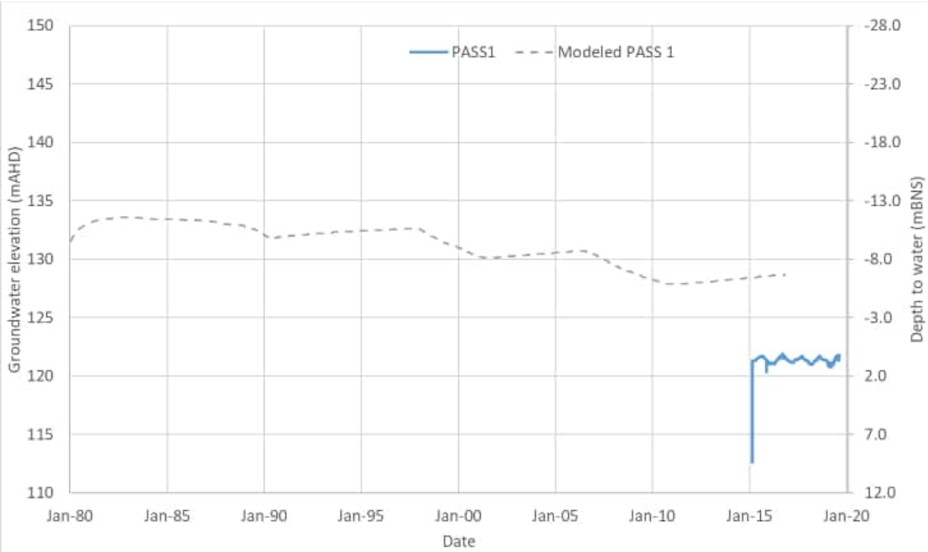
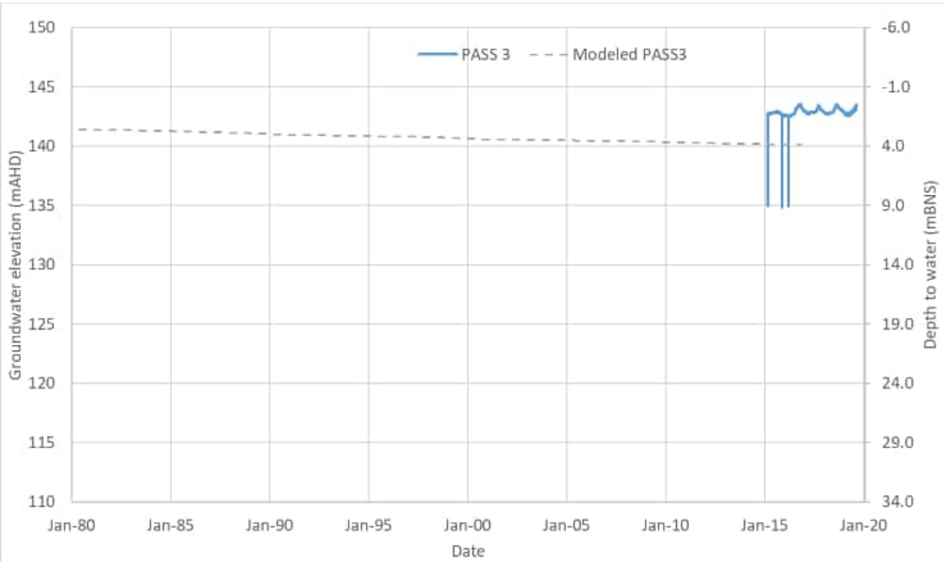


Figure H.6: Groundwater hydrograph – bore PASS 3



H.2 East of the graben

There are 22 groundwater monitoring bores scattered across this area and 17 of these are currently monitored. The bores are all deep bores monitoring the LTA at depths ranging between 117 and 610 m.

Bores 82845, 82846 and 82847 are all monitoring the LTA in the Bambra Fault zone at depths ranging between 114 and 226 m. Bore 82847 is located closest to the Barwon Downs borefield, followed by bore 82845 and 82846 respectively. Groundwater levels in bores 82845 and 82847 are influenced by pumping, and groundwater levels are around 10 m lower than the levels recorded in the 1980s. Bore 82846 shows only a very marginal decline in groundwater levels over the monitoring period (1-2 m).

Bore 82843 monitors the confined LTA on the north western side of the Bambra Fault zone. The groundwater levels are strongly influenced by pumping from Barwon Downs in this location. Although groundwater levels are around 10-15 m lower than the 1980s levels, the aquifer is artesian at this location with groundwater levels recently recorded about 5 m above ground surface.

Bores 82838, 82840 and 82841 are nested bores monitoring the confined LTA at different depths. These bores were discussed in detail in Section 5.4, as they are located close to the Barwon River. The groundwater levels in the deeper bores (82840 and 82841) are strongly influenced by pumping, while the shallower bore (82838) shows a stronger seasonal response and much less drawdown. A condition assessment is required on bore 82838 as the recent water levels are questionable and also make it difficult to assess the vertical gradient in the LTA at this location.

Bores 82844 and 102869 also monitors the confined LTA in the centre of the graben. Bore 82844 is no longer monitored, but did show a strong response to pumping until 2010 when monitoring ceased. Bore 102869 also shows a strong response to pumping and levels are around 5 m below water levels recorded in the 1980s. The aquifer is marginally artesian with current water levels about 1 m above ground surface.

PASS4 is located on the eastern floodplain of Yan Yan Gurt Creek (Jacobs, 2017b). The bore monitors the shallow MTD and groundwater levels in this bore are artesian. This suggests there is an upward gradient at this location supported by groundwater pressures in the MTD.

Table H.2: Groundwater bores – East of graben

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Comments?
PASS 4	Alluvial	8.0	2015 – 2017	Active (datalogger)
47771	LTA	345.0	Nov-1985 to Aug-2019	Active
47773	LTA	297.5	Sep-1986 to Aug-2019	Active
47774	LTA	222.5	Dec-1987 to Aug-2019	Active
47775	LTA	381.2	Dec-1988 to Aug-2019	Active
48249	LTA	135.3	Oct-1982 to Aug-2019	Active
82838	LTA	285.1	Jan-1974 to Aug-2019	Active
82840	LTA	610.8	Dec-1973 to Aug-2019	Active
82841	LTA	484.6	Jun-1974 to Aug-2019	Active
82842	LTA	385.5	Nov-1985 to Aug-2008	Inactive
82843	LTA	462.0	Apr-1986 to Aug-2019	Active
82844	LTA	233.0	Mar-1985 to Nov-2007	Inactive
82845	LTA	226.0	Jan-1986 to Aug-2019	Active

Bore	Aquifer monitored	Bore depth (m)	Monitoring record	Comments?
82846	LTA	131.0	Apr-1986 to Aug-2019	Active
82847	LTA	117.0	May-1986 to Aug-2019	Active
82848	LTA	352.6	Jul-1985 to May-1997	Inactive
102865	LTA	435.9	Dec-1973 to Nov-2011	Inactive
102867	LTA	281.6	Dec-1973 to Sep-2008	Inactive
102868	LTA	577.0	May-1984 to Aug-2019	Active
102869	LTA	431.0	Jan-1986 to Aug-2019	Active
107716	LTA	254.0	Dec-1987 to May-2016	Inactive
107717	LTA	193.5	Dec-1987 to Aug-2019	Active
107720	LTA	259.0	Dec-1988 to Aug-2019	Active

Figure H.7: Groundwater hydrograph – bore 47771

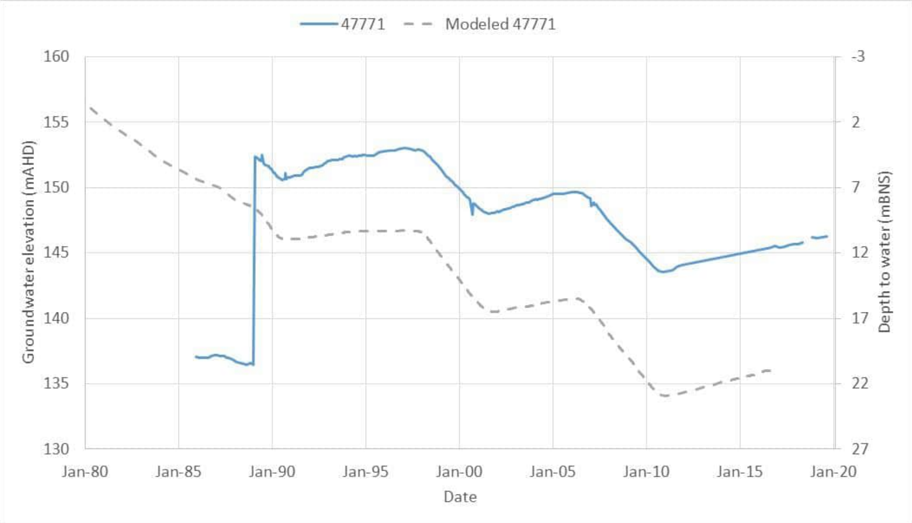


Figure H.8: Groundwater hydrograph – bore 47773

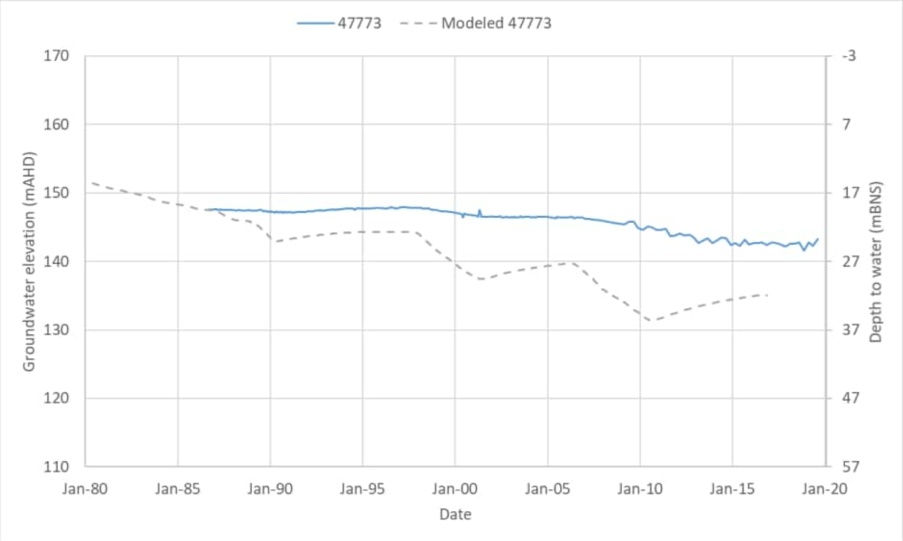


Figure H.9: Groundwater hydrograph – bore 47774

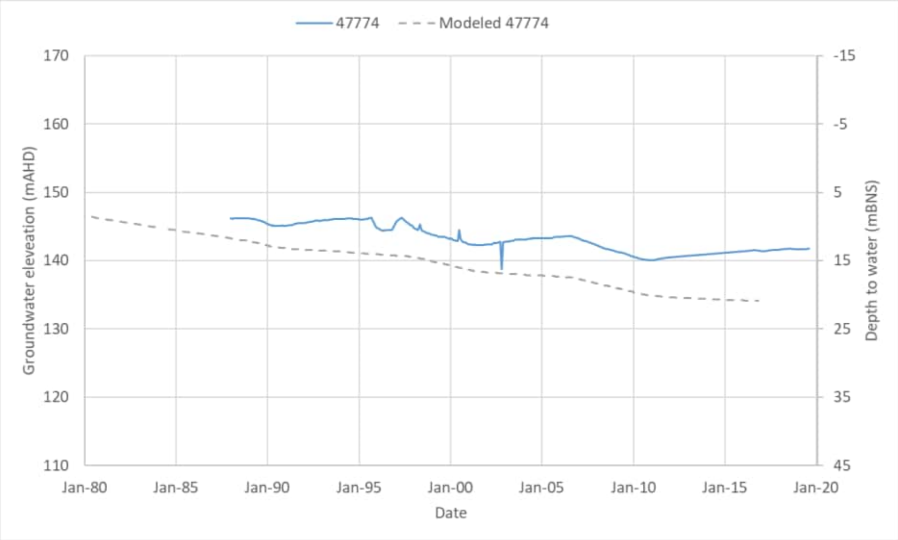


Figure H.10: Groundwater hydrograph – bore 47775

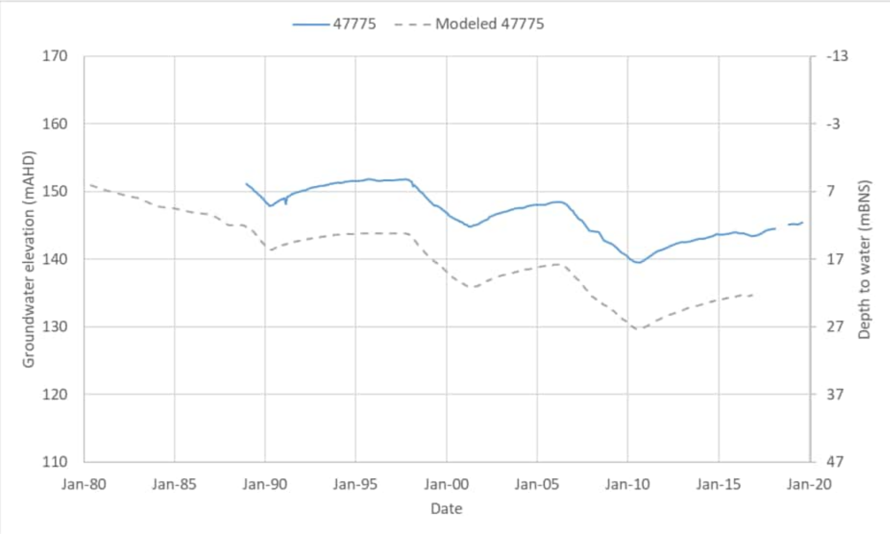


Figure H.11: Groundwater hydrograph – bore 82838

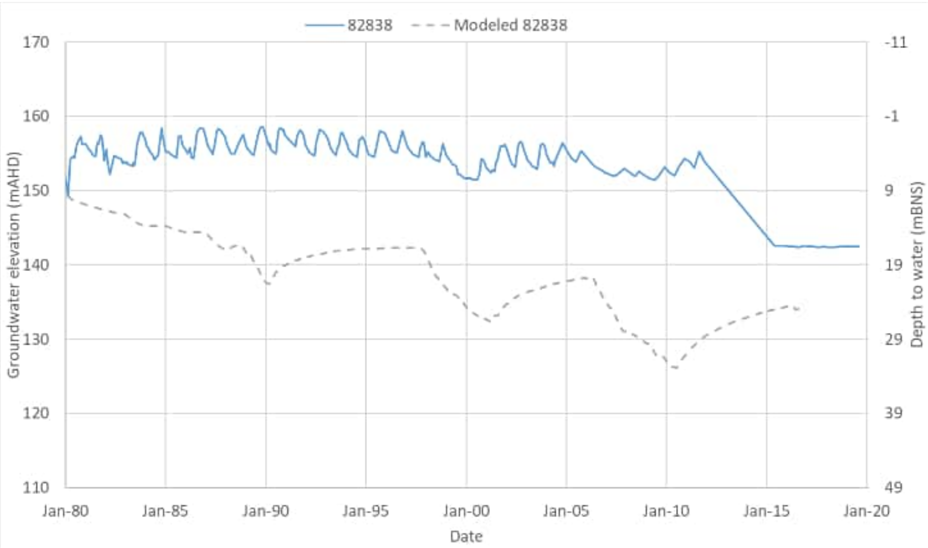


Figure H.12: Groundwater hydrograph – bore 82840

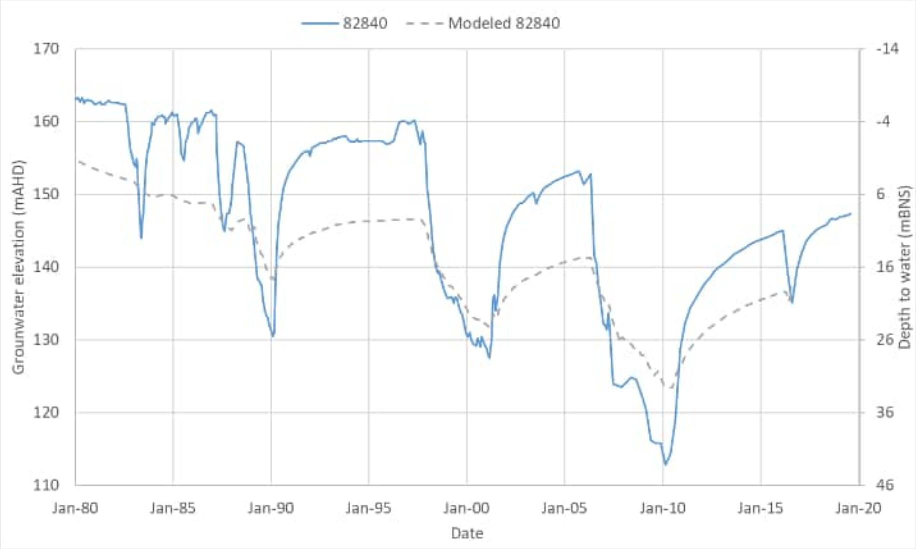


Figure H.13: Groundwater hydrograph – bore 82841

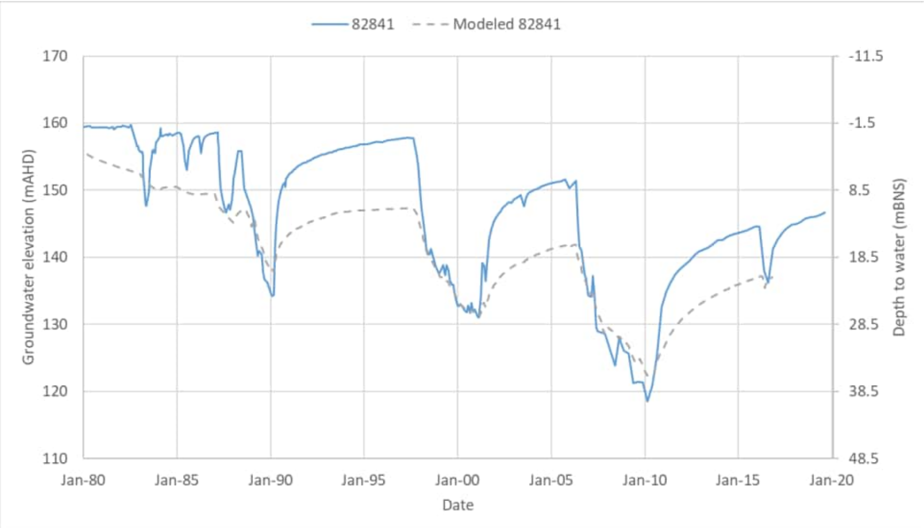


Figure H.14: Groundwater hydrograph – bore 82843

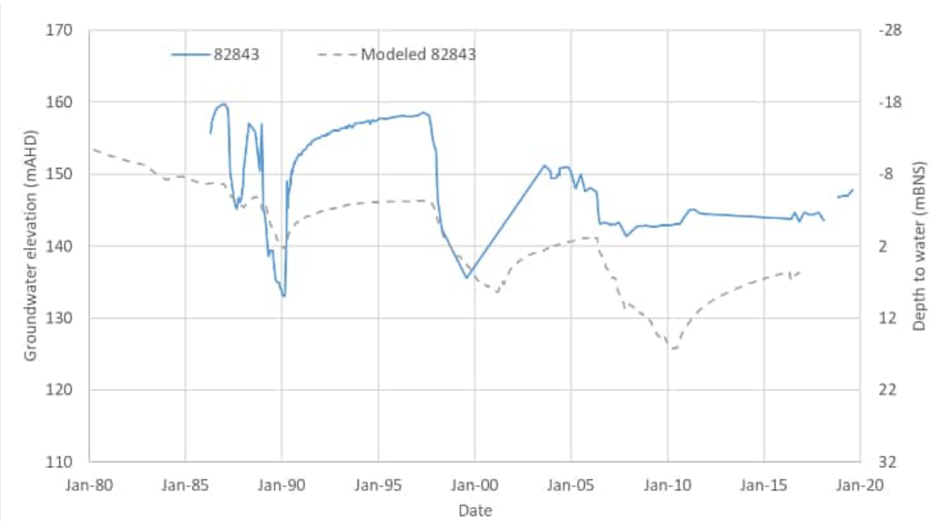


Figure H.15: Groundwater hydrograph – bore 82845

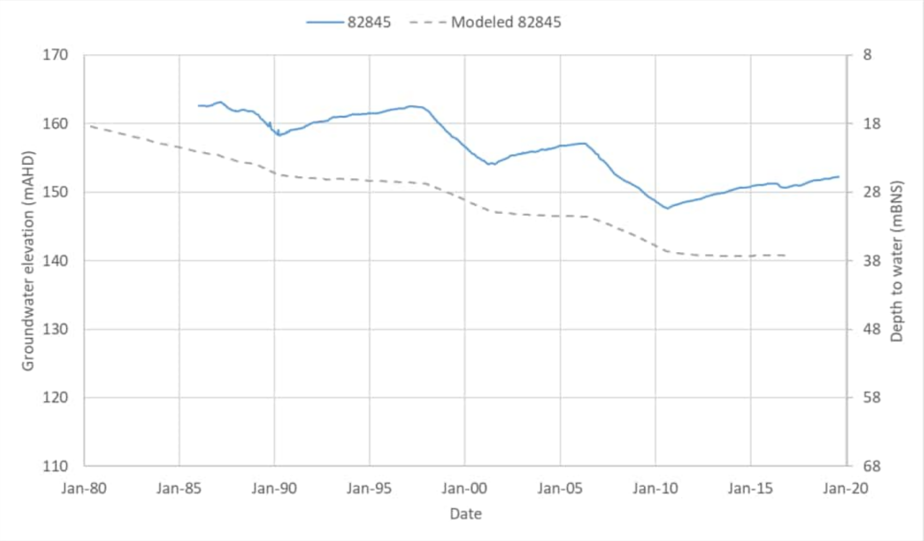


Figure H.16: Groundwater hydrograph – bore 82846

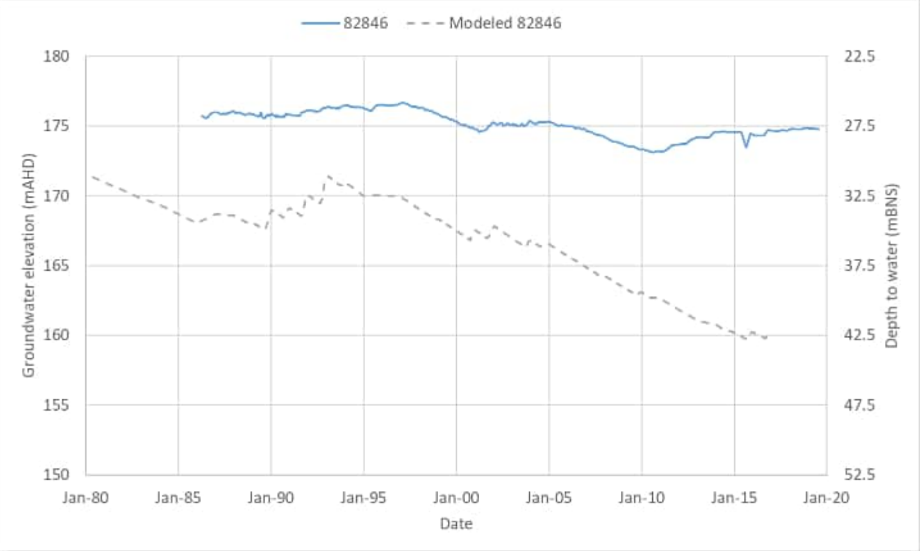


Figure H.17: Groundwater hydrograph – bore 82847

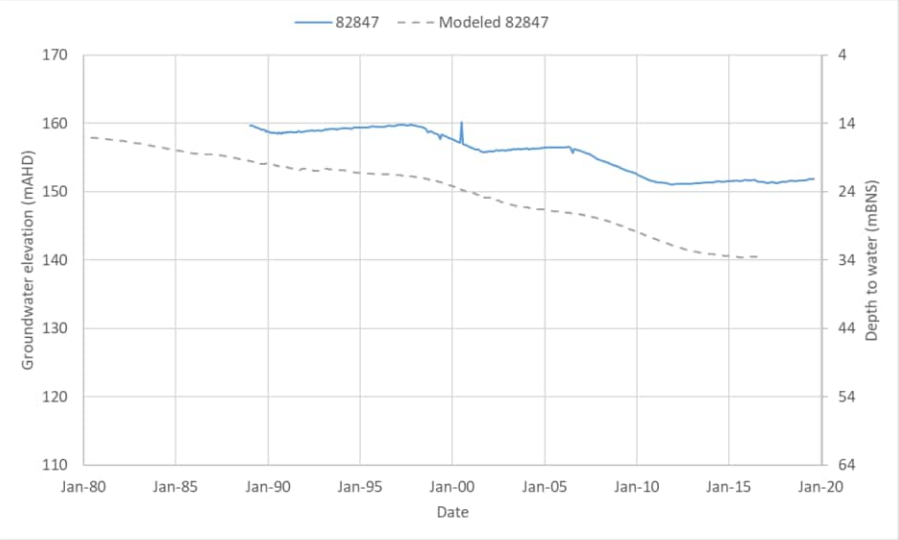


Figure H.18: Groundwater hydrograph – bore 102868

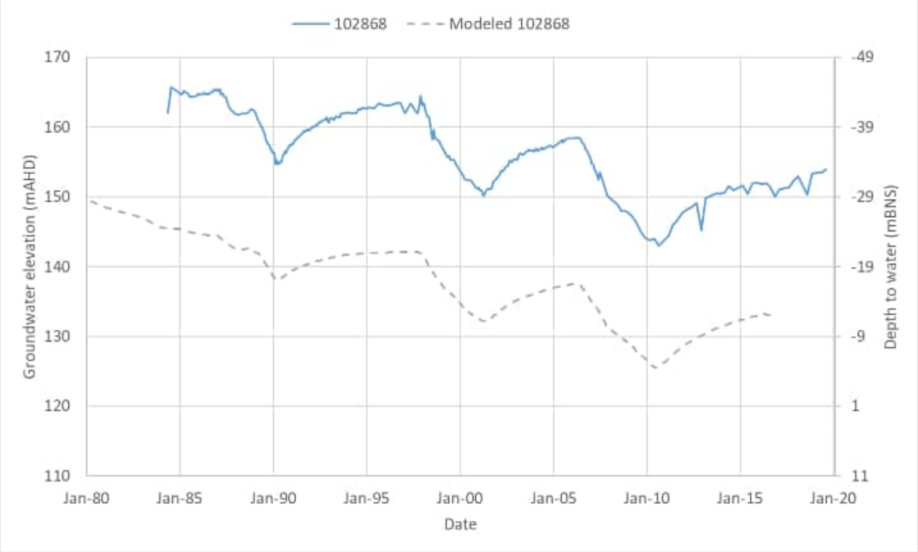


Figure H.19: Groundwater hydrograph – bore 102869

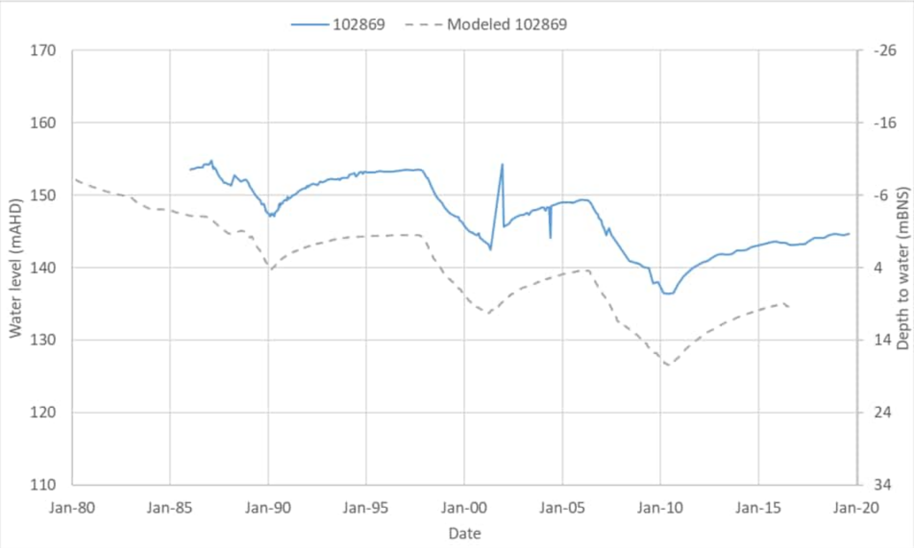
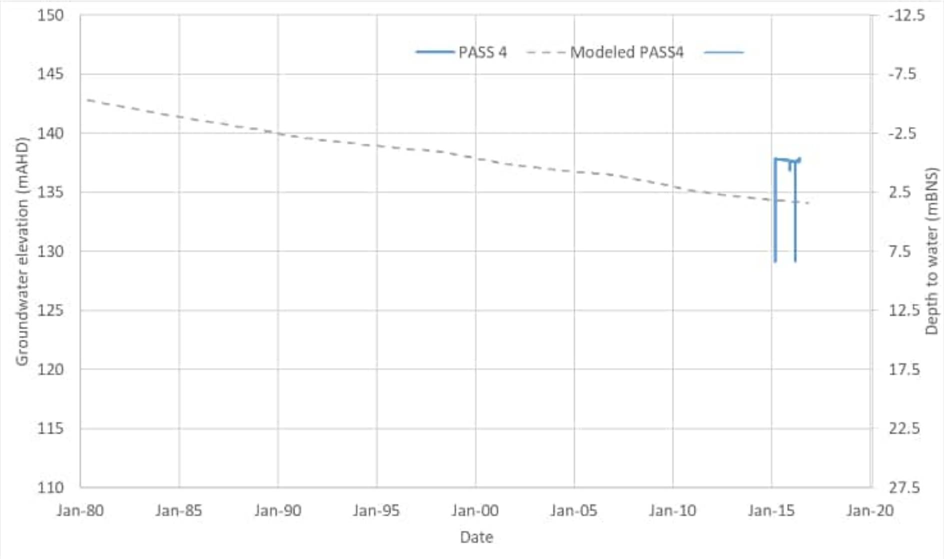


Figure H.20: Groundwater hydrograph – bore PASS 4



H.3 South of the graben

As previously noted in Appendix E, there is only one bore currently monitored on the northern side of the Gellibrand River. The waterlevels in this bore are influenced by seasonal fluctuations and show a marginal decline over the monitoring period. The groundwater model represents the waterlevel in this bore reasonably well.

Table H.3: Groundwater bores around Gellibrand (north and south of the river)

Bore	Aquifer monitored	Location	Bore depth	Monitoring record	Current status
108916	Shallow LTA*	North of river	14.9	1981 to 2011	Inactive
108917	Shallow LTA*	North of river	15.0	1981 to 2013	Inactive
108918	Shallow LTA*	North of river	15.3	1981 to 1994	Inactive
108919	Shallow LTA*	North of river	16.6	1981 to 2011	Inactive
108920	Shallow LTA*	North of river	18.0	1981 to 1998	Inactive
108898	LTA	North of river	272.0	1981 to 2013	Inactive
108899	LTA	North of river	34.0	1981 to 2013	Inactive
108958	Unknown	North of river	N/A	1979 to 1985	Inactive
108959	Unknown	North of river	N/A	1979 to 1983	Inactive
108960	Unknown	North of river	N/A	1979 to 1985	Inactive
108961	Unknown	North of river	N/A	1979 to 1985	Inactive
108907	Unknown	North of river	362.5	1982 to 2019	Active
116489	Unknown	North of river	210.0	1993 to 2011	Inactive
108897	Unknown	South of river	86.0	1981 to 2019	Active
108921	Unknown	South of river	19.7	1981 to 2000	Inactive
108922	Unknown	South of river	20.2	1981 to 2011	Inactive
108924	Unknown	South of river	16.7	1981 to 2016	Inactive
108925	Unknown	South of river	19.5	1981 to 2016	Inactive
108933	Unknown	South of river	11.7	1982 to 2011	Inactive
108934	Unknown	South of river	12.0	1982 to 2011	Inactive
108935	Unknown	South of river	11.8	1982 to 2011	Inactive
108945	Unknown	South of river	88.7	1979 to 2011	Inactive
108946	Unknown	South of river	40.0	1979 to 2016	Inactive
108947	Unknown	South of river	64.0	1979 to 2011	Inactive
108949	Unknown	South of river	79.0	1979 to 2009	Inactive
110737	Unknown	South of river	42.6	1980 to 2011	Inactive

Figure H.21: Groundwater hydrograph – bore 108907

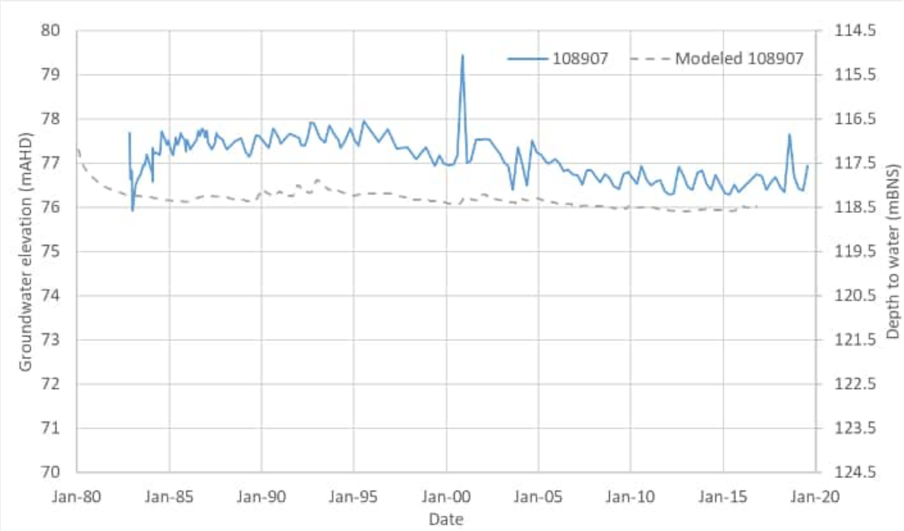


Figure H.22: Groundwater hydrograph – bore 108922

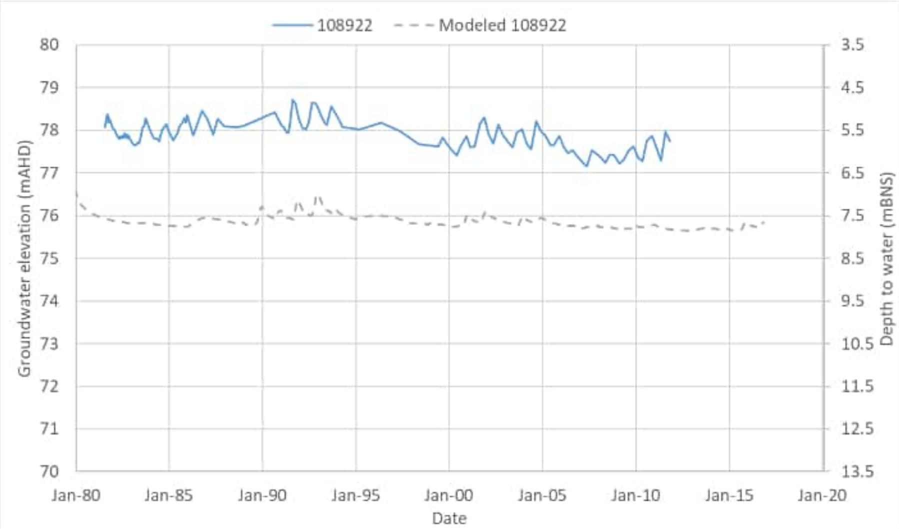


Figure H.23: Groundwater hydrograph – bore 108924

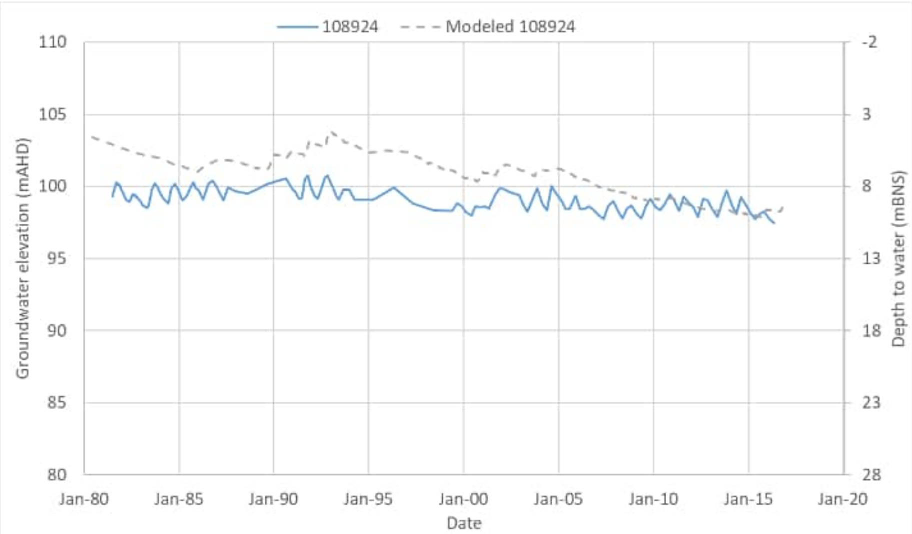


Figure H.24: Groundwater hydrograph – bore 108933

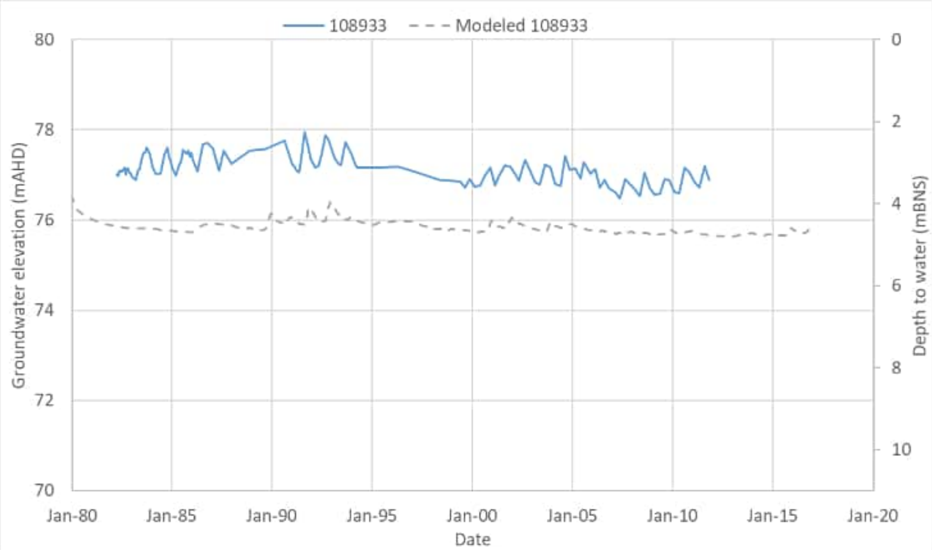


Figure H.25: Groundwater hydrograph – bore 108935

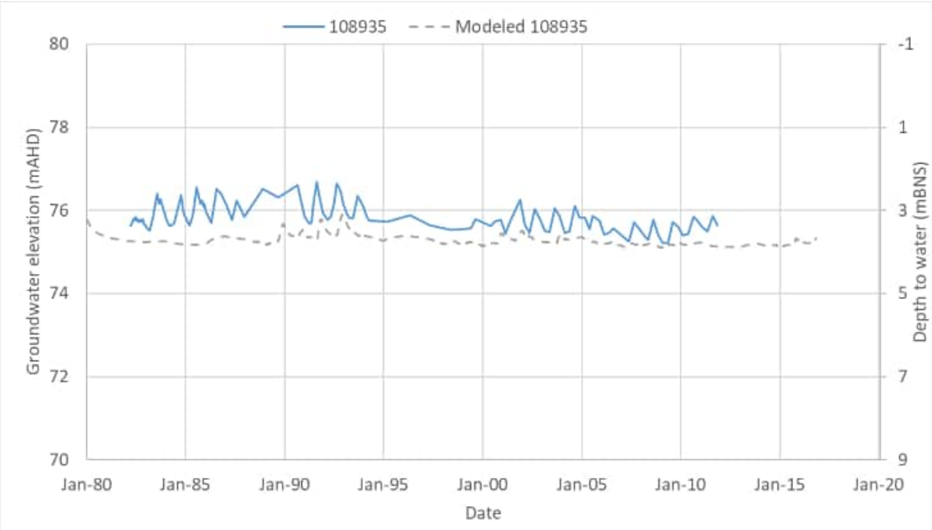


Figure H.26: Groundwater hydrograph – bore 108946

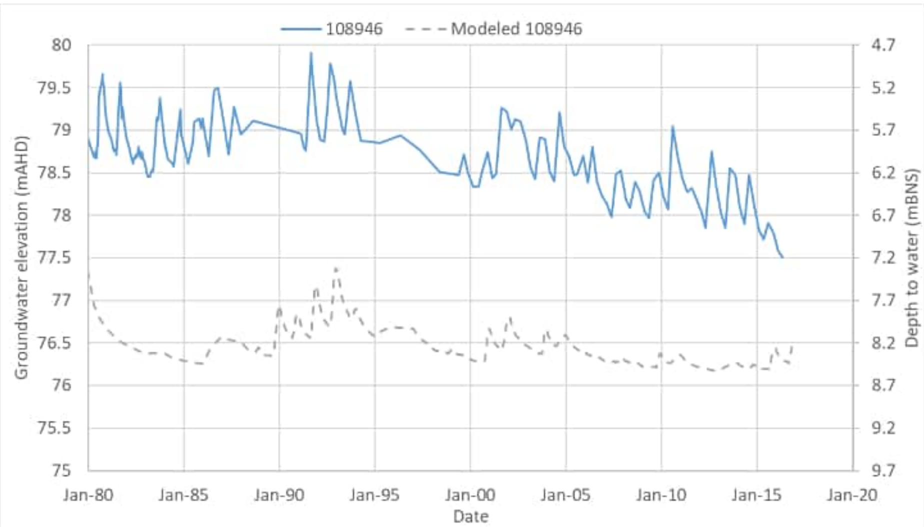


Figure H.27: Groundwater hydrograph – bore 108947

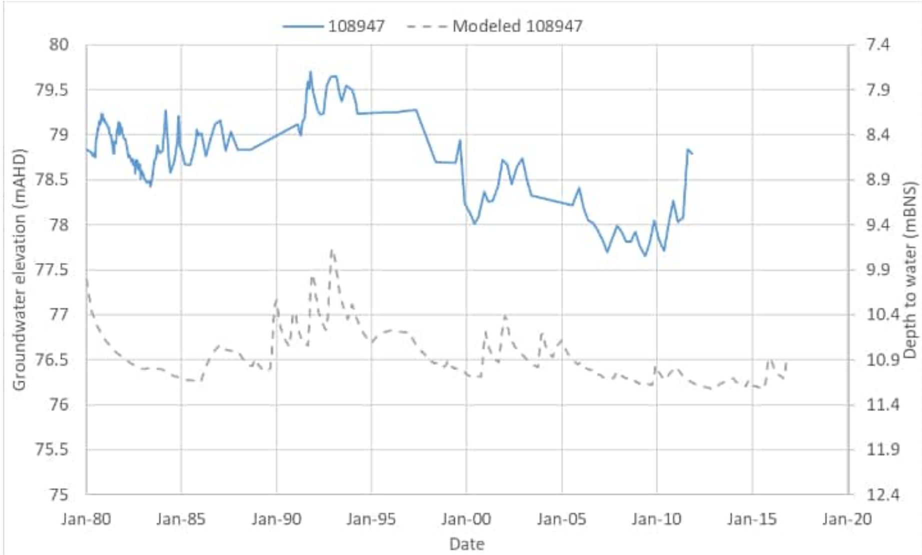


Figure H.28: Groundwater hydrograph - 108949