Barwon Downs Technical Works Program

Barwon Water

Groundwater Assessment Report

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Barwon Downs Technical Works Program

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Contents

Executive Summary

Introduction

This Groundwater Assessment Report (GAR) has been prepared to fulfil the licence requirements of Groundwater Extraction Licence BEE032496 under which Barwon Water (BW) operates which is valid until June 2019. This report is intended to accompany the application to renew the licence.

The GAR provides an overview of the technical studies commissioned by BW since 2004. These studies were designed to address key data gaps and improve the understanding of potential impacts associated with the Barwon Downs borefield.

The key objectives of this report are to:

- Consolidate the available technical information
- Outline the approaches used to assess the potential impacts associated with groundwater extraction from the borefield
- Present the results of the numerical modelling related to proposed extractions regimes under the new licence and associated risk assessment to quantify the predicted impacts, and
- Recommend a monitoring and management plan for the new licence that mitigates areas with potential high risk.

Study area

The groundwater licence is associated with the Barwon Downs Borefield, which is located south west of Geelong. The borefield extracts groundwater from the Lower Tertiary Aquifer (LTA) at a depth of around 500 m. The aquifer is deepest in the centre of the graben and rises to the surface at the edges (see Figure 1).

Groundwater in the LTA is part of the Gerangamete Groundwater Management Area (GMA). The location of the GMA is shown in Figure 2 together with the surface water catchments in the area. The aquifer extends beneath two major surface water catchments – the Barwon River catchment (including Boundary Creek) and the Gellibrand River catchment. Boundary Creek is a key tributary of the Barwon River which flows across the recharge area for the LTA aquifer and has been the focus of community concerns.

Barwon Downs borefield and proposed extraction rates

The Barwon Downs Borefield consists of six production bores and has been used intermittently since construction in 1981. Historically, the borefield was used heavily between 1997 and 2001 before reaching its greatest period of use between 2006 and 2010.

Barwon Water is proposing to apply for a reduced volumetric entitlement compared to the current licence. This change is based on an assessment by Barwon Water of the likely need for the borefield over the next 15 years. The current and proposed volumetric limits are provided in Table 1.

Table 1: Volumetric limits of the current and proposed licence

Condition	Current Licence	Proposed Licence
Maximum daily rate (ML)	72	45
Maximum annual rate (ML)	20,000	12,000
Maximum 10-year rate (ML)	80,000	N/A
Maximum 15-year rate (ML)	N/A	60,000
Long term (100 year) extraction	400,000	N/A

Figure 1: Schematic of the Lower Tertiary Aquifer and where it outcrops at the surface

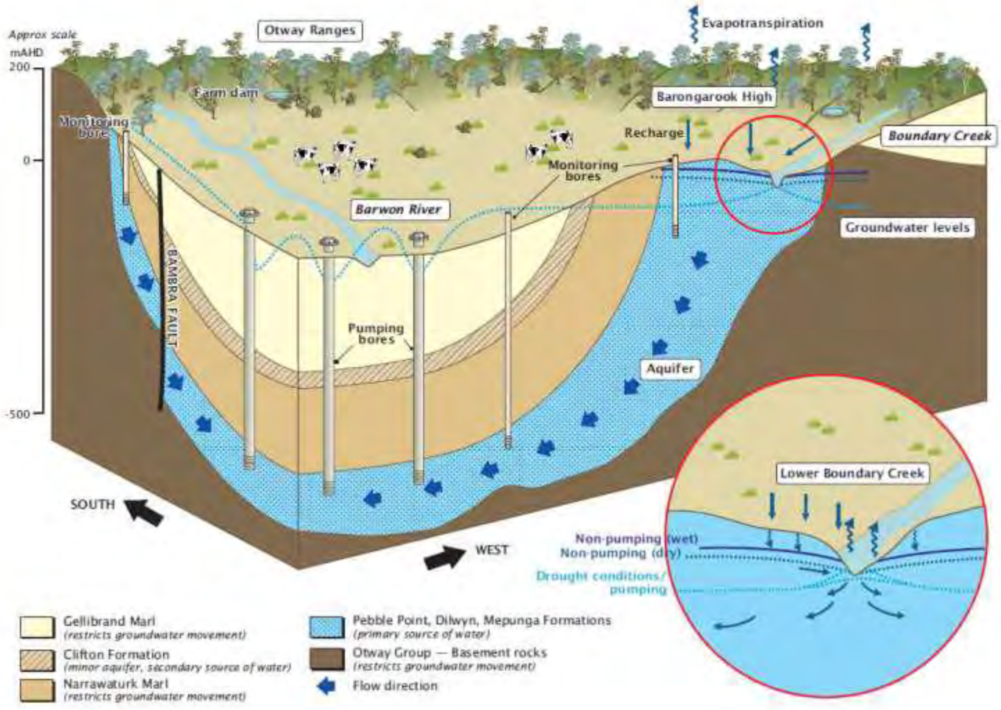
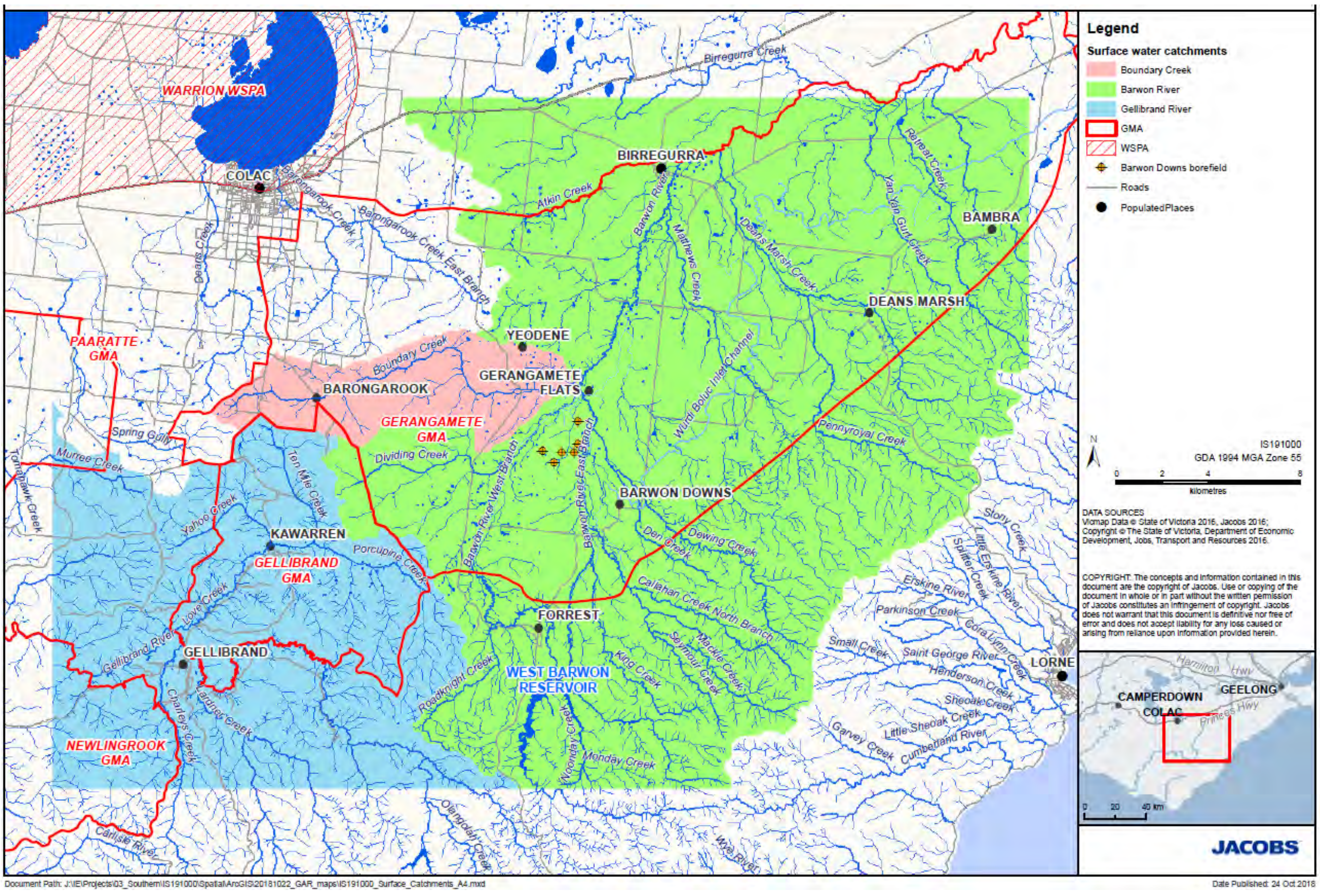


Figure 2: Map of the Barwon Downs region GMAs and surface water catchments



Hydrogeological conceptual model

While the hydrogeological conceptual model of the Barwon Downs Graben is reasonably well understood, information gaps were identified during the current licence period. To address these data gaps, additional monitoring bores, surface water gauges and vegetation and potential acid sulfate soils (PASS) monitoring sites were established. Information collected from these studies were used to refine the conceptual understanding and to update and recalibrate the numerical groundwater model.

Key geological formations, aquifers (from the Victorian Aquifer Framework) and the corresponding layer in the numerical groundwater model are summarised in Table 2. The LTA is the primary aquifer in the graben.

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

System	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

Key focus areas of the refinement of the hydrogeological conceptual model were as follows:

- Extent and thickness of key formations
- Groundwater flow across faults
- Recharge to groundwater
- Understanding drawdown in the Lower Tertiary Aquifer
- Groundwater surface water interactions along Boundary Creek

In addition to these improvements in the hydrogeological conceptual model, the vegetation monitoring network was also revised and baseline monitoring sites for potential acid sulfate soils (PASS) were established.

Extent and thickness of key formations

Previous versions of the numerical groundwater model included five of the seven layers outlined in the table above. A revised geological model was developed as part of the Technical Works Monitoring Program with the aim of including the additional two layers (Pember Mudstone and Bedrock). The extent and thickness of the LTA, the Narrawaturk Marl and the Gellibrand Marl were also revised using the information collected from the new monitoring bores. This information was used to develop the revised numerical groundwater model.

Groundwater flow across faults

There are two key faults in the region – the Colac Fault and the Bambra Fault. The LTA is uplifted across the Bambra Fault and is not continuous, which has a significant influence on groundwater flow across the fault. The Bambra Fault forms the south eastern boundary of the numerical model and understanding flow across the fault is important to understand how the fault will influence groundwater behaviour.

A review of the local hydrogeology around the Colac and Bambra Faults highlighted that there is very little groundwater flow across the faults. This information was used in the update of the numerical model.

Recharge to groundwater

Recharge to groundwater occurs through rainfall infiltration across the entire study area. It is the key recharge process for the LTA, with over 90% of recharge to the aquifer occurring as infiltration where the aquifer outcrops. Less than 10% of LTA recharge occurs via downward leakage from overlying units (Jacobs, 2018a).

Recharge from rainfall has been estimated by several practitioners over the years using different approaches, however these studies often incorporated little or no field data and provide a broad range of recharge estimates. As part of the Technical Works Monitoring Program a study was completed to improve understanding of recharge across the catchment. The overall objective was to estimate rates of recharge to the LTA using independent techniques to improve the accuracy and confidence in the numerical model.

There is considerable variability in the spatial and temporal distribution of recharge and it is considered best practice to apply multiple methods to reduce the uncertainty of recharge estimates. Two methods were used to estimate recharge using chemical tracers – the tritium method and the chloride mass balance method.

Recharge rates estimated using field techniques by Jacobs (2016a) indicated long term average recharge rates to be around 10% of rainfall which is equivalent to approximately 11,000 ML/year across the Lower Tertiary Aquifer (LTA) outcrop area. This recharge rate was used as an input into the model. However the calibration model highlighted that the average recharge to the LTA outcrop area over the last 30 years is estimated to be 5,900 ML/year. This volume is equivalent to around 5% of rainfall, which is lower than some of the field estimates from Jacobs (2016a).

Groundwater flow in the Lower Tertiary Aquifer (LTA)

When the Barwon Downs Borefield is operational, the drawdown cone in the aquifer spreads in a north east – south west direction within the Graben. An investigation by Jacobs (2016e) confirmed that drawdown extends to the Kawarren area. However, there are other bores located closer to the borefield (between the borefield and the Kawarren area) that have negligible drawdown. The lack of drawdown is likely to be related to heterogeneities in the local hydrogeology.

Drawdown also varies between the different hydrogeological units and at different depths within the same hydrogeological unit. Bores monitoring the lower part of the LTA show more drawdown than bores monitoring the upper part. Similarly, bores monitoring the lower Mid Tertiary Aquitard (MTD) show greater response than bores monitoring the upper part. The reason for this is that drawdown in an aquifer takes more time to move vertically, so the drawdown responses in formations overlying the LTA will be more subdued than those in the LTA some distance from the point of extraction. In addition to this, lower permeability layers in the LTA buffer the surficial aquifers from the effects of pumping.

The conceptual understanding of drawdown in the LTA and how this propagates through the different units was incorporated into the revised numerical groundwater model.

Groundwater surface water interactions

The groundwater surface water interactions in the Barwon and Gellibrand River catchments are reasonably well understood in terms of whether creeks are gaining or losing. In recent times, given the changes in Boundary Creek and Yeodene (Big) Swamp, there has been a significant effort to improve the understanding of groundwater-surface water interactions in this sub-catchment. This included the installation of additional surface water monitoring gauges, additional groundwater bores, vegetation and PASS monitoring sites and a study on the Yeodene Swamp. The overall objective was to understand the potential impacts of groundwater extraction on the creek. The current conceptualisation is described below.

Boundary Creek flows across the Barongarook High over a mixture of outcropping LTA, Basement and Quaternary Alluvium (see Figure 3). The Creek has been divided into three reaches:

1. Upstream of McDonalds Dam
2. McDonalds Dam outlet to the downstream end of Yeodene (Big) Swamp
3. Downstream of Yeodene (Big) Swamp to the confluence with Barwon River.

In Reach 1 hydrogeology is locally variable and groundwater levels in this part of the catchment have not experienced any drawdown in response to the operation of the borefield. Monitoring bores in this part of the catchment indicate the creek is gaining along this reach.

Downstream of McDonalds Dam (Reach 2), the creek flows across outcropping LTA. Groundwater levels in this reach show significant drawdown as a result of the combined influence of drought and borefield operations. Groundwater monitoring data suggests that the creek was gaining along this reach until the late 1990s and since then the creek has become a losing stream upstream of Yeodene (Big) swamp.

In Reach 3, downstream of Yeodene (Big) Swamp, the creek flows across a shallow alluvial aquifer underlain by a regional aquitard. The watertable is close to the surface along this reach. Nested bores show there is an upward gradient from the underlying aquitard to the alluvial aquifer which indicates that groundwater levels in the aquitard have been buffered from the drawdowns observed in the LTA. Groundwater surface water interaction in this part of the catchment is likely to be gaining as demonstrated by the levels in the shallow aquifer.

This conceptual understanding of groundwater surface water interactions was incorporated into the revised numerical model.

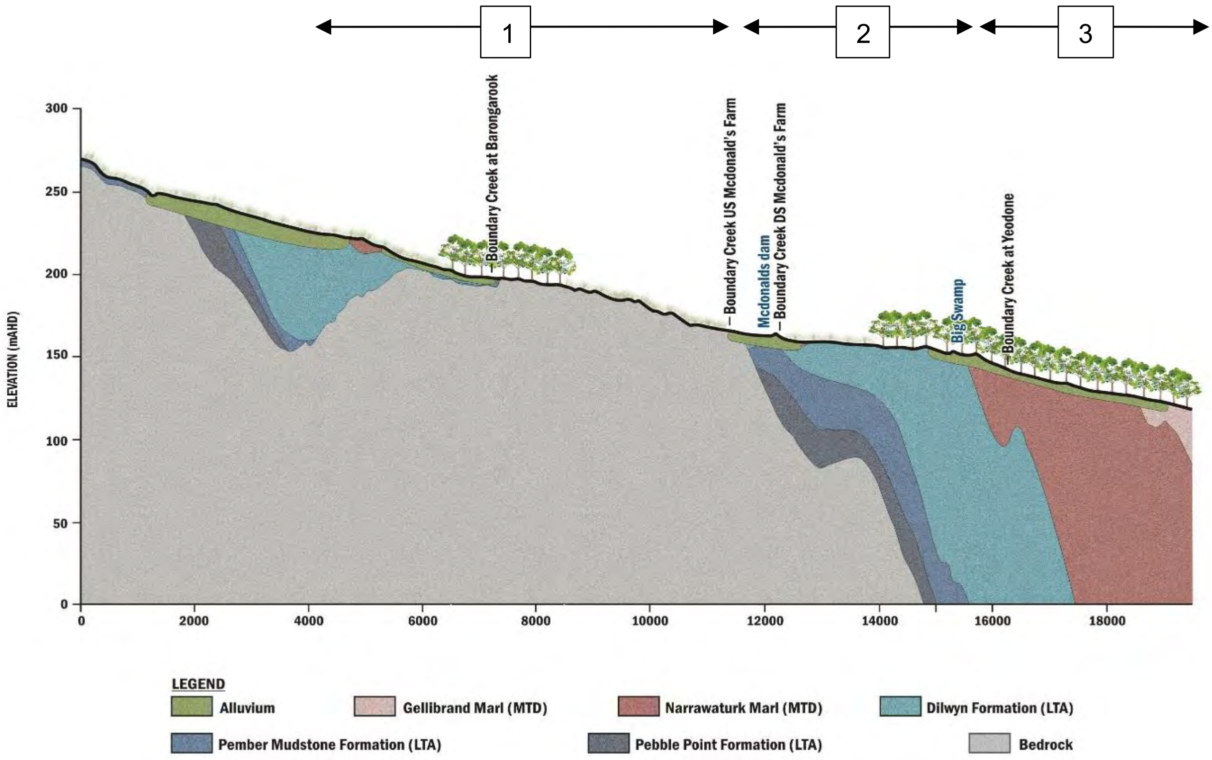
Vegetation monitoring sites

The licence conditions for the groundwater extraction licence for Barwon Downs specify that Barwon Water monitor and protect riparian vegetation, especially vegetation that is groundwater dependent. Although the vegetation condition across the catchment has been monitored regularly since the mid 1990s, a more comprehensive monitoring program was recommended in previous studies to provide more confidence in the results.

A revised monitoring network was established in 2014/15 and comprises 14 vegetation monitoring transects located in potential groundwater dependent ecosystems throughout the Otway Forest. Monitoring locations are defined as reference and impact sites located where the Lower Tertiary Aquifer (LTA) is unconfined and confined, to compare and contrast the likely causes of potential changes in vegetation condition.

The Technical Works Monitoring Program identified that the majority of these sites have local alluvial aquifers that are buffered from impacts from drawdown induced by groundwater pumping (Jacobs 2017a, Jacobs, 2017b). The exception to this is T2, which is located in Reach 2 of Boundary Creek where groundwater levels have declined in response to pumping, and the alluvial aquifer is not present in this reach. The shallow groundwater bores at this location are currently dry. There is no evidence from observed data that predicted drawdown in the regional aquifer as a result of historic pumping has propagated to the shallow alluvial aquifer at any other monitoring sites.

Figure 3: Hydrogeological long section along Boundary Creek



PASS monitoring sites

There are several areas in the Barwon River catchment with ASS, the most well know of these is Yeodene (Big) Swamp, which causes water quality issues in the lower reach of Boundary Creek. Given the community interest in potential impacts from the borefield and acid sulphate soils, Barwon Water initiated a review of potential acid sulphate soils across the catchment (Jacobs 2017a, Jacobs, 2017c).

A total of 14 sites were identified through a combination of desktop assessment and field inspections. Soils samples were collected at six of these sites to confirm the presence or absence of ASS. All sites were found to have ASS. Of these, four sites were selected for a baseline monitoring program that would involve ongoing monitoring of groundwater and surface water. The sites selected are located in areas where groundwater levels have declined in response to pumping from Barwon Downs borefield. These sites have been selected for the PASS baseline assessment and will be monitored to assess potential impacts on PASS from the borefield.

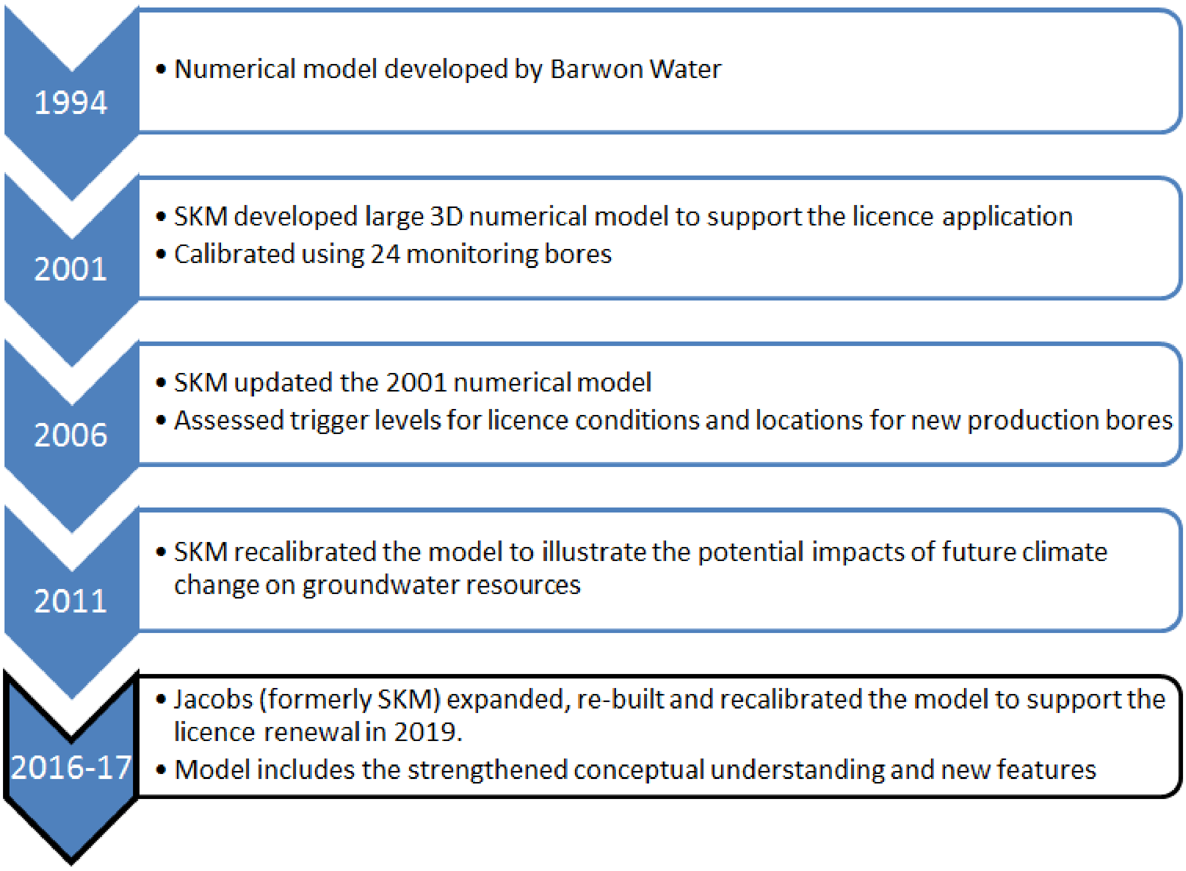
Numerical groundwater model – calibration

The numerical groundwater model has been developed and refined over the years and an overview is shown in Figure 4. The most recent calibration 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. More detail on the re-calibration is outlined in Jacobs (2018a).

The model is conservative in some areas (that is, it over-states the potential effects), in particular areas where there are Quaternary aquifers present (but not in the model) and regional aquitards. These physical constraints that restrict groundwater flow (and therefore drawdown impacts) are present in the real world, but not well represented, or include significant levels of predictive uncertainty in the model.

The Technical Works Monitoring Program has confirmed the presence of many Quaternary alluvial aquifers which are not influenced by pumping (Jacobs 2018a). In these areas, the model over predicts impacts caused by pumping and thus also over-predicts the subsequent risk to environmental receptors. The predicted impacts in these areas and associated risk will need to be confirmed with further technical site-specific investigations to understand the best way to mitigate potential adverse impacts receptors in this area.

Figure 4: Overview of the development and calibration of numerical models of the Barwon Downs Graben



Numerical groundwater model – predictive scenarios

The revised model was used to run predictive scenarios to quantify the potential impacts of operating the borefield in the future. The climate sequence used to derive recharge rates and pumping regimes for the predictive models was based on measured daily rainfall from 1st January 1971 to 31st December 2014 with an additional 7 years of "average" conditions to make 50 years. This climate sequence was selected as it incorporates recent climate change and includes a wet period, a dry period (i.e. Millennium Drought) and an average period. The average years were included at the end of the climate sequence to allow the groundwater system to recover after a long dry period. The resultant climate sequence was then modified to produce the various climate change scenarios described below.

Climate change scenarios

Consistent with the Guidelines for Assessing Climate Change on Water Availability in Victoria (DELWP, 2016), four climate change scenarios were applied to each pumping scenario:

- Low climate change – 10th percentile of the global climate models (GCM),
- Medium climate change – 50th percentile of the GCM,
- High climate change – 90th percentile of the GCM,
- Step change climate change – repeat of the climate sequence between July 1997 to 2016.

The different climate scenarios have a significant influence on recharge to the LTA, as the primary recharge mechanism is rainfall infiltration over the LTA outcrop area. The historical recharge and the predicted future recharge based on the assumed climate regime and the climate change scenarios is shown in Table 3.

Table 3: Predicted recharge to the LTA outcrop area for the different climate change scenarios

Climate change scenario	Groundwater recharge over LTA Outcrop (ML/year)	Comment
Current	5,835	Average recharge in the calibration model (30 years)
Low	6,336	This is an increase of 8% compared to average over last 30 years
Medium	5,371	This is a reduction of 8% compared to average over last 30 years
High	4,410	This is a reduction of 25% compared to average over last 30 years
Stepped	4,145	This is a reduction of 29% compared to average over last 30 years

Pumping scenarios

Four pumping scenarios were run:

- Model Scenario 0 – no historical or future pumping from Barwon Downs. The baseline used to estimate cumulative impacts (the combination of remnant impacts from previous borefield operations and those predicted in future) of different pumping regimes.
- Model Scenario 1 – no future pumping from Barwon Downs. This scenario is used to predict the rate of aquifer recovery from historical pumping and to estimate incremental impacts (impacts due to future pumping only).
- Model Scenario 2 – constant rate (future) pumping. This scenario is used to predict the potential impacts if the borefield is operated at a constant rate of 4,000 ML/year.
- Model Scenario 3 – intermittent (future) pumping. This scenario is used to predict the potential impacts assuming the borefield is operated in a similar manner to that used historically. Extraction rates are higher over shorter timeframes where the resource is needed to supplement surface water storages during drought. The pumping included in this scenario is in line with the current license application and has been derived from water demand modelling.

The results from the predictive scenarios are summarised below. The results are discussed in terms of the potential impacts on the LTA and the risk to baseflow to rivers, groundwater dependent vegetation and PASS.

Potential impacts on the LTA

To address section 40 (D) of the Water Act (1989), potential adverse effects of the allocation on the aquifer were considered. The technical works completed to date demonstrate that there is no adverse effect on the LTA likely to arise from the allocation or use as proposed under the licence application.

The potential adverse effects of the groundwater extraction from the Barwon Downs borefield on the LTA or any other aquifer was considered in terms of the following:

- Groundwater mining leading to long term loss of groundwater storage from the resource as a whole,
- Degradation of the aquifer through irreversible changes of the aquifer matrix, and
- Loss of beneficial uses due to degradation in water quality.

Groundwater mining

There has been some community concern that the aquifer is being mined. This refers to operations where groundwater extraction rates exceed recharge rates, so groundwater levels decline over the long term (50 to

100 years). In the case of Barwon Downs, the proposed extraction rates do not exceed recharge. In addition to this, the rate of decline in groundwater levels is predicted to stabilise slowly over time. When pumping ceases, groundwater levels have recovered in the past, and are predicted to recover in the future. The aquifer will return to its pre-development condition when pumping ceases.

The maximum proposed 15 year extraction limit is 60,000 ML. The predicted recharge rates and the proposed extraction rates as a percentage of the recharge is shown in Table 4. Based on the assumptions used in the groundwater model, the percentage of recharge proposed to be extracted ranges between 63% and 97%. Irrespective of the balance between recharge and long term groundwater extraction, while the borefield is operational, groundwater levels will always be lower than pre-pumping groundwater levels. This is a feature of all groundwater extractions in all aquifers.

Table 4: Recharge rates compared to proposed extraction limit

Climate change scenario	Groundwater recharge to LTA (ML/year)	15 year recharge rate (ML)	Proposed extraction rate of 60,000 ML
Low	6,336	95,040	63% of recharge
Medium	5,371	80,565	76% of recharge
High	4,410	66,150	90% of recharge
Stepped	4,145	62,175	97% of recharge

Irreversible changes to the aquifer matrix

It is acknowledged that in certain circumstances, groundwater extraction and drawdown can reduce pressures in confined aquifers to a level that will induce settlement in the aquifer itself that could permanently diminish its ability to transmit and store water. In most instances of reported land subsidence arising from groundwater extraction, the compaction has occurred in clay rich aquitards that bound the productive aquifers. For this reason, groundwater extraction is not likely to impact on the aquifer matrix.

Groundwater salinity

Groundwater salinity has been monitored in accordance with the groundwater extraction licence and while there has been some variability in groundwater salinity, operating the borefield has not had an adverse impact on the groundwater quality. If anything, the groundwater salinity has decreased in all bores since monitoring commenced. The range of salinities recorded is within the typical range expected for the LTA.

In summary, the proposed groundwater extraction rates are not expected to cause adverse impacts to the LTA.

Risk assessment framework for receptors

The potential risk to receptors in the study area was assessed using a method based on the Ministerial Guidelines for High Value Groundwater Dependent Ecosystems (GDEs) which were developed by the Department of Environment, Land, Water and Planning. These guidelines have been adopted for the Barwon Downs region to assess the potential risk to vegetation and rivers and have also been adapted to assess the risk to PASS. 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 PASS.

The risk has been considered in terms of potential unmitigated and mitigated risk where:

- **Unmitigated risk** is based on the risk assessment framework and defined by the depth to watertable and drawdown predicted in the groundwater model.
- **Mitigated risk** considers modelled drawdown accounting for the physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in the real world, but not well

represented or include significant levels of predictive uncertainty in the model. These include alluvial aquifers and the regional aquitards.

For receptors classified as high risk, the Guidelines note that further work is required to confirm the presence of high value GDEs, their connectivity to groundwater and sensitivity to changes in groundwater levels.

Risk assessment outcomes across the study area

The key outcomes of the risk assessment for vegetation, PASS and rivers is detailed in Table 5. For each receptor there is typically a range of risk depending on the location and proximity of the receptor to the borefield. This table presents the maximum mitigated (residual) risk for each environmental receptor in the final column. The residual risk considers the physical mitigating constraints that restrict groundwater flow and drawdown impact present in real world but have a higher degree of uncertainty in the model, including alluvial aquifers and the aquitards.

The maximum predicted change in the groundwater flux to the rivers is documented for each river/creek.

Table 5: Outcomes of the risk assessment for environmental receptors across the study area

Environmental receptors	Risk assessment outcomes	Maximum residual risk ranking
Vegetation across the catchment	Vegetation monitoring of the 14 sites has demonstrated that most of these sites have local alluvial aquifers that are buffered from impacts from drawdown induced by groundwater pumping. The exception to this is T2, which is located in Reach 2 of Boundary Creek where groundwater levels have declined in response to pumping, which is discussed in Table 3. There is no evidence from observed data that predicted drawdown in the regional aquifer as a result of historic pumping has propagated to the shallow alluvial aquifer at any other monitoring sites. Over the majority of the study area vegetation is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. Areas of high risk exist where the regional aquifer outcrops and there are no alluvial aquifers. For example, on the Barongarook High, along Reach 2 of Boundary Creek and small areas along the Gellibrand River. In summary groundwater dependent vegetation across 98% of the study area is classified as low residual risk and 2% is classified as high residual risk. Vegetation dependent on groundwater in the regional aquifer in the areas of high risk has the potential to be impacted by drawdown from the borefield.	High risk in small areas where the regional aquifer outcrops and there are no local alluvial aquifers.
Potential acid sulfate soils	Naturally occurring PASS sites have the potential to be oxidised and become acidic, as a result of declining groundwater levels in response to pumping. Site specific investigations at the four PASS monitoring sites indicate that all sites have a local shallow alluvial aquifer overlying the regional aquifer/aquitard. Monitoring has demonstrated that PASS sites interacting with local alluvial aquifers are buffered from impacts from drawdown induced by groundwater pumping. Over the majority of the study area PASS are considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers providing an additional source of water. There are small areas of high risk along Reach 2 of Boundary Creek and Barwon River East Branch. Naturally occurring PASS sites are present in these areas and the regional aquifer outcrops at these locations.	High risk in Reach 2 of Boundary Creek and Barwon River East Branch.

Environmental receptors	Risk assessment outcomes	Maximum residual risk ranking
	Although there are small areas of high risk (as determined by predicted drawdown) along the Gellibrand River, there are no known areas with naturally occurring PASS in this location.	
Boundary Creek flows reach 1	Reach 1 is a low risk classification as drawdown has not extended to this part of the regional aquifer.	Low
Boundary Creek flows reach 2	Reach 2 of Boundary Creek, where the creek flows over the regional aquifer between McDonalds Dam and Yeodene Swamp, is considered to be at high risk of potential impact. The predicted reduction in groundwater contribution to the river is around 2 ML/day which is more than 100% of low flows. The predicted drawdown with potential future pumping is predicted to be marginally less than historical pumping. Regardless of future pumping, if remediation works are not undertaken, groundwater levels in reach 2 of Boundary Creek are predicted to take 20-30 years to recover from historic pumping and for Boundary Creek to become a gaining creek.	High
Boundary Creek flows reach 3	Reach 3 is a medium risk classification as this reach is not directly connected to the regional aquifer.	Medium
Barwon River (east branch)	Barwon River East branch is thought to be gaining flow from groundwater in some sections where it flows over the Lower Tertiary Aquifer to the south east of the borefield. The model over predicts drawdown in this local area due to the representation of the fault, the aquitard and local alluvial aquifers. In this local area, the model predictions are conservative and most likely an overestimate. Predictive scenario modelling indicates that the greatest risk of impact to the Barwon East Branch will occur to the south of the intersection between the river and the Birregurra-Forrest Road. Given the potential physical mitigating factors, the Barwon River is classified as potential medium risk where the East Branch flows over the aquifer and aquitard. The model has highlighted there could be a potentially significant impact to surface flows in the East Branch during low flow periods.	Medium
Barwon River (west branch)	The mitigated risk to the West Barwon River is considered low where it flows over the aquifer and aquitard due to the presence of alluvial aquifers.	Low
Barwon River (confluence)	Downstream of the confluence between the East and West Branches, the mitigated risk is considered low as alluvial aquifers are present.	Low
Dividing Creek	Dividing Creek is a losing creek that is disconnected from the regional aquifer. The risk classification for Dividing Creek is medium because although there is a low likelihood that the stream is connected to the regional aquifer, more than 2 m of drawdown is predicted.	Medium
Gellibrand River	The Gellibrand River is a key discharge feature for the regional aquifer. Alluvial sediments are present in the floodplain and this local aquifer will be buffered from drawdowns predicted in the regional aquifer. The risk to the Gellibrand River is considered to be medium given the presence of an alluvial aquifer. However, there are some small areas of high risk where the alluvial aquifer may not be present and the Lower Tertiary Aquifer outcrops at the surface.	Medium
Porcupine Creek	Porcupine Creek flows over the aquitard and into Loves Creek which is a tributary of the Gellibrand River. The risk to the creek is considered to be low	Low

Environmental receptors	Risk assessment outcomes	Maximum residual risk ranking
	given the potential physical mitigating factors such as the presence of alluvial aquifers that buffer the effect of pumping.	
Ten Mile Creek	Ten Mile Creek is a tributary of Loves Creek and flows over a small outcrop of the Lower Tertiary Aquifer. The creek is considered to be a gaining creek where it flows over the aquifer. Modelling predicts that there is a low to medium risk to the creek, given the physical mitigating factors such as the presence of alluvial aquifers.	Medium
Yahoo Creek	Yahoo Creek is also a tributary of Loves Creek and similar to Ten Mile Creek, the creek flows the regional aquifer in the upper reaches. Given the physical mitigating factors such as the presence of alluvial aquifers, the modelling predicts that there is a low risk to majority of the creek and small areas of medium risk.	Medium
Loves Creek	Loves creek predominantly flows over the aquitard, however the aquifer outcrops near the confluence with the Gellibrand River, where drawdown is predicted to be minor (less than 0.1 m). Given the presence of mitigating factors such as the presence of alluvial aquifers and regional aquitards, the risk is considered to be low as a result of low connectivity with the regional aquifer.	Low
Barongarook Creek	Barongarook Creek is located north of Boundary Creek and flows north west to Lake Colac. The creek flows over the aquitard and modelling predicts that there is a medium risk in the upper reaches of Barongarook Creek and a low risk for the lower reaches.	Medium

Summary

The key findings for the impacts and risk assessment are:

1. Groundwater levels in the LTA will be lower than pre-pumping levels as long as the borefield is operational. The proposed extraction limit of 60,000 ML over 15 years ranges between 63% and 97% of the predicted recharge rate to the LTA over the same timeframe, depending on the climate scenario.

2. The aquifer is not being mined. Modelling has demonstrated that the rate of decline in groundwater levels in response to pumping stabilises slowly over time and when pumping ceases, groundwater levels rise. The rate of recovery may be slow (i.e. 20-50 years) in some areas, however the aquifer is predicted to recover to near pre-pumping groundwater levels.

3. There is no comparable difference in overall risk between operating the borefield at a constant rate of 4 GL/year compared to intermittent pumping (for the same total volume extracted over 15 year the licence period).

4. Groundwater modelling and risk assessment indicate that operating the borefield according to the intermittent pumping scenario can be considered to be sustainable, providing the current trigger levels are maintained and additional site-specific studies are completed in areas identified as high risk, to confirm that high value GDEs are either not present or not impacted by pumping.

5. The predicted impacts associated with operating the borefield are either similar to, or less than, the impacts that have occurred historically. That is, predicted drawdown is typically less than what was observed during the Millennium Drought and is not predicted to be any worse.

6. The proposed groundwater extraction rates are not expected to cause adverse impacts to the LTA in terms of aquifer mining, changes to the aquifer matrix or groundwater salinity.

7. Where the LTA is unconfined, the model predicts more than 15 m drawdown in some areas on the Barongarook High. While this is classified as a high impact on the aquifer, the impact can be offset by the provision of the supplementary flow to Boundary Creek.

8. It is acknowledged that the same area (Reach 2 of Boundary Creek) was highlighted as a potential high impact area to the aquifer and Boundary Creek in the previous licence, and a supplementary flow was recommended to offset the impacts. Barwon Water have provided the supplementary flow according to the licence conditions, however there have been issues with the supplementary water being released downstream of McDonalds Dam during the summer months. These issues and their effect have been described in detail in Jacobs (2018b).

9. The model over-predicts drawdown in many areas at the surface as a result of physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in the real world, but not represented well in the model or include a higher degree of uncertainty. These include the presence of alluvial aquifers and the regional aquitard.

10. Most of the catchment will not be significantly impacted by pumping because of physical hydrogeological barriers that buffer drawdown in the regional aquifer at or near the surface.

11. While operating the Barwon Downs borefield is likely to reduce groundwater contribution to rivers and creeks, the risk associated with these impacts is typically low to medium. Further investigation of the high risk areas is warranted to determine the nature of the impact and if further mitigating measures are required. Exceptions to this are Reach 2 of Boundary Creek and potentially the middle reaches of the Barwon River East Branch, which are both classified as high risk.

12. The majority of the study area vegetation is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. Approximately 2% of the area is at high risk in areas located along Reach 2 of Boundary Creek, Barwon River East Branch and the Gellibrand River. A study using NDVI to assess potential impacts from historical pumping on trees across the vegetation monitoring sites showed no evidence of impact on vegetation health.

13. The drawdown predicted at the PASS monitoring sites is within the range of drawdown experienced in the past and a baseline assessment in 2015 highlighted there was no evidence of drawdown from the borefield influencing PASS at these sites.

Proposed Management Plan

The proposed management plan involves recommendations for ongoing monitoring of groundwater levels, surface water, vegetation monitoring sites and PASS monitoring sites. Trigger levels for key groundwater bores are also recommended, which includes the existing triggers as well as additional triggers in areas identified as potential high risk. The monitoring plan and recommended triggers are outlined below.

Groundwater monitoring

There are 89 bores that are currently monitored in the Barwon Downs graben and all bores that are currently monitored are recommended for ongoing monitoring. The primary objective of monitoring these bores is to record accurate and timely observations of water level responses to pumping and climate variability.

Although there has been a rationalisation of the SOBN monitoring network, Barwon Water has also expanded the monitoring network to address key data gaps and there are bores monitoring every hydrogeological unit, with the exception of the Pember Mudstone. More detail on the bores recommended for monitoring is outlined in Section 12.1.

In accordance with the, the groundwater salinity has been monitored in bores 109114, 107720 and 102868. The salinity has been monitored annually since 2004 and ongoing annual monitoring of the salinity in these bores is recommended in the future.

Surface water monitoring

There are currently 12 relevant surface water gauges that are currently monitored:

- 5 gauges on Boundary Creek
- 4 gauges on the Barwon River
- 3 gauges on the Gellibrand River

Two additional gauges are recommended to be re-instated – one on Ten Mile Creek and one on Yahoo Creek. This is discussed in more detail in Section 12.4.

Vegetation monitoring

A condition of the existing licence specifies vegetation condition to be monitored at specific sites. As described in Section 9.1, the vegetation monitoring network was re-designed in 2014 to ensure the monitoring locations target areas that are groundwater dependent. The revised list of vegetation monitoring sites is recommended for on-going monitoring as part of this licence application, together with the corresponding monitoring bore details. This is described in more detail in Section 12.5.

PASS monitoring

Although monitoring of PASS is not a condition of the existing licence, naturally occurring PASS sites are known to exist in the study area and are therefore recommended as part of the ongoing licence. Four PASS monitoring sites have been installed (at areas representing the relatively highest risk of impact) and ongoing monitoring of the soils, surface water and groundwater levels at these site is recommended to monitor potential borefield impacts on PASS. This is described in more detail in Section 12.6.

Trigger levels

The risk assessment identified key environmental receptors that may be at risk from future pumping. These environmental receptors will require close monitoring into the future. Accordingly, appropriate triggers and management responses were identified to allow Barwon Water to actively manage and prevent adverse impacts from pumping. These triggers and management responses will need to be reassessed and, where appropriate, adjusted as more site specific information becomes available.

Table 6 provides an overview of the recommended trigger levels and more detail is provided in Section 12.7.

Table 6: Summary of trigger levels

Receptor	Intent of trigger	Trigger	Management action
Regional groundwater levels	• To ensure the extraction rates are sustainable	• Groundwater observation bore 64229 (G13) to be set at 85.2 mAHD	• Reduce pumping rates until the groundwater level has recovered above the trigger value
		• Groundwater observation bore 64236 (G20) to be set at 98.7 mAHD	
		• Groundwater observation bore 82844 (M28) to be set at 124.1 mAHD	

Receptor	Intent of trigger	Trigger	Management action
		• Groundwater observation bore 109131 (Yeo40) to be 142.3 mAHD.	
Boundary Creek	• To indicate when supplementary flows are required to ensure a minimum flow in Boundary Creek	• Groundwater observation bore 109131 (Yeo40) to be 158.5 mAHD which was the groundwater level prior to 1997 (may need to be adjusted pending outcomes of survey of stream bed elevation) AND minimum flow of 0.5 ML/day in Yeodene Swamp	• Provide a supplementary flow to Reach 2 of Boundary Creek. The required volume of this flow will be confirmed by future studies focussing on the remediation of the Yeodene Swamp.
Gellibrand River	• To maintain adequate upward gradient to ensure groundwater base flow contribution to the river during summer flow conditions	• If river is gaining in area identified at high risk, groundwater level in the regional and alluvial aquifer remains >0.5m above the streambed elevation bed. • Note that this trigger will require further investigation before it can be fully implemented	• Reduce pumping rates until the groundwater level has recovered above the trigger level
Ten Mile Creek	• To maintain upward gradient into the creek to ensure adequate groundwater base flow contribution to the river during summer flow conditions	• Trigger level in bore 113705 to be 0.5m above the average stream bed elevation • Trigger level in bore 113706 to be 0.5m above the average stream bed elevation	• Reduce pumping rates until the groundwater level has recovered above the trigger level
Barwon River East Branch	• To enable upward gradient into the river so as to maintain adequate groundwater base flow contribution to the river during summer flow conditions	• If river is gaining in area identified at high risk, groundwater level in the regional aquifer remains >0.5m above the streambed elevation bed. • Note that this trigger will require further investigation before it can be fully implemented	• Reduce pumping rates until the groundwater level has recovered above the trigger level
Vegetation	• To ensure water is available for the groundwater dependent vegetation in Reach 2 of Boundary Creek (T1 and T2)	See trigger for Boundary Creek	
PASS	• No recommended triggers for pumping as PASS monitoring sites are not directly connected to the regional aquifer.		

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to assess the impacts of the future operation of the Barwon Downs borefield beyond the existing licence, in accordance with the scope of services set out in the contract between Jacobs and Barwon Water. That scope of services, as described in this report, was developed with Barwon Water.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Barwon Water and/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 conclusions as expressed in this report may change.

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

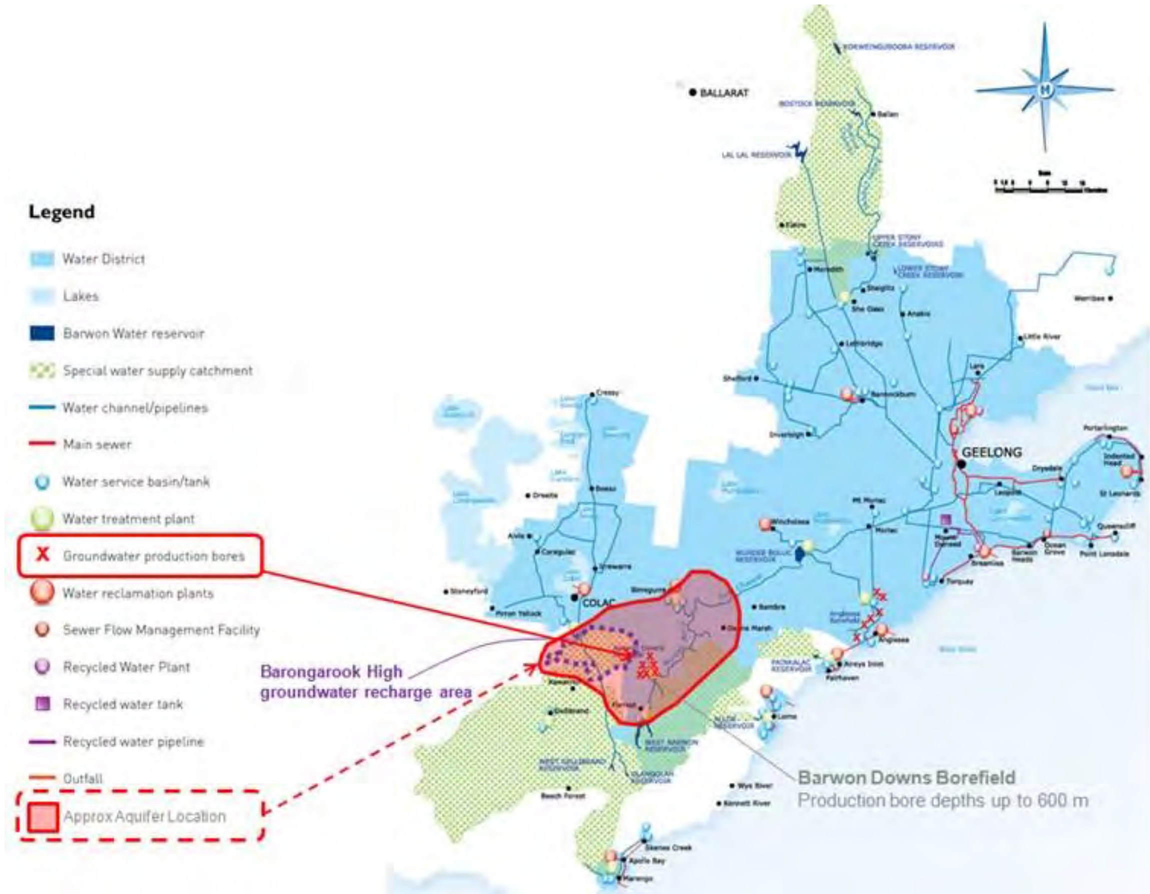
This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, Barwon Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Barwon Water. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

This report has been prepared specifically to fulfil the requirements of the Groundwater Assessment Report required by Groundwater Extraction Licence No. BEE032496 (formerly #893889) and is intended to accompany the application for renewal of the licence. The groundwater licence is associated with the Barwon Downs borefield, which is located approximately 70 km south west of Geelong and 30 km south east of Colac (refer to Figure 1-1).

Figure 1-1 Map of the Barwon Downs region including the aquifer extent and the primary groundwater recharge area



1.1 Objective

The GAR provides an overview of the technical studies commissioned by BW since 2004. These studies were designed to address key data gaps and improve the understanding of potential impacts associated with the Barwon Downs borefield. The key objectives of this report are to:

- Consolidate the available technical information
- Outline the approaches used to assess the potential impacts associated with groundwater extraction from the borefield
- Present the results of the numerical modelling and risk assessment to quantify the predicted impacts, and
- Recommend a monitoring and management plan for the new licence that mitigates areas with potential high risk.

1.2 Scope

The Barwon Downs borefield is owned and operated by Barwon Water and extracts groundwater under licence from Southern Rural Water. This licence authorises the works and take and use of groundwater and was granted in 2004 and is due for renewal by June 2019.

The take and use licence makes provision for extraction limits on a volumetric basis over a range of time scales. As part of the licence conditions, Barwon Water monitors groundwater levels and quality, land subsidence, surface water flow in Boundary Creek and the Barwon River. The licence also requires protection of riparian vegetation, protection of stock and domestic use and protection of flows in the Barwon River tributaries.

Reporting of compliance against these licence conditions is provided in an annual report to Southern Rural Water who administers and regulates groundwater licences as a delegate of the Water Minister.

The scope of this document is to present a summary of the findings of technical studies conducted during the period of the current licence and to fulfil the requirements of licence conditions 7.2 (b) and 9.4 (b).

These conditions state:

- 7.2 (b). when it applies for the renewal of this Licence, a report assessing the degree of dependence of riparian vegetation at the sites specified in sub-clause 7.1 on the regional groundwater system, and that includes recommendations for any further work necessary to ensure their protection.

- 9.4 (b). when it applies for the renewal of this Licence, a report containing an assessment of the loss of flow in the East Barwon River between the stream gauge referred to in sub-clause 9. l and the aqueduct crossing on the East Barwon River east of Yaugher due to pumping under this Licence.

The groundwater assessment report also includes a management plan for potential impacts on environmental receptors and reporting requirements to the delegate. The management plan outlines the recommended monitoring requirements for groundwater, surface water, vegetation, potential acid sulfate soils and subsidence and also recommends triggers levels and actions where necessary.

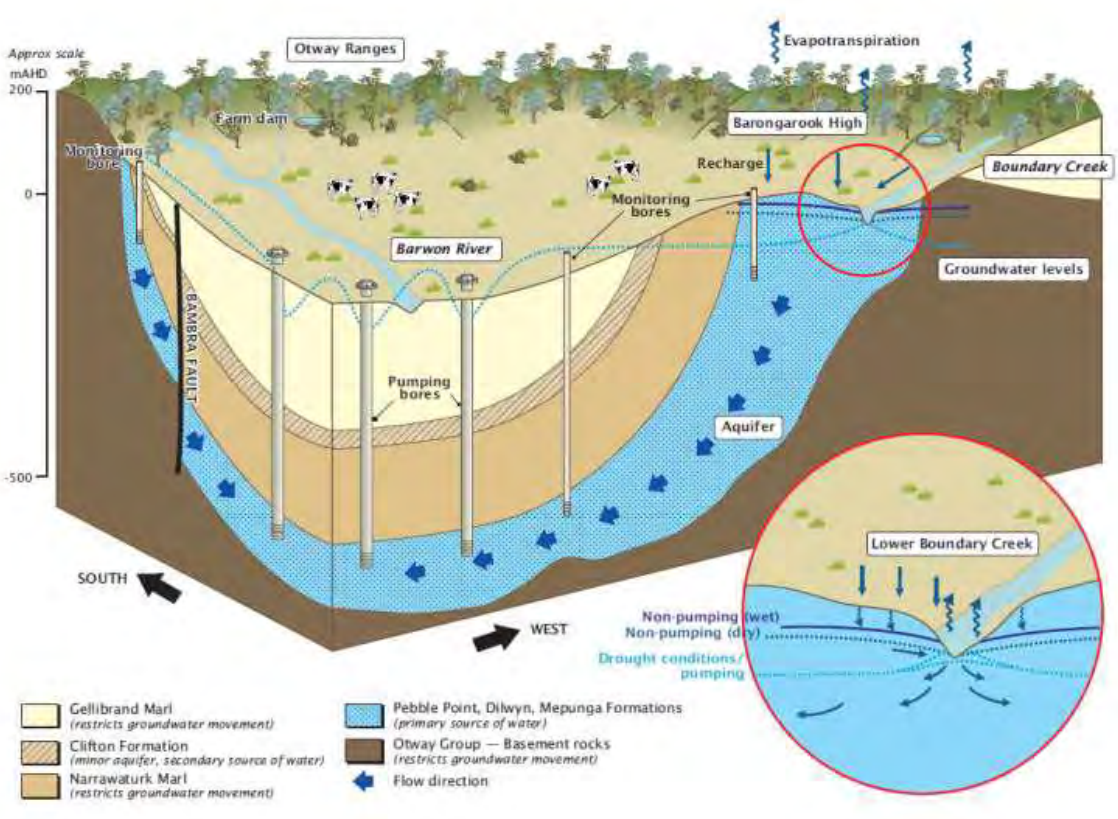
2. Barwon Downs study area

2.1 Location

The Barwon Downs borefield is located in the Otways in southwest Victoria, approximately 100 km southwest of Melbourne, between the town of Colac to the north and the Otway Ranges to the south. The borefield extracts groundwater from the Lower Tertiary Aquifer (LTA) at a depth of around 500 m. Figure 2-1 shows a conceptual diagram of the LTA and overlying hydrogeological units within the Barwon Downs graben.

Surface elevation is highest in the west of the study area known as the Barongarook High, near the settlement of Barongarook. The topographic high is the primary recharge area for the LTA and also contains the headwaters of a number of creeks and streams that drain radially to the north, south, east and west (e.g. Boundary Creek).

Figure 2-1 Schematic of the Lower Tertiary Aquifer and where it outcrops at the surface

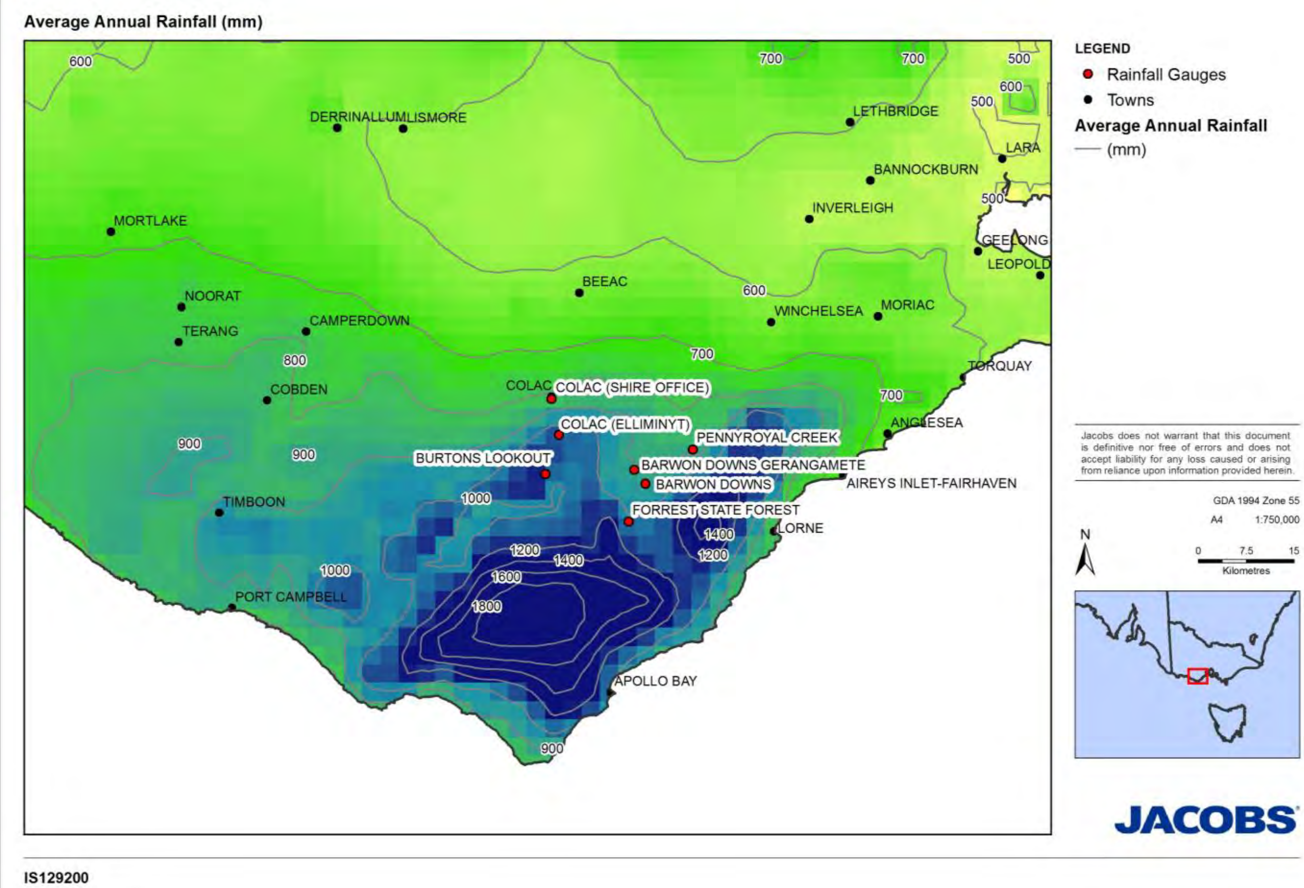


2.2 Rainfall

There are five operational rainfall gauges in the area that are monitored by the Bureau of Meteorology (BOM) as part of the national rainfall monitoring network. The location of these gauges is shown in Figure 2-2. Of the seven gauges shown in this figure, Burtons Lookout and Colac (Elliminyt) are no longer operational.

Figure 2-2 also shows the distribution of rainfall across the region. The Otway Ranges are one of the wettest places in Victoria with rainfall greater than 1,500 mm per year in the highest parts of the ranges. There is a steep rainfall gradient across the Otways and the average annual rainfall varies from 800 in the north to 1,800 mm in the south.

Figure 2-2 : Rainfall distribution across the study area



The Forrest State Forest rain gauge has been used to understand the influence of rainfall variability over time for the Technical Works Monitoring Program. This gauge was selected as it is centrally located and has a long record. The other rainfall gauges continue to be monitored by BOM.

Figure 2-3 shows the cumulative deviation from the mean monthly rainfall at the Forrest State Forest and Barwon Downs rainfall gauges since 1900. This plot highlights periods of above and below average rainfall conditions (e.g. drought), where periods of above average rainfall are represented by rising trends and periods of below average rainfall are shown as declining trends.

Figure 2-3 shows a significant period of below average rainfall conditions was experienced between 1915 and 1945. Rainfall was generally above average between 1945 and 1995 with two periods of drought in the late 1960s and early 1980s. Since 1995 rainfall has fluctuated between periods of below average and average conditions. This long term rainfall record highlights that the Millennium Drought (1998-2010) was not unprecedented and are likely to be experienced in the future.

Figure 2.4 shows the same rainfall pattern between 1970 and 2000. A significant period of drought was experienced across Victorian between 1997 and 2000, 2005 and 2010 and more recently in 2014 to 2015. These dry periods had a significant impact on surface water flows and groundwater levels across the state, and the Barwon Downs region was no exception to this.

Figure 2-3 : Rainfall cumulative deviation from mean for the Forrest State Forest and Barwon Downs gauges 1900 - 2016

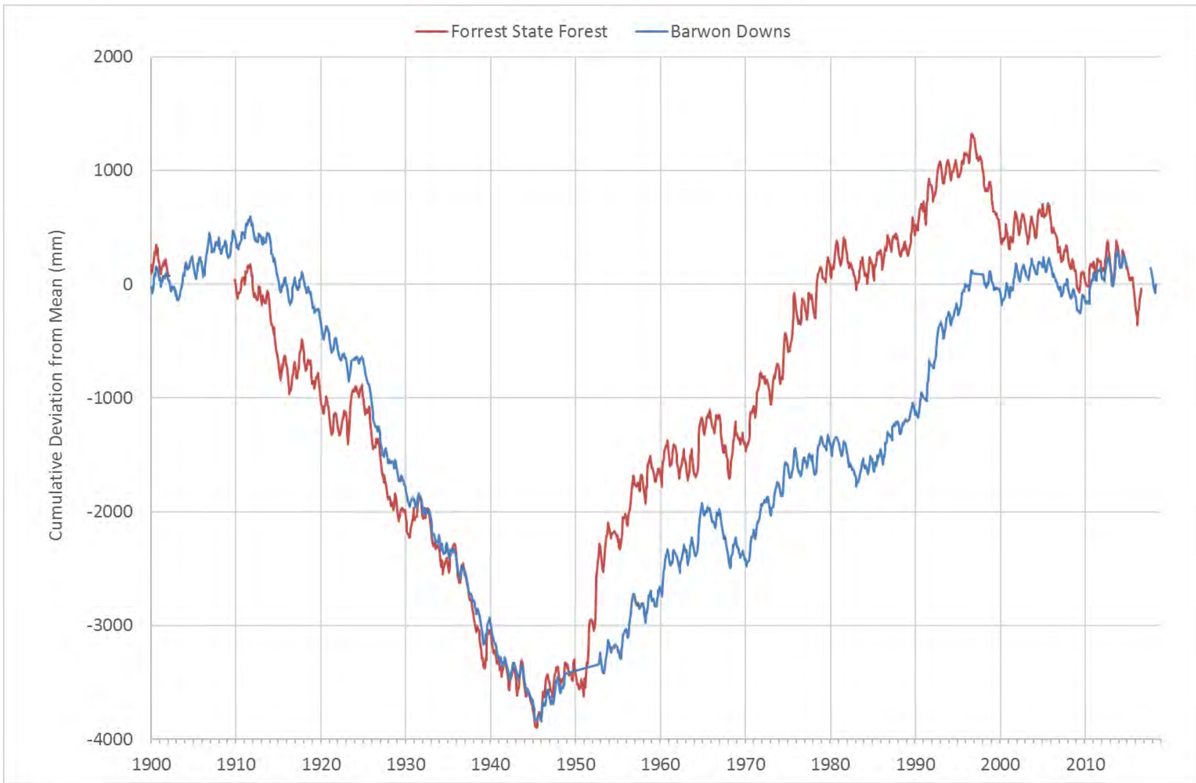
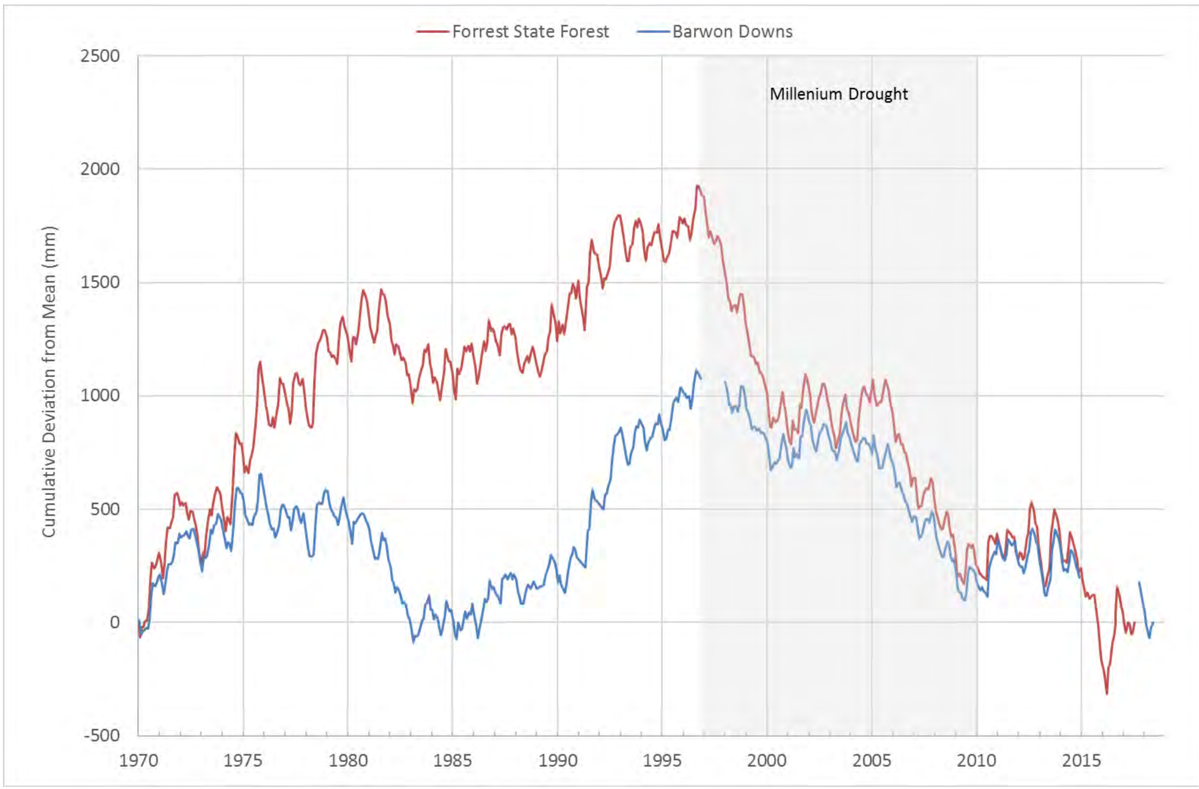


Figure 2.4: Rainfall cumulative deviation from mean for the Forrest State Forest and Barwon Downs gauges 1970 - 2016



2.3 Surface water catchments

The Barwon Downs borefield is located within the Barwon River catchment (see Figure 2-5), however the LTA extends beneath both the Barwon and Gellibrand River catchments.

2.3.1 Barwon River catchment

The majority of the Barwon River's tributaries rise in the Otway Ranges to the south east of the borefield and flow north towards Birregurra. The remaining tributaries, including Boundary Creek, rise in the west of the catchment and flow across the Barongarook High before joining the Barwon River at the Gerangamete Flats. Figure 2-5 shows the location of the borefield in relation to these features.

The technical works program has focussed heavily on the Boundary Creek catchment, given the changes that have occurred in the catchment over the last four decades. Boundary Creek flows across the Barongarook High which is the primary area where there is a surface expression of the LTA. The catchment has also been highly modified over the last century. Changes to the catchment, some of which are permanent and irreversible, have significantly altered the natural hydrological flow regime of Boundary Creek. These changes include a range of natural and human factors including:

- Land clearing and construction of drainage lines across the catchment to facilitate agriculture in the early 1900s
- Construction of the McDonalds Dam in 1979 which has a licence to extract 160 ML/year
- Private diverters and farm dams
- Groundwater extraction from the Barwon Downs bore field
- The drying of Yeodene (Big) Swamp and subsequent fires and fire management including the construction of fire trenches to prevent fire spreading (this has had considerable impacts on both the quantity and quality of water flowing out of the swamp).
- The release of a supplementary flow to Boundary Creek (currently 2 ML/day) as a precautionary measure to mitigate any potential loss of flows impacts on stock and domestic users related to groundwater extraction.

More detail on these changes and their causes is discussed in the following chapters.

2.3.2 Gellibrand River catchment

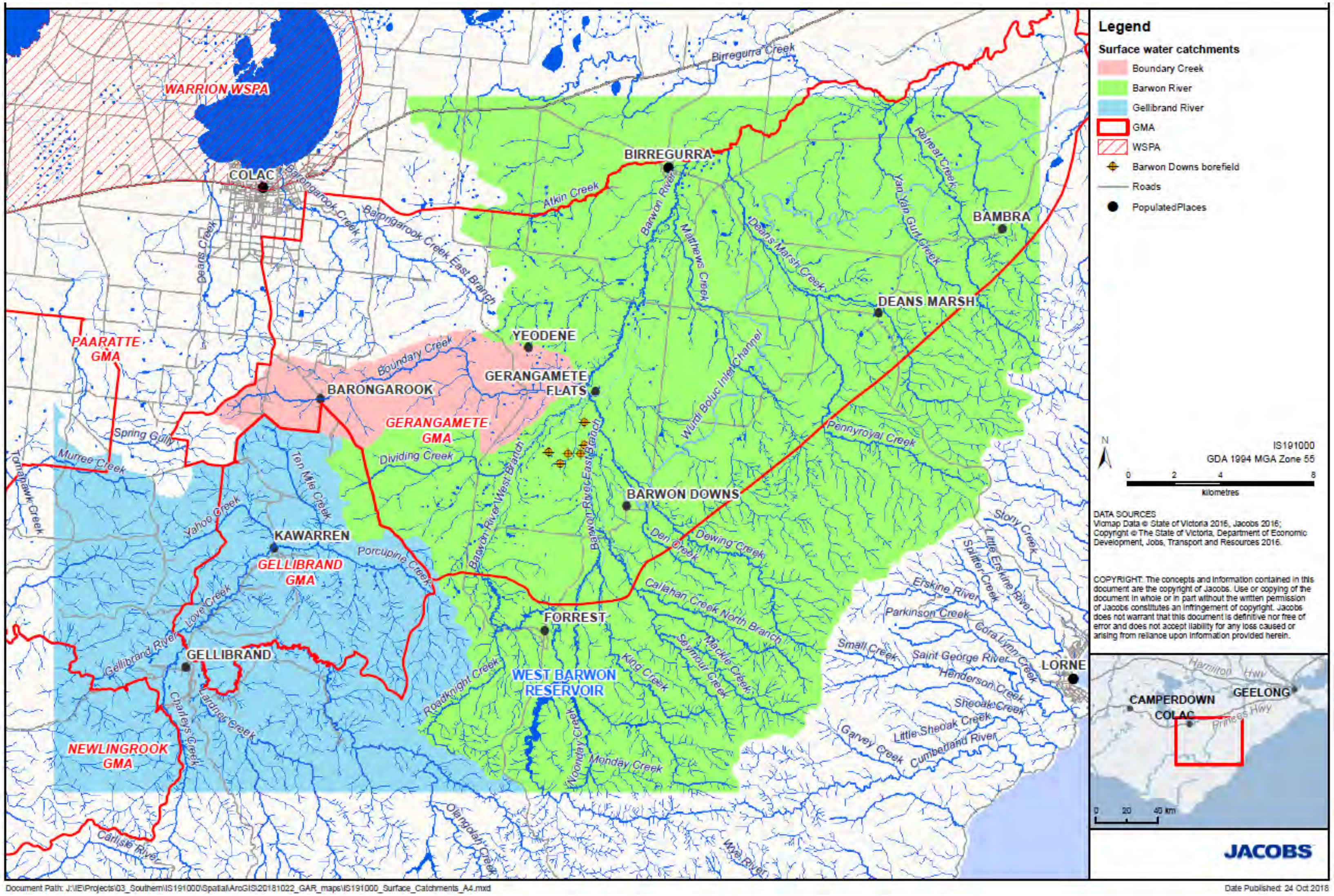
The Gellibrand River is located to the south west of the borefield with tributaries rising in the Otway Ranges and the Barongarook High. This includes Porcupine Creek and Ten Mile Creek which converge and become Loves Creek just upstream of the township of Kawarren (see Figure 2-5). Yahoo Creek is another tributary of Loves Creek and joins the creek downstream of Kawarren.

2.4 Groundwater management areas

Groundwater in the LTA is part of the Gerangamete Groundwater Management Area (GMA) and the boundary is shown in Figure 2-5 (plan reference number LEGL./04-135). The Permissible Consumptive Volume (PCV) is 20,000 ML/year in any one year and 80,000 ML in any consecutive period of ten years (SRW, 2016). The PCV applies to the Middle and Lower aquifer which includes all Lower Mid Tertiary (LMTA) and Lower Tertiary (LTA) Aquifers to 50 metres below the base of the Tertiary age formations or 200 metres from the surface, whichever is the deeper.

The full PCV is currently allocated to Barwon Water for groundwater extraction from Barwon Downs.

Figure 2-5 Location of the Barwon Downs borefield, surface water catchments and Groundwater Management Areas (GMA)



3. Proposed Groundwater Extraction

3.1 Barwon Downs borefield

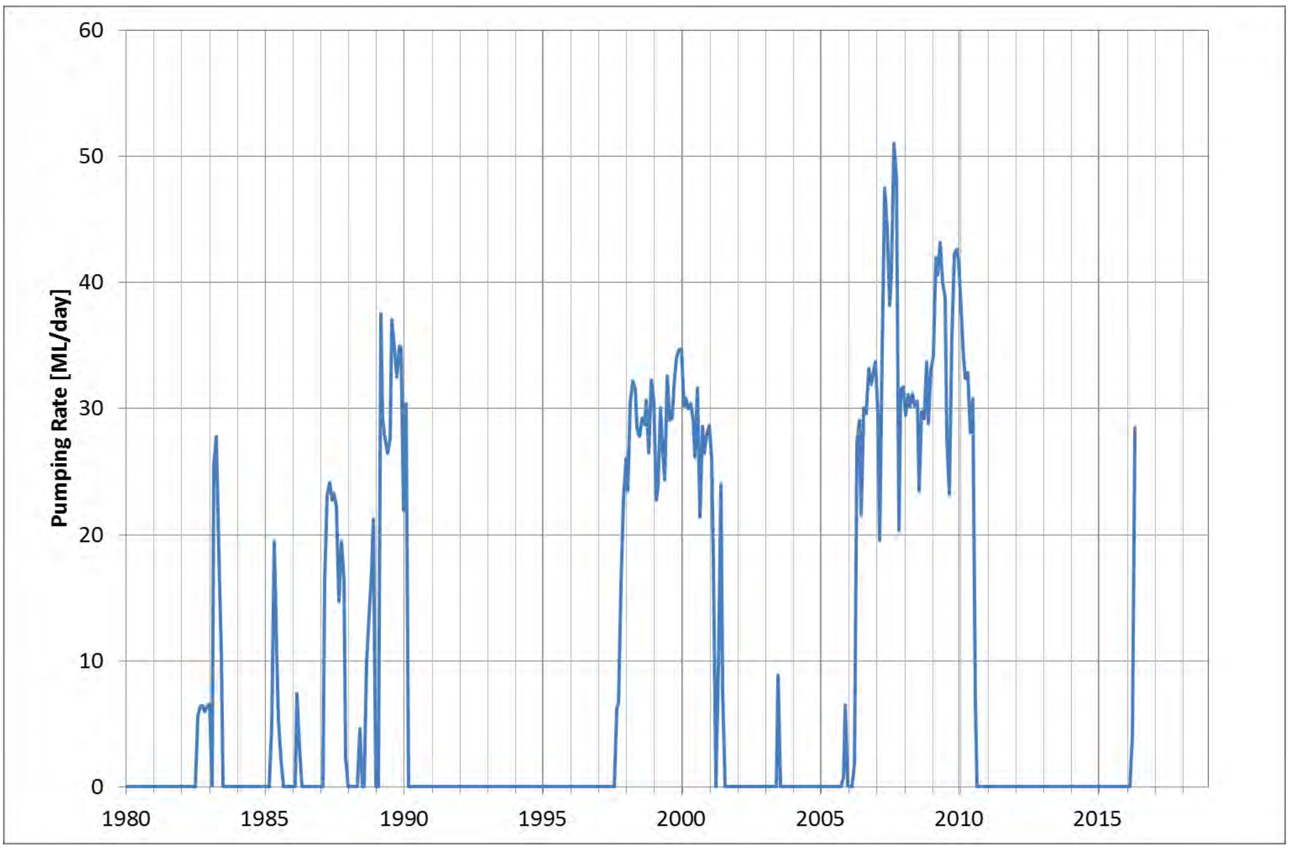
The Barwon Downs bore field consists of six production bores. Initially four bores were drilled and constructed between 1981 and 1983 - GW2A, GW3, GW4 and GW5. The borefield was expanded in 2001 with an additional two production bores - GW6 and GW8. The location and identification number of each bore is detailed in Table 3-1 below.

The borefield has been used intermittently since construction in 1981. This included an initial brief extraction period in 1982/83, followed by intermittent extraction between 1985 and 1990 Figure 3-1. The borefield became more active between 1997 and 2001 before reaching its greatest period of activity between 2006 and 2010.

Table 3-1 Production bores in Barwon Downs borefield

Barwon Water ID	State Database ID	MZ	Easting	Northing	Depth (m)	Screen (m)
GW2A	WRK040900	55	215197	5739976	542	383 - 542
GW3	WRK040901	55	214175	5739136	539	361 - 539
GW4	WRK040902	55	215214	5740400	645	453 - 645
GW5	WRK040899	55	214764	5739560	508	350 - 502
GW6	WRK040903	55	215180	5739569	491	329 - 484
GW8	WRK040904	55	213214	5739725	551	335 - 545

Figure 3-1 Groundwater extraction rate over time from Barwon Downs bore field



In 2016, Jacobs assessed the production bore condition and supervised the refurbishment of the bores in order to reactivate the borefield. Bore conditions and preliminary refurbishments were undertaken in April 2016 and subsequent refurbishments are planned for August/September 2016 to ensure the ongoing integrity of the production bores. Details regarding the 2016 refurbishment works program have been reported in Jacobs (2016a) and are summarised in Table 3-2 below.

Table 3-2 Summary of Barwon Downs bore refurbishment works

Barwon Water ID	Completed works
GW2A	Mechanical cleaning, debris removed from sump, pump housing relined with stainless steel swages, protector grill (grizzly) at the base of the pump house replaced.
GW3	Mechanical cleaning, debris removed from sump, damaged pump housing milled and re-lined, protector grill (grizzly) at the base of the pump house replaced.
GW4	Mechanical cleaning, debris removed from sump, pump housing relined with stainless steel swages, protector grill (grizzly) at the base of the pump house replaced.
GW5	Mechanical cleaning, debris removed from sump, pump housing relined with stainless steel swages, protector grill (grizzly) at the base of the pump house replaced.
GW6	Mechanical cleaning, debris removed from sump, chemical cleaning.
GW8	Mechanical cleaning, debris removed from sump, chemical cleaning, stainless steel screen sleeve installed across existing damaged screen.

3.2 Proposed groundwater extraction rates

Barwon Water are proposing to apply for reduced volumetric entitlement. This change is based on an assessment by Barwon Water of the likely need for the borefield over the next 15 years.

The current and proposed volumetric limits are provided in Table 3-3. The calibrated numerical groundwater model was used to determine the potential impacts under different climate regimes and this is discussed more in the following chapters.

Table 3-3 : Volumetric limits of the current and proposed licence

Condition	Current Licence	Proposed Licence
Maximum daily rate (ML)	72	45
Maximum annual rate (ML)	20,000	12,000
Maximum 10-year rate (ML)	80,000	N/A
Maximum 15-year rate (ML)	N/A	60,000
Long term (100 year) extraction	400,000	N/A

4. Hydrogeological Conceptual Model

The hydrogeological conceptual model of the Barwon Downs Graben has been refined over many years. The current conceptual understanding of the graben and in particular, the groundwater resource in the LTA, is described in the following sections. The conceptual understanding forms the basis for a numerical groundwater model.

4.1 Key formations

The stratigraphy of the Barwon Downs Graben includes a series of sedimentary units overlying basement rocks. These units have been deposited in a series of transgressive and regressive cycles and include the Pebble Point Formation, Pember Mudstone, Dilwyn Formation, Mepunga Formation, Narrawaturk Marl, Clifton Formation, Gellibrand Marl and Quaternary Alluvium. A representative cross section of the Barwon Downs Graben is illustrated in Figure 4-1. This shows a progressive thickening of the sedimentary units from the Barongarook High in the west into the centre of the Graben, before being truncated by the Bambra Fault in the east.

Figure 4.2 shows the surficial hydrogeology of the key formations listed above. The Victorian Aquifer Framework simplifies the stratigraphy of the graben into the following four hydrogeological units:

- Basement (BSE)
- Lower Tertiary Aquifer (LTA)
- Mid-Tertiary Aquitard (MTD)
- Quaternary Alluvium (QA)

A brief description of the formations and the grouping of these into the four simplified units is provided in Table 4-1.

Previous versions of the numerical groundwater model included five of the seven layers shown. A revised geological model was developed as part of the Technical Works Monitoring Program with the aim of including the additional two layers (Pember Mudstone and Bedrock). The extent and thickness of the LTA, the Narrawaturk Marl and the Gellibrand Marl were also revised using the information collected from the new monitoring bores (Jacobs, 2016b). This information was used to develop the revised numerical groundwater model.

Due to the relatively very small spatial extent of the Quaternary Alluvium combined with the difficulty of representing this discontinuous unit in a regional model, this unit has been excluded from the numerical model.

Table 4-1 Hydrogeological units of the Barwon Downs Graben and relationship to model layers in the 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**	

VAF aquifer	Geological Unit	Description	Type	Model layer
	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

4.2 Faults

Faults are hydrogeologically important to the Barwon Downs Graben as they cause discontinuities and partially bound the principal hydrogeological units. 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 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 groundwater model boundary (SKM, 2001 and SKM, 2011). Recent work indicates that there is a continuation of stratigraphic units across the fault, suggesting that it may not necessarily act as a complete no-flow boundary (Jacobs, 2015a). However, a further assessment of drawdown responses found that there was limited connectivity across the Colac Fault (Jacobs, 2015b). This 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 stratigraphy to the southeast of the fault. In a recent review of borefield related groundwater responses in the Lower Tertiary Aquifer, Jacobs (2015a) found that the Bambra Fault was best represented in a numerical 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 could potentially be represented as a no-flow boundary in a numerical model.

Figure 4-1 Representative cross section of the Barwon Downs Graben

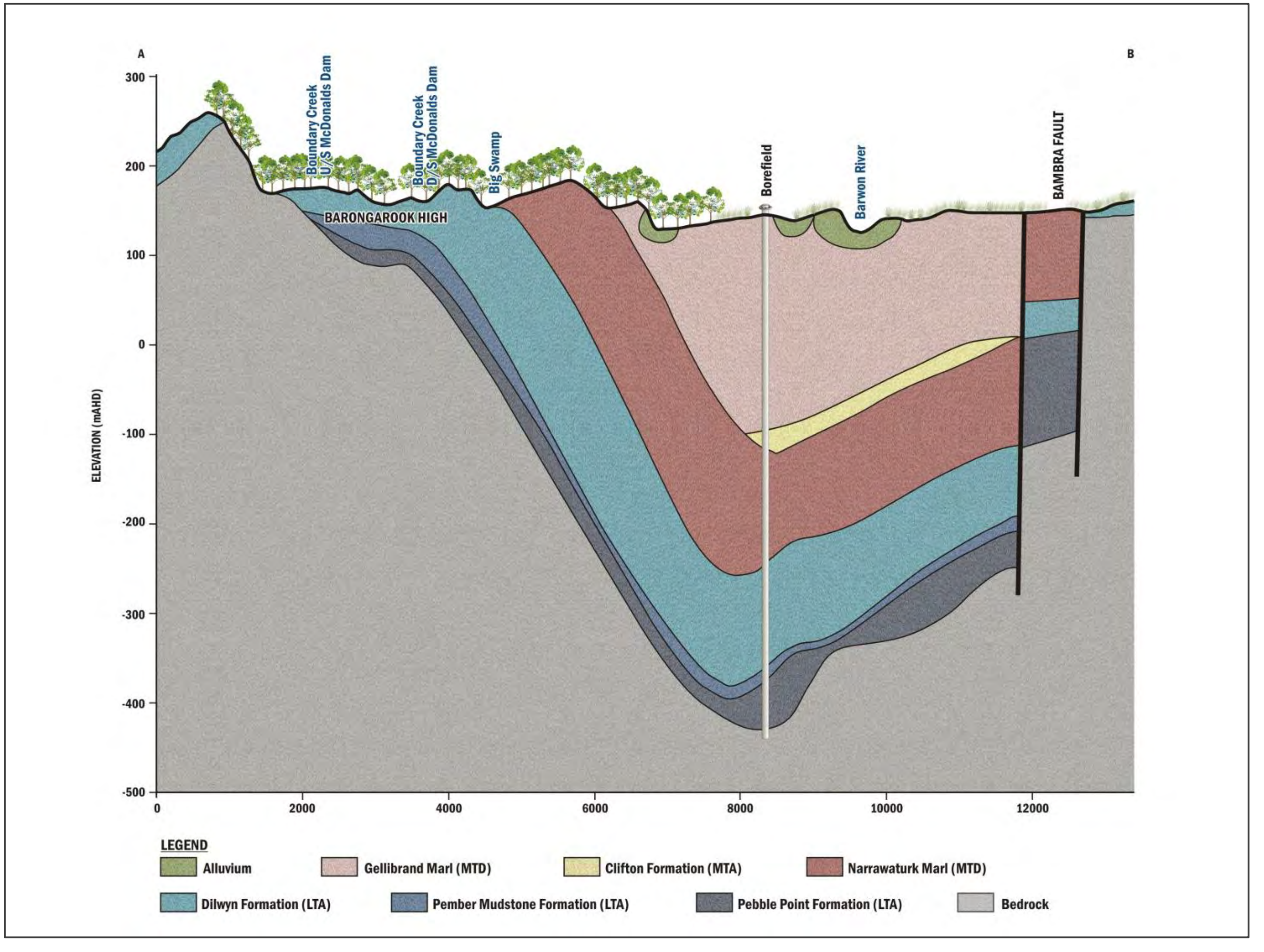
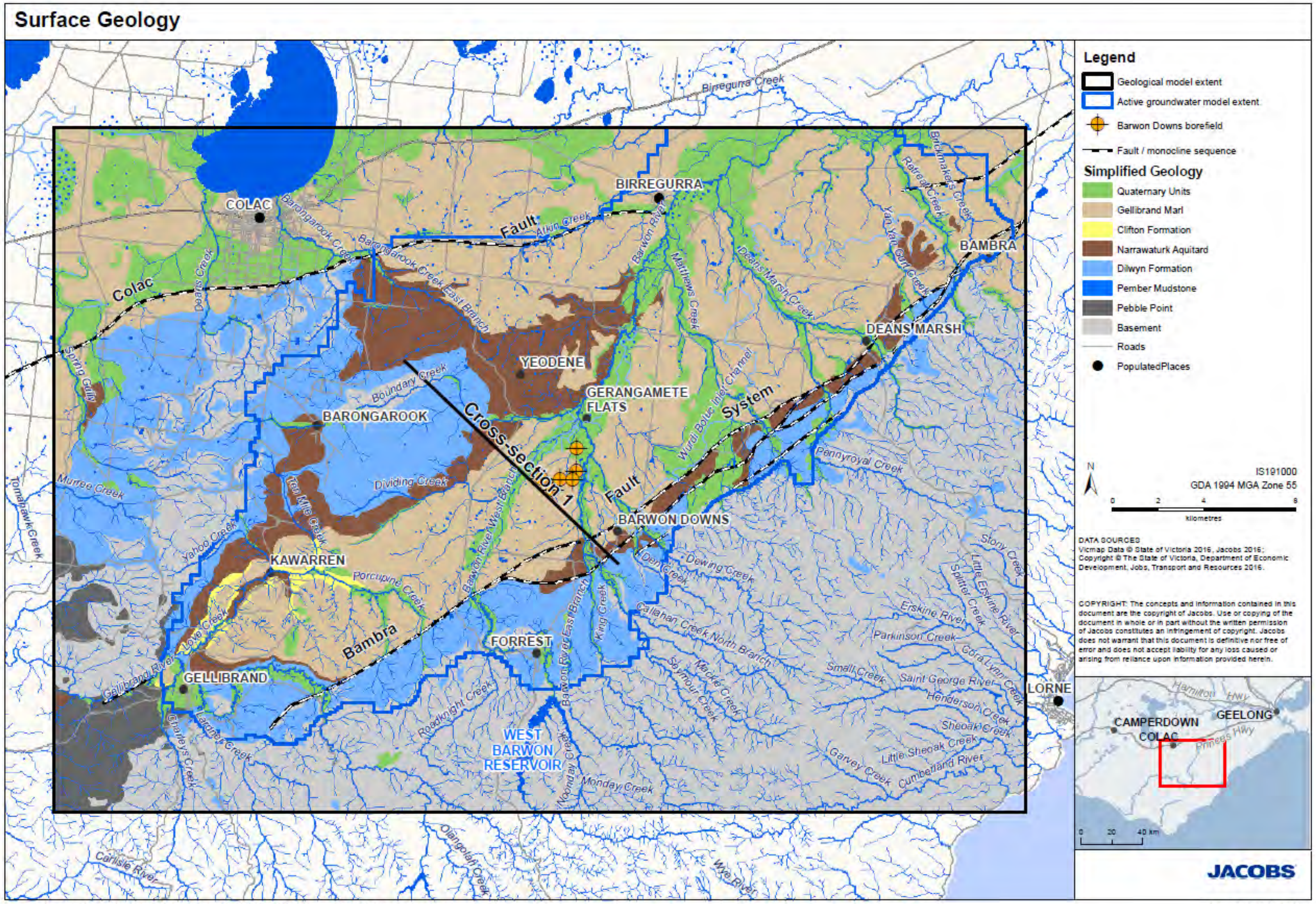


Figure 4.2: Surficial geology in the Barwon Downs graben



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Date Published: 24 Oct 2018

4.3 Key hydrogeological units

The Gerangamete GMA includes all Middle and Lower Tertiary aquifers, which are:

- Lower Mid Tertiary Aquifer (LMTA) – Clifton Formation
- Lower Tertiary Aquifer (LTA) – Mepunga, Dilwyn and Pebble Point Formations

The Clifton Formation aquifer (LMTA) exists in the centre of the graben and is a minor aquifer. The LMTA lies between two thick aquitards being the overlying Gellibrand Marl and underlying Narrawaturk Marl, both part of the Mid Tertiary Aquitard (MTD). The LMTA outcrops in the valleys around Kawarren (see Figure 4.2).

The Mepunga, Dilwyn and Pebble Point Formations together form the LTA which is the major aquifer in the graben. The LTA outcrops on the Barongarook High on the north western side of the graben and in the Bambra Fault zone on the south east side of the graben.

The hydraulic parameters are reasonably well understood for the LTA as there has been substantial work undertaken over the years to understand the groundwater resource. The aquifer parameters used in the model have been based on previous groundwater models and are discussed in detail in Jacobs (2018c).

The hydraulic parameters for the MTD and LMTA were less well understood. To address this data gap, the Technical Works Program installed 37 new bores and three existing bores were replaced. The new bores targeted the Quaternary Aquifer, MTD, outcropping / sub-cropping LTA and one bore was installed in the LMTA. Hydraulic testing was undertaken on all bores to provide an estimate of the hydraulic parameters for inclusion in the groundwater model. The results from Jacobs (2016b) are outlined below.

4.3.1 Quaternary Alluvium

Slug tests conducted in the Quaternary Alluvium (QA) yielded reasonably high hydraulic conductivity values ranging from 0.005 to 4.7 m/day and an average value of 0.63 m/day. This is largely due to the coarse nature of the sediments. As the deposits have formed relatively recently along drainage lines, the high energy of these environments will generally include the deposition of layers with coarser sediments. The gamma logs further indicate the absence of significant clay layers in the aquifer.

4.3.2 Middle Tertiary Aquitard (MTD)

The hydraulic conductivity of the MTD appears to show a broad correlation with screen depth. Bores screened at depths less than 25 m (TB8, A3, A5b and A6b) generally have higher hydraulic conductivities compared to deeper bores. Hydraulic conductivities in these shallow bores range from 0.026 to 0.3 m/day. In contrast, most bores screened below 35 m depth (A1, A2, A4, A5a) have relatively low hydraulic conductivities, ranging from 1.8×10^{-5} to 5.8×10^{-4} m/day. These values are consistent with the lithology of the formation, and with values adopted for the unit in previous numerical modelling. The hydraulic conductivity recorded in A6a was 3.6×10^{-3} m/day and is considered slightly high for a bore screened below 35 m in the MTD.

4.3.3 Lower Middle Tertiary Aquifer (LMTA)

One bore screened in the Lower Middle Tertiary Aquifer (LMTA), also known as the Clifton Formation, was slug tested (64235). Results indicate a hydraulic conductivity of 0.54 m/d in the LMTA which is consistent with the unit acting as a minor aquifer, similar to the Quaternary Aquifer.

4.3.4 Lower Tertiary Aquifer (LTA)

The hydraulic conductivity values determined from bores screening the LTA is variable. It is important to note that the focus of hydraulic testing in the Technical Works Monitoring program described above was in the outcrop areas of the LTA, and not at depth within the graben. Within the LTA outcrop area, generally the hydraulic conductivity declines with depth as bores screened below 30 m depth have lower conductivities.

It should be noted that as vehicle access to 10943 and 10940 prevented the development of these bores during field investigations, the hydraulic conductivity values were not confirmed. Bore 109143 reported the highest conductivity value of 1.5 m/day, while Bore 109140 reported a value of 1.6×10^{-4} m/d.

Of the remaining bores screened in the LTA, bores screened at depths greater than 30 m (TB3 and TB5) had the lowest hydraulic conductivities, ranging from 9.2×10^{-5} to 2.9×10^{-4} m/day. The exception to this is UDvCk which is screened at around 57 m depth in particularly coarse material (sandy gravels) and consequently has a relatively high hydraulic conductivity (1.1×10^{-1} m/day) at this site.

Bores screened at shallower (<20 m) depths in the LTA (TB6 and TB7) yielded higher hydraulic conductivities representative of a minor aquifer, with values ranging from 0.20 to 0.22 m/day. It should be noted that with the exception of TB7, both shallow and deeper screened bores in the LTA identified the presence of clay layers in the formation.

4.3.5 Basement

The hydraulic conductivity of the basement appears to be relatively well constrained, with slug tests yielding hydraulic conductivity values falling in a relatively narrow range of 3 to 7.2×10^{-3} m/day. It is noted however that this is based on three tests only. However, the results suggest that the basement in this area has a moderate hydraulic conductivity (compared to other hydrogeological units in the area).

4.4 Natural groundwater recharge and discharge processes

The LTA, consisting of the Pebble Point, Dilwyn and Mepunga Formations, is the major aquifer in the region. The aquifer has various recharge and discharge processes. The major recharge process is rainfall infiltration where the aquifer outcrops with some additional recharge from downward leakage from overlying formations and leakage from some rivers where they cross the aquifer outcrops. Discharge processes include evapotranspiration from shallow groundwater and vegetation, aquifer throughflow to the north and south of the graben, upward leakage from the basement and discharge to some rivers.

When an aquifer is in equilibrium, recharge will be similar in magnitude to the discharge from the aquifer and groundwater levels will be relatively stable. If there is more recharge than discharge, for example during periods of above average rainfall, the storage in the aquifer will increase and groundwater levels will rise. If there is more discharge from an aquifer, such as by the introduction of pumping, water is removed from storage and groundwater levels will decline. In large groundwater systems such as the Barwon Downs graben, there can be significant time delays to shift the storage balance.

4.4.1 Recharge

The key recharge process for the LTA is recharge from rainfall, with over 90% of recharge to aquifer occurring via infiltration where the aquifer outcrops. Less than 10% of recharge occurs via downward leakage from overlying units (Jacobs, 2018a). Recharge from rivers is discussed in Section 4.5.

Recharge to groundwater mainly occurs through rainfall infiltration to the shallowest aquifer across the entire study area. It is expected that the most significant recharge will occur at those locations where surface sediments are coarse grained and/or more permeable. In the catchment area this generally corresponds with the major aquifer units outcrop (as shown in Figure 4-5). Less recharge is expected across the remainder of the model domain where the low permeability Gellibrand Marl outcrops.

Previous studies have provided some estimates of groundwater recharge to the LTA; however these often incorporate little or no field data and provide a broad range of recharge estimates. Blake (1974) estimated recharge using a recharge rate of 5% of rainfall, but it is unclear what the percentage was based on. It is expected that a generalised “rule of thumb” was used. The estimated recharge was 170 L/sec, or 5,361 ML/year (Blake, 1974).

Lakey and Leonard (1984), described by Petrides & Cartwright (2006), used flow net and baseflow analysis to estimate a recharge rate of 14% of rainfall for the Barongarook High.

More recent work conducted by Atkinson *et al.* (2014) focussed on using groundwater hydrographs to estimate recharge to the LTA in the Gellibrand River catchment. These recharge estimates were between 11% and 32% of rainfall, however as the study focussed on recharge processes around the rivers, these estimates are not considered to be representative of the recharge in the aquifer outcrop area, which is the area of most significance with respect to the borefield.

Numerical modelling of the Barwon Downs Graben was undertaken by SKM (2001) and calibration was achieved incorporating a recharge rate of 20% of rainfall to the LTA at the Barongarook High, 8% for the LTA south of the Bambra Fault and 3% for the other sediments (mainly Gellibrand Marl). The 2001 model estimated total recharge to the LTA to be around 18,000 ML/year.

Subsequent modelling by SKM (2011) included further spatial subdivision of these areas into five different zones of recharge, representing 0.2%, 3.0%, 5.2%, 23.5% and 28.3% of rainfall. The recharge estimate in the 2011 model was less than 2001 and ranged between around 9,000 and 14,000 ML/year, depending on the climate sequence.

Recharge rates have subsequently been estimated independent of the model by Jacobs (2016a) in areas where the aquifer outcrops and the Gellibrand Marl is present at the surface using both analytical studies and modelling including:

- Isotope analysis,
- Chloride mass balance, and
- 1-D unsaturated zone modelling.

This assessment concluded that groundwater recharge rates to the outcropping LTA over the last 50 years is most likely to be at a rate equivalent to between 9% and 11% of annual rainfall. However, recharge in preferential recharge zones may be as high as 26% of the annual average rainfall. Additionally, it was found that historical recharge rates over the last 100 to 1000s of years may be considerably lower, representing around 5% of the modern annual average rainfall.

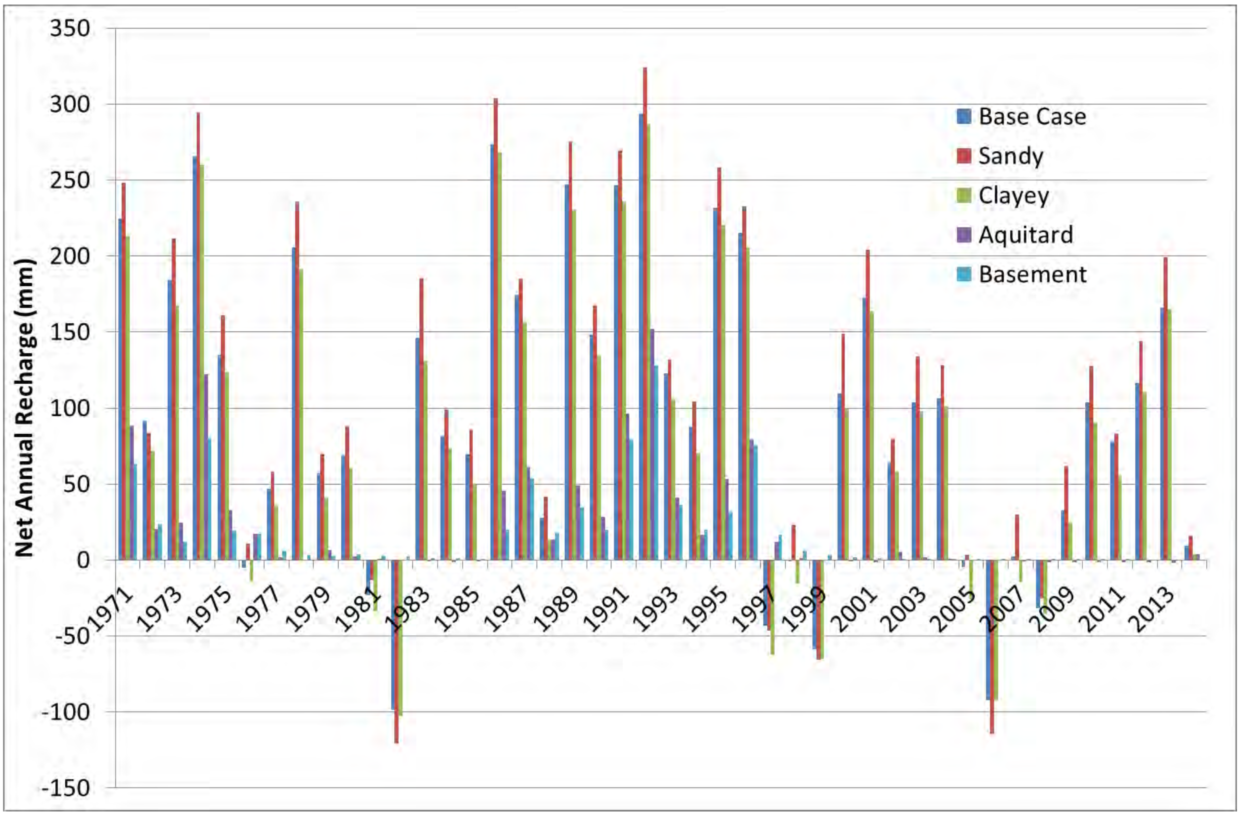
To support the isotope and chloride based estimates of recharge, a one dimensional unsaturated zone model was developed (Jacobs, 2018a). This model was used to simulate recharge in a number of different soil profiles. The main advantage of the model is that it can provide more detailed estimates of the temporal distribution of recharge from month to month and year to year variability compared to the overall average figures from chemical tracers.

The unsaturated zone model used the MIKE-SHE software and simulated recharge (and discharge) from a standard soil column. Soil types in the column were estimated based on samples from other studies in the Technical Works Monitoring Program and rainfall used in the recharge model is based on records from the Barwon Downs Gauge. Evaporation included in the model is based on the daily pan evaporation at Wurdee Boluc and occurs evenly over 24 hours.

The modelling found that there is significant variability in recharge from year to year. The simulated annual recharge for the five soil profiles is shown in Figure 4-3. The key conclusion from this work was that in any year the recharge can vary substantially (according to rainfall) and that in low rainfall periods when the borefield is likely to be used, it is also likely that there is low recharge and that water use by vegetation is indicated to cause overall discharge in some years.

Recharge rates estimated using field techniques by Jacobs (2016a) indicated recharge rates are around 10% of rainfall which is equivalent to approximately 11,000 ML/year across the Lower Tertiary Aquifer (LTA) outcrop area. The calibration model highlighted that the average recharge to the LTA outcrop area over the last 30 years is estimated to be 5,900 ML/year. This volume is equivalent to around 5% of rainfall, which is lower than some of the field estimates from Jacobs (2016a) but similar to the long term recharge rate.

Figure 4-3 Estimated recharge rates for the period 1971 to 2014.



4.4.2 Discharge

The key discharge process in the Barwon Downs Graben is evapotranspiration, aquifer throughflow, leakage to overlying layers, discharge to rivers and groundwater pumping. Discharge to rivers is discussed in Section 4.5.

4.4.3 Evapotranspiration

The combination of direct evaporation and transpiration of water by vegetation (collectively known as evapotranspiration or ET) is one of the major water losses from the Barwon Downs Graben. In the previous version of the numerical groundwater model, the maximum ET rate was defined as 2,000 mm/year (SKM, 2011). No additional work has been undertaken in recent years as part of the Technical Works Monitoring Program to improve the estimates of ET as the estimates in the previous groundwater model are considered to be appropriate.

4.4.4 Groundwater flow

Groundwater levels at the Barongarook High are currently greater than 240 m AHD (at the top of the groundwater system) and this drives groundwater flow to the east towards the Gerangamete Flats and south towards Gellibrand (Figure 4-5). Groundwater flow within the graben discharges to the south west (towards Gellibrand) and north east (towards Bambra).

Since borefield operation began in 1982, groundwater levels in the Lower Tertiary Aquifer (LTA) system have responded to groundwater extraction and climatic impacts over time (i.e. periods of reduced rainfall recharge). When the borefield is operational the drawdown cone spreads along the axis of the graben from northeast to southwest.

As shown in Figure 4-4, drawdown in the Lower Tertiary Aquifer (LTA) from the Barwon Downs borefield propagates in an elongated drawdown cone that extends north east and south west within the Graben. An investigation by Jacobs (2016e) confirmed that drawdown extends to the Kawarren area. However, there are other bores located closer to the borefield (between the borefield and the Kawarren area) that have negligible drawdown. The lack of drawdown is likely to be related to zones of reduced hydraulic conductivity in localised areas and the development of this conceptual understanding was incorporated into the numerical model.

Drawdown in bores screened relatively shallow in the LTA outcrop areas is often less than expected compared to drawdown deeper in the LTA (including throughout areas of the Barongarook High, including Yeodene (Big) Swamp and several drainage lines to the east of the high). This is consistent with stratigraphic variability in the LTA as suggested by SKM (2008) and represents an improved conceptual understanding of the system for incorporation into the numerical model. A number of shallow bores throughout these areas has also helped to identify the presence of alluvial aquifers and minor perched aquifer systems within the Barongarook High. These aquifers have been buffered from drawdown in the regional aquifer, as a result of the stratigraphic variability in the LTA.

The most recent potentiometric map (2014) for the LTA is shown in Figure 4-5. The highest groundwater levels in the LTA are on the Barongarook High where the Basement and the LTA outcrop. Groundwater flows predominantly east towards the Gerangamete Flats and to the south west towards Gellibrand. These major flow paths are separated by an east-west trending groundwater divide. Groundwater flow to the north is also apparent, facilitated in part by the basement ridge through the Barongarook High which acts as a geological divide from the rest of the Barwon Downs Graben. From the Gerangamete Flats groundwater flows in a north-east direction towards Deans Marsh (Figure 4-5).

While these trends have remained broadly similar over time, at the peak of borefield extraction, drawdown in the borefield reversed groundwater flow directions in some areas. For example, groundwater flow near Deans Marsh is currently north east (as it was in 1987), however at the height of borefield operation, groundwater flow was south west – towards the borefield.

Additionally, rapid recovery in the centre of the borefield immediately after extraction facilitated groundwater flow from the graben to the south west, in areas where flow would have previously been north east. Changing groundwater flow directions will alter the aquifers natural recharge and discharge zones. For example, groundwater that previously discharged to surface water can be reversed so that the surface water feature becomes a recharging zone for the aquifer. Alternatively, groundwater may have discharged out of some parts of the Barwon Downs graben historically, these areas now act as recharge areas (e.g. Reach 2 of Boundary Creek).

Figure 4-4 Drawdown in the LTA (1987-2012) (Jacobs, 2015b)

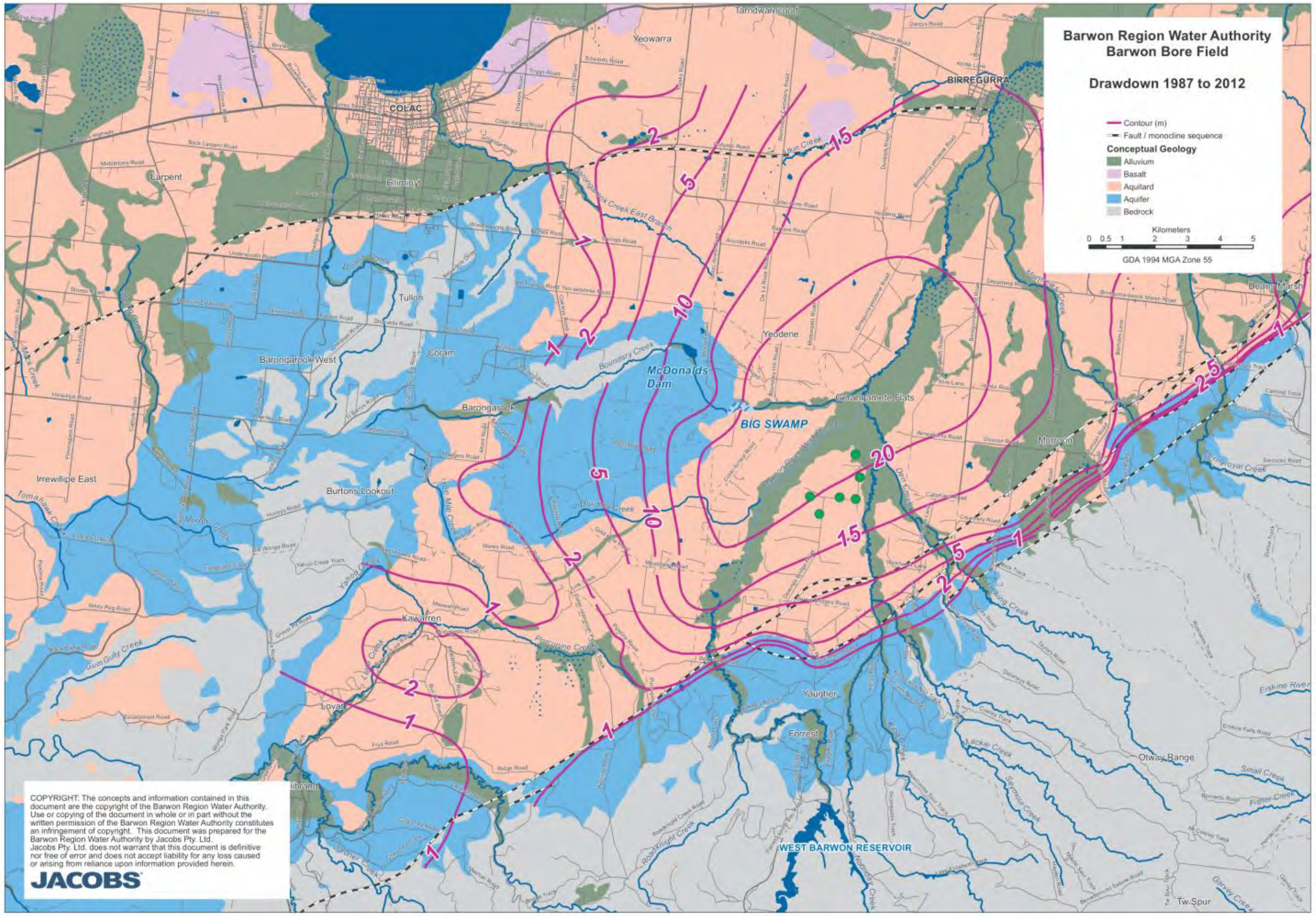


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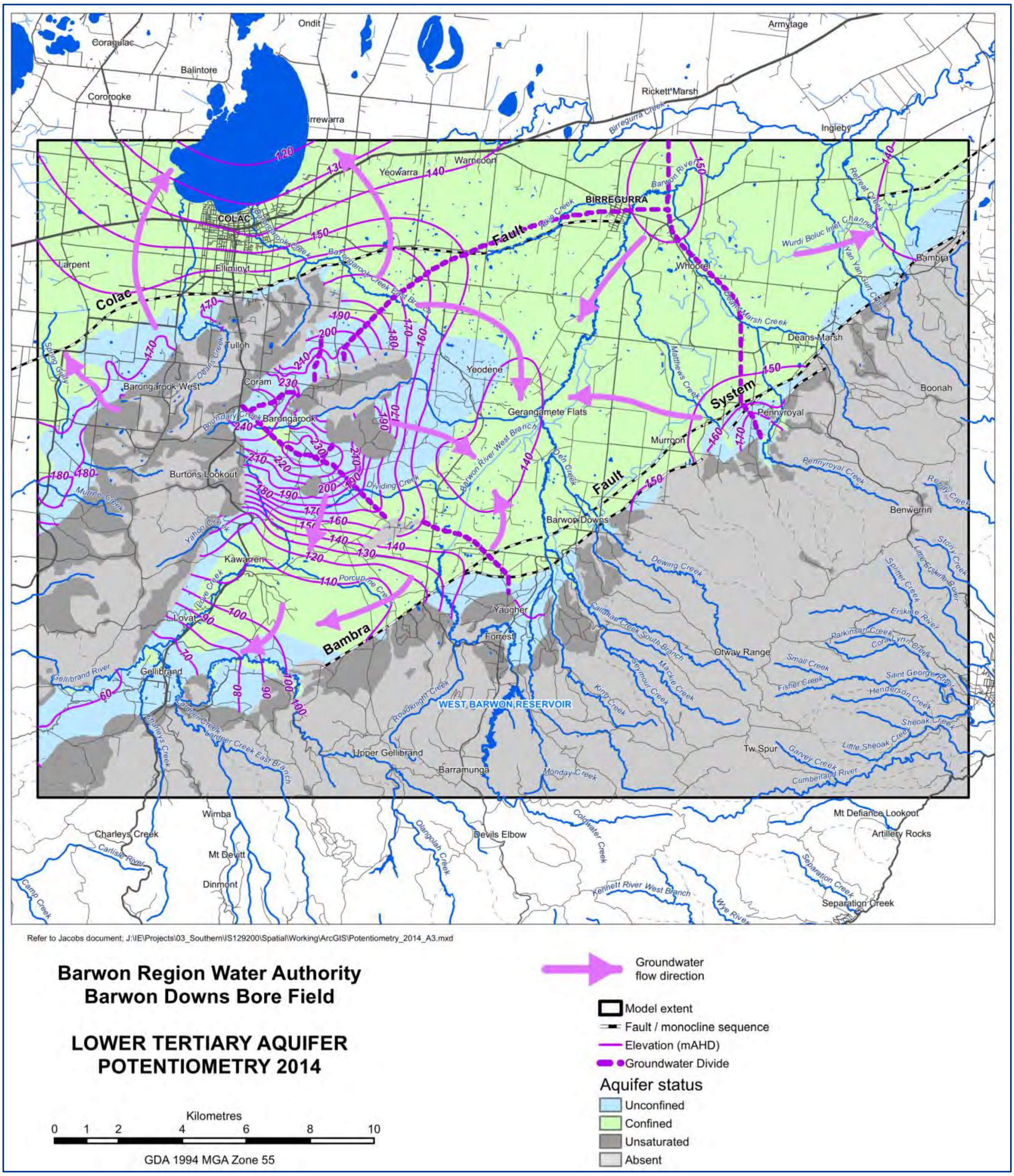
Figure 4-5 Groundwater flow direction in the LTA in 2014 (Jacobs, 2018a)



4.4.5 Vertical flow processes

Vertical flow processes 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. Previous assessments of vertical hydraulic gradients between aquifers and aquitards in the Barwon Downs Graben have been limited and this section outlines the current conceptual understanding.

It is generally understood that upward hydraulic gradients 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. SKM (2008) suggested that while the potential for leakage between the LTA and MTD is apparent and that future drawdown in the MTD could occur, inadequate monitoring and characterisation of the MTD prevented definitive commentary on the matter. It was also postulated that perched water tables are likely to be present throughout the Barongarook High (where the LTA outcrops). However, the location cannot be reliably predicted due to the limited number of shallow monitoring bores.

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

While historical assessments indicate upward leakage from the LTA, there is potential for this to reverse under extraction. Groundwater monitoring has identified this in some areas, where groundwater levels in the LTA have fallen below the overlying MTD for periods of time (see Figure 4-6).

There are also vertical flow gradients present within the LTA. Figure 4-7 shows two hydrographs for the LTA in 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 subdued response to pumping.

The 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.

Figure 4-6 Bore hydrographs in LTA and MTD near the borefield

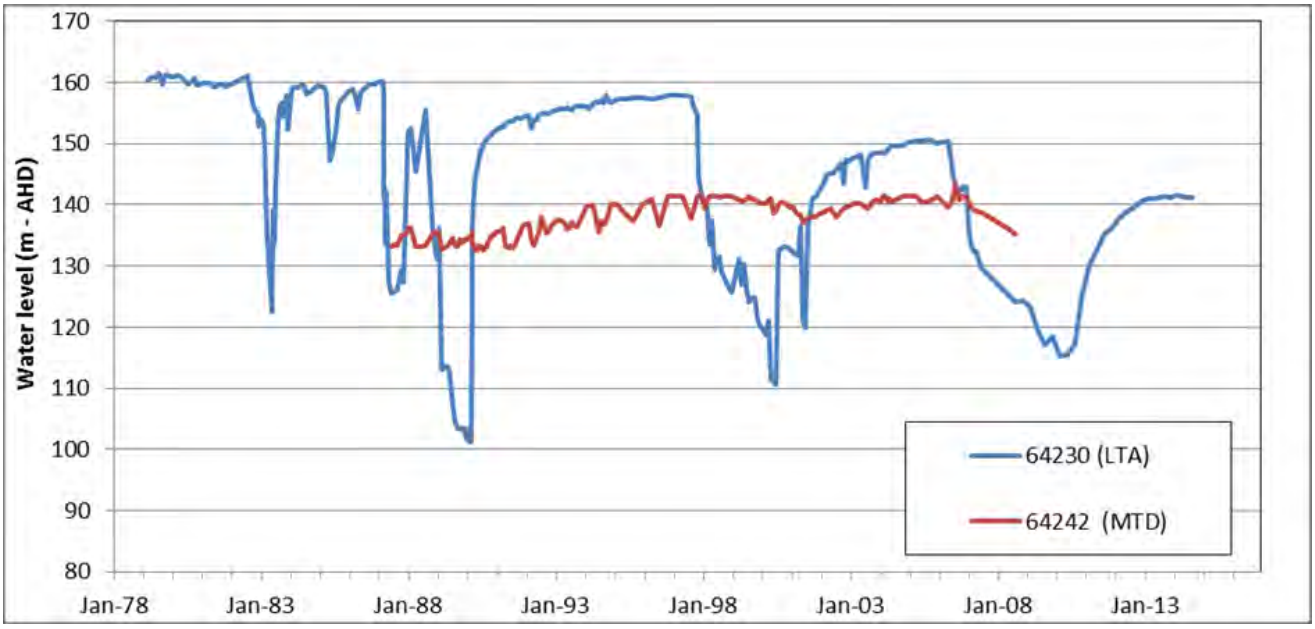
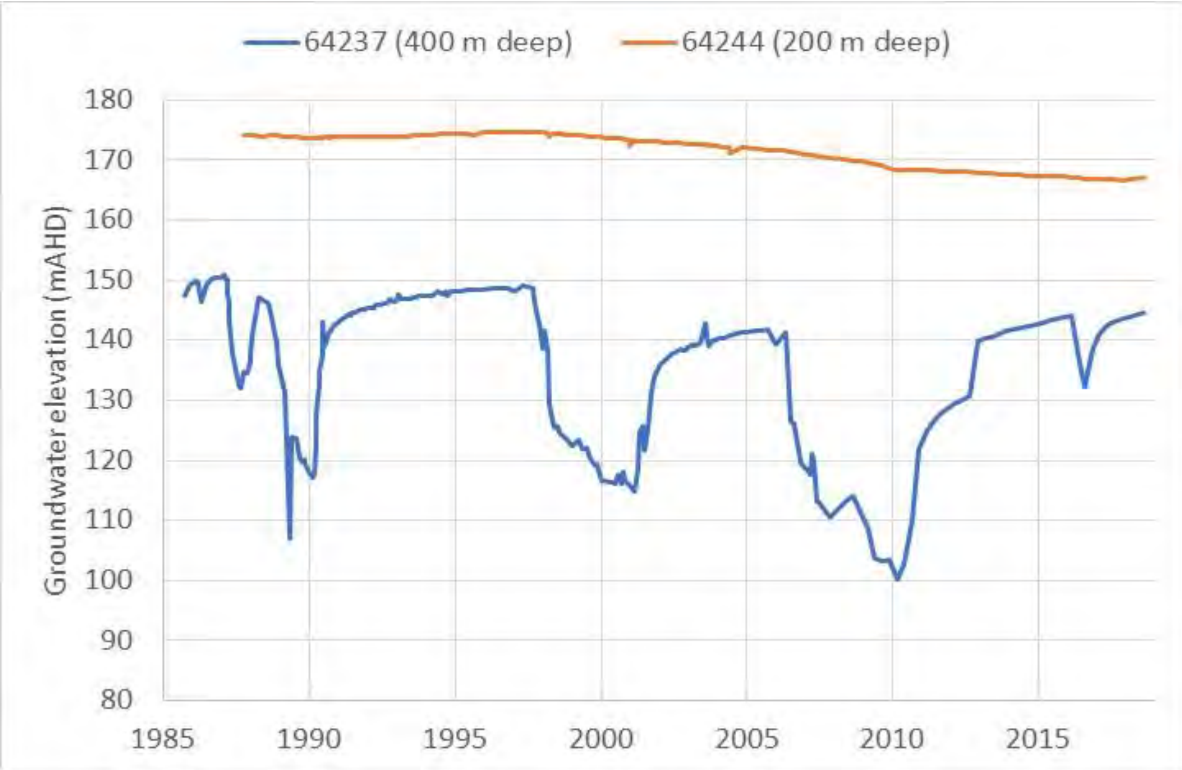


Figure 4-7 Examples of groundwater level trends at different depths in the LTA



4.5 Groundwater quality

Groundwater quality data in the Barwon Downs study area is largely limited to salinity and pH. The Water Management Information System (WMIS) has some groundwater salinity and pH data for bores screening the LTA and LTMA (Clifton Formation). For other aquifers and aquitards, groundwater samples were collected from bores installed in 2008 and 2014 (SKM, 2008, Jacobs, 2016b).

4.5.1 Groundwater salinity

Groundwater salinity can be measured as Electrical Conductivity (EC µs/cm) or Total Dissolved Solids (TDS mg/L). EC is easily measured in the field, while TDS must be determined in the laboratory. EC can be used to estimate TDS using a conversion factor of 0.65 to estimate the salinity as TDS (mg/L).

Groundwater from bores screened in the Quaternary Alluvium generally yielded low EC's, ranging from 200 to 460 µs/cm (Jacobs, 2016b). This is typical of a shallow aquifer with short groundwater flow paths and recharged from rainfall and surface water. TB1a is an exception to this where the groundwater salinity was 1,430 EC. This bore is monitoring the shallow groundwater beneath Big Swamp which is a groundwater discharge site. Evaporation from the groundwater system increases the groundwater salinity in this local area.

Groundwater salinity in the MTD is higher, ranging from 1,070 to 3,890 EC (Jacobs, 2016b). This is considered to be typical of the unit, where longer flow paths allow for more evaporation and rock water interaction which increases the salinity.

The salinity of the LTMA is available on WMIS and is typically less than 500 mg/L TDS, ranging between 207 and 526 mg/L. Using a conversion factor of 0.65, this is equivalent to an EC ranging between 318 and 800 µs/cm.

In the LTA, the Mepunga and Dilwyn Formations have a similar groundwater salinity as the Pebble Point Formation. There are 48 bores with groundwater salinity data on the WMIS and the salinity ranges between 76 and 706 mg/L TDS (equivalent to 127 to 1,167 μs/cm EC). Bores screened in the Pebble Point Formation show a similar range in salinity.

An additional 7 bores were installed in the LTA in 2014 and these show a similar range in salinity, generally ranging between 146 and 858 mg/L TDS (equivalent to 224 and 1,320 μs/cm EC). This is consistent with an intermediate groundwater residence time and the current conceptual hydrogeological understanding (Jacobs 2016b). Groundwater salinity is particularly low at TB7 (170 μS/cm) which is a shallow bore located in the recharge (unconfined) area of the LTA. Groundwater from TB3 has a particularly high EC of 10,000 μS/cm. It is noted that the basement is thought to be relatively shallow in this area and given the relatively deep screen at TB3 (about 35 m), it is possible that this water is impacted by upward leakage of saline water from the basement.

Groundwater from the basement has a relatively high EC compared to most other units, ranging from 890 to 5,440 μS/cm, with an average EC of 3,490 μS/cm (based on 3 samples) (Jacobs 2016b).

4.5.2 pH

The pH was measured in bores installed in 2014 (Jacobs, 2016b) and the results are summarised below.

The pH in the Quaternary aquifer ranged between 5.4 and 6.6, with an average of 6. The pH in the MTD ranged between 5.5 and 7.8, with an average of 7.1. The pH in the LTA generally ranged between 5 and 8.1, with one bore (TB3) reporting a significantly higher value of 13.4.

Higher pH values may be associated with carbonate dissolution during longer groundwater residence times and greater interaction with geological units such as the Gellibrand and Narrawaturk Marls. Conversely, terrestrial vegetation monitoring bores screened closer to the surface have less potential to interact with minerals in the aquifer and more potential to be impacted by the vertical infiltration humic acids or waters affected by acid sulphate soils. Such factors may be contributing to the relatively low pH values found in shallow groundwater.

The groundwater surface water interactions across the study area are discussed in the following sections.

4.6 Groundwater surface water interaction

The major river systems in the study area are the Barwon River and the Gellibrand River. The groundwater-surface water interaction between the LTA and the rivers is spatially and temporarily variable. An overview of the conceptual understanding of the groundwater surface water interactions in each catchment is provided below.

4.6.1 Gellibrand River Catchment

The Gellibrand River is located in the south west of the Barwon Downs borefield and the key tributaries relevant to this study are Porcupine Creek, Ten Mile Creek, Yahoo Creek and Love Creek. Near the south western boundary of the groundwater model, the LTA outcrops along the Gellibrand River and the river is gaining in this area (SKM, 2012). This is a discharge zone for the LTA.

The headwaters of Porcupine Creek rise where the LTA outcrops along Bambra Fault and the creek then flows over outcropping MTD and LMTA which is a minor aquifer. There are several springs that provide base flow to headwaters of the creek. The creek is therefore gaining in the upper reaches and then becomes losing as it approaches the confluence of Ten Mile Creek (SKM, 2012).

Ten Mile and Yahoo Creeks both flow over outcropping LTA in the upper reaches and the MTD in the lower reaches before their confluence with Loves Creek. Loves Creek flows over the MTD to its confluence with the Gellibrand River, downstream of the Gellibrand township. SKM (2012) confirmed that there are several springs along Ten Mile Creek, Yahoo Creek and Love Creek. These springs flow from the MTD, which is supported by an upward gradient from the underlying LTA (as discussed in the previous section). Importantly these springs are not interpreted to be the result of flow out of the LTA, rather the underlying high LTA pressures preclude deep drainage and support the formation of springs from the MTD. These springs provide baseflow to Ten Mile Creek and Yahoo Creek.

A spring survey was conducted in 2007 as part of the Newlingrook Investigation. This purpose of this investigation was to characterise a potential additional groundwater resource. The spring survey was conducted on springs identified by RWC (1991) and the springs were described in terms of their location, historical information, current use, areal extent and water quality. All the springs surveyed were diffuse springs ranging in size from small (10 by 10 m) to larger (10 by 200 m). It was noted that the majority of spring were highly modified and typically in poor condition due to cattle accessing the springs. The exception to this was springs on Malcolm Gardiner's property which were all fenced off and had a diverse range of ecology. The underlying hydrogeology and source of water for the springs was not identified during the survey. Likewise the potential impact that pumping has had on these springs was not assessed.

4.6.2 Barwon River Catchment

The majority of tributaries of the **Barwon River** rise in the Otway Ranges to the south. These tributaries flow over the Basement and then the LTA in the vicinity of the Bambra Fault zone. The LTA is likely to provide base flow to these tributaries east of the Bambra fault zone, however no field studies have been undertaken to confirm this. The significance of the groundwater surface water interaction on the south east side of the fault zone (in terms impact of groundwater extraction from the Barwon Downs borefield) is considered to be low as studies completed to date indicate a low degree of connection across the fault zone (Jacobs, 2016f).

Two tributaries of the Barwon River rise on the Barongarook High – Dividing Creek and Boundary Creek. Some reaches along both creeks flow over the LTA and these areas have the most potential for groundwater surface water interactions with the LTA.

Boundary Creek flows across the Barongarook High over a mixture of Basement, LTA, MTD and Quaternary Alluvium. Given the direct connection between Boundary Creek and the LTA, the number of receptors and community interest in this part of the catchment, there has been a significant amount of work done recently to understand the interaction between groundwater and surface water. The groundwater surface water interactions along Boundary Creek are discussed in more detail in the following section.

There are no stream flow gauges on **Dividing Creek.** Based on available information, the depth to regional watertable is greater than 2 m, the creek drains rainfall runoff and groundwater from the LTA does not provide baseflow to creek. The creek is interpreted to recharge the LTA in the upper reaches.

The **Barwon East and West** branches are key tributaries of the Barwon River, which typically flow in the MTD through the centre of the graben. The Barwon West Branch is regulated by the West Barwon Reservoir but it likely to be gaining slightly as it flows over the MTD, where some (deeper) bores are known to be artesian.

4.6.2.1 Boundary Creek

Boundary Creek can be divided into three reaches which exhibit broadly uniform geomorphology, hydrology, hydrogeology and system operation. The three reaches are:

- Reach 1 - Upstream of an on-stream dam hereafter referred to "McDonalds Dam" after an earlier land holder.
- Reach 2 – "McDonalds Dam" outlet to the downstream end of Yeodene Swamp
- Reach 3 - Downstream of Yeodene Swamp to the confluence with Barwon River

A long section along Boundary Creek is shown in Figure 4-9 and the surficial hydrogeology is shown in Figure 4-10. These figures show where the creek crosses over the LTA, MTD, bedrock and alluvial sediments at the surface.

Between the Barongarook gauge and the gauge upstream of McDonalds Dam (Reach 1), Boundary Creek flows over outcropping bedrock. Two bores recently installed in the basement aquifer show that groundwater levels are higher than the stream bed which indicates that the creek is gaining in this part of the catchment. The bedrock has lower permeability than the LTA so the relative contribution of baseflow is lower than for the LTA. Witebsky (1995) and subsequent field investigations indicate that indirect discharge from springs at the bedrock-aquifer interface and then overland flow to the creek also contribute to baseflow. Groundwater levels in this part of the catchment have not been influenced significantly by groundwater extraction from the Barwon Downs borefield.

The **LTA** outcrops in the upper part of the catchment (Reach 1) and downstream of McDonalds Dam (Reach 2). Due to the relatively high permeability of the sediments, the contribution to baseflow (prior to the impact of pumping) is higher than in other sections of Boundary Creek. Downstream of McDonalds Dam (Reach 2) groundwater levels have been heavily influenced by extraction from the borefield with drawdown in the LTA ranging between 15 and 20 metres below pre-pumping groundwater levels. The water levels in bore 109130 (Figure 4-8) suggest that the creek was historically gaining in this location and is now losing. This reach includes the Damplands and Yeodene (Big) Swamp.

The shallow alluvial aquifer beneath the Damplands is thought to be supported by rainfall and surface water flow in Boundary Creek. It is likely that groundwater in the LTA historically provided upward leakage to the alluvial aquifer and in turn to Boundary Creek in the Damplands. In contrast there is a thick alluvial aquifer at Yeodene (Big) Swamp underlain by MTD (with thickness increasing across the swamp from west to east), and while it is likely the alluvial aquifer at this location has been buffered by declining groundwater levels in the LTA, the alluvial aquifer has also received less streamflow from upstream in recent years.

Downstream of Yeodene (Big) Swamp (Reach 3) the watertable lies within the shallow alluvial aquifer and is close to the surface. Nested bores show there is an upward gradient from the underlying aquitard to alluvial aquifer which indicates that groundwater levels in the aquitard have been buffered from the drawdowns observed in the LTA. The alluvial aquifer here is of limited extent and hence groundwater surface water interaction is effectively controlled by the MTD. Surface water in this part of the catchment is thought to be gaining (from the aquifer) as demonstrated by the levels in the shallow aquifer. Due to the low permeability of the MTD, groundwater baseflow to the creek here is typically less than summer evaporation rates.

Figure 4-8 Hydrograph of Bore 109130 (downstream of McDonalds Dam, upper part of Reach 2)

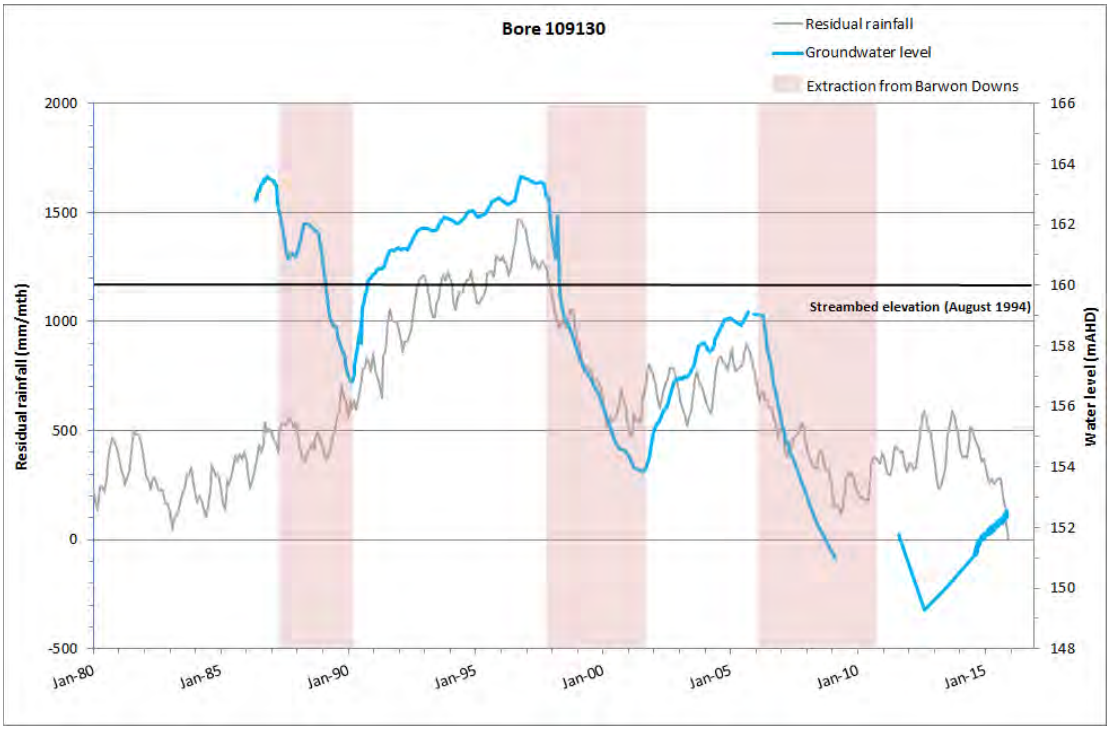


Figure 4-9 Long section along Boundary Creek displaying the different aquifer units that intersect the creek along the creek.

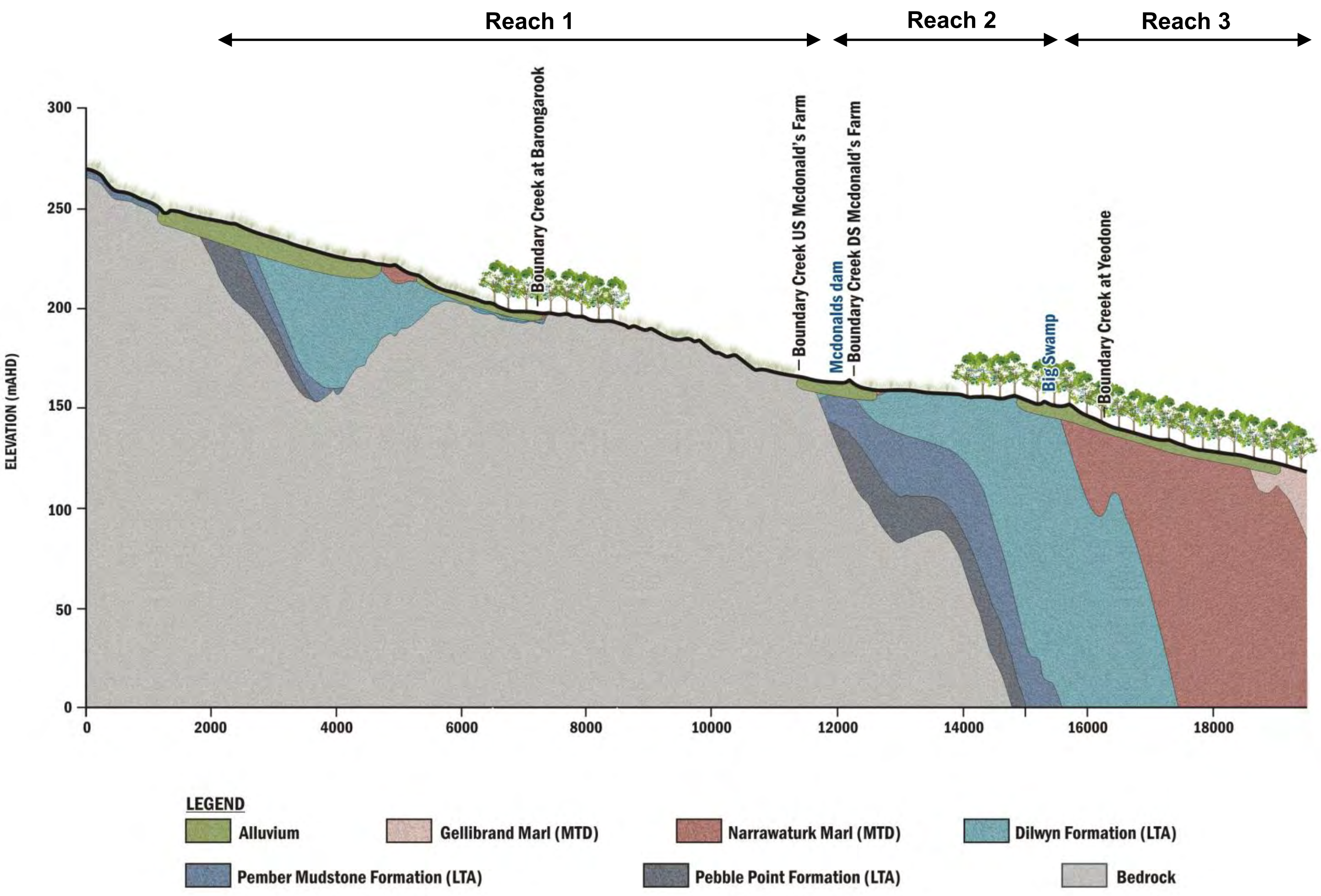
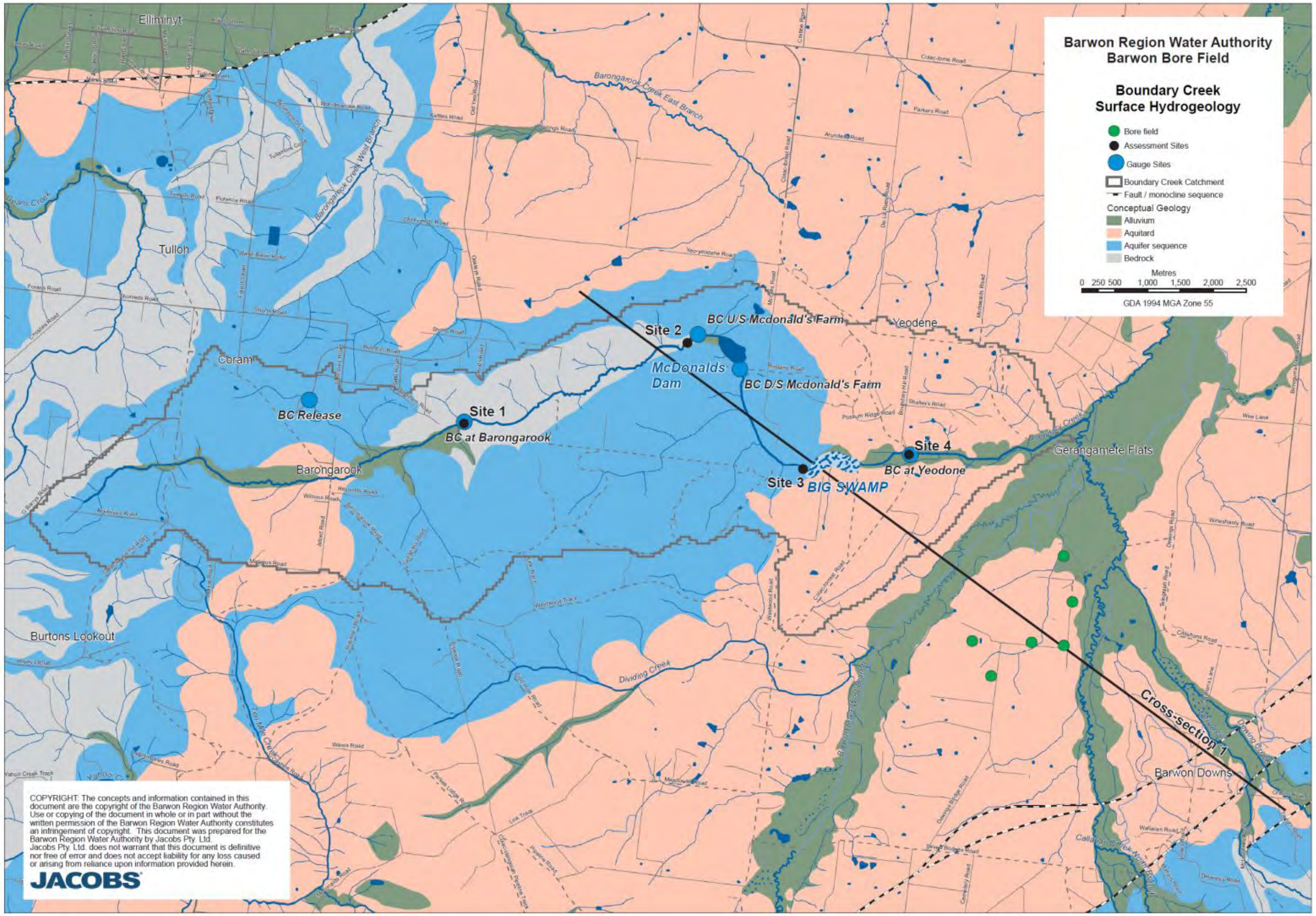


Figure 4-10 Surface hydrogeology in the Boundary Creek area



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5. Numerical groundwater model

The design and calibration of the revised numerical groundwater model is described in detail in Jacobs (2018c). The model is a Class 3 Confidence Level Classification according to the Australian Groundwater Modelling Guidelines (Barnett *et al.,* 2012) which is consistent with the modelling objectives and with the high value of the environmental and economic assets at risk.

The model can accurately differentiate future pumping impacts from impacts associated with climate variability and identify environmental receptors at potential risk from future operation of the Barwon Downs borefield. However the model is conservative, as it over predicts drawdown in some areas, particularly where there are alluvial aquifers present that have not been included in the model and where there are regional aquitards.

A summary of the climate scenarios and pumping scenarios used for the predictive model is described in the following sections. More detail on the development of the model, calibration process and the predictive scenarios is provided in Jacobs (2018a, 2018c).

5.1 Climate scenarios

The climate sequence used to derive recharge rates and pumping regimes for the predictive models was based on measured daily rainfall from 1st January 1971 to 31st December 2014 with an additional 7 years of “average” conditions to make 50 years. This climate sequence was selected as it incorporates recent climate change and includes a wet period, a dry period (i.e. Millennium Drought) and an average period. The average years were included at the end of the climate sequence to allow the groundwater system to recover after a long dry period. The resultant climate sequence was then modified to produce the various climate change scenarios described below.

Consistent with the Guidelines for Assessing Climate Change on Water Availability in Victoria (DELWP, 2016), four climate change scenarios were applied to each pumping scenario:

- Low climate change – 10th percentile of the global climate models (GCM)
- Medium climate change – 50th percentile of the GCM
- High climate change – 90th percentile of the GCM
- Step change climate change – repeat of the climate sequence between July 1997 to 2016.

The rainfall sequence was adjusted to reflect the DEWLP Climate Change Guidelines and was then converted to recharge using an unsaturated zone model that simulated deep water percolation (Mike SHE). The three climate change scenarios assume a linear progression of future rainfall from current levels to the relevant GCM predicted levels at 2040 and at 2065. There is a gradual ramping down (although it is noted that the 10th percentile case includes a small increase in rainfall) of recharge over the duration of the scenarios.

In addition to low, medium and high climate change scenarios, a step-change scenario has been formulated that represents a permanent shift in climate similar to that experienced since July 1997 (or 1997 to date).

DELWP (2016) provide estimates of changes in rainfall that should be considered when assessing potential climate change impacts on water resources. Guidelines estimates of rainfall changes for the Barwon River Basin are tabulated in Table 5-1. These estimated reductions in rainfall will lead to a decline in groundwater recharge rates as there is less rainfall in the catchment. Currently average rainfall for the Barwon River Basin ranges between 800 and 1,200 mm/year.

Table 5-1: Estimated changes in future rainfall for the Barwon River Basin (DELWP, 2016)

	Low climate scenario (10th Percentile)		Medium climate scenario (50th Percentile)		High climate scenario (90th Percentile)		Step change climate	
Date	% Change	(mm/year)	% Change	(mm/year)	% Change	(mm/year)	% Change	(mm/year)
Year 2040	2.0%	837	-3.0%	796	-11.5%	725	-5.0%	780
Year 2065	1.2%	675	-5.2%	632	-19.6%	535	-5.0%	633

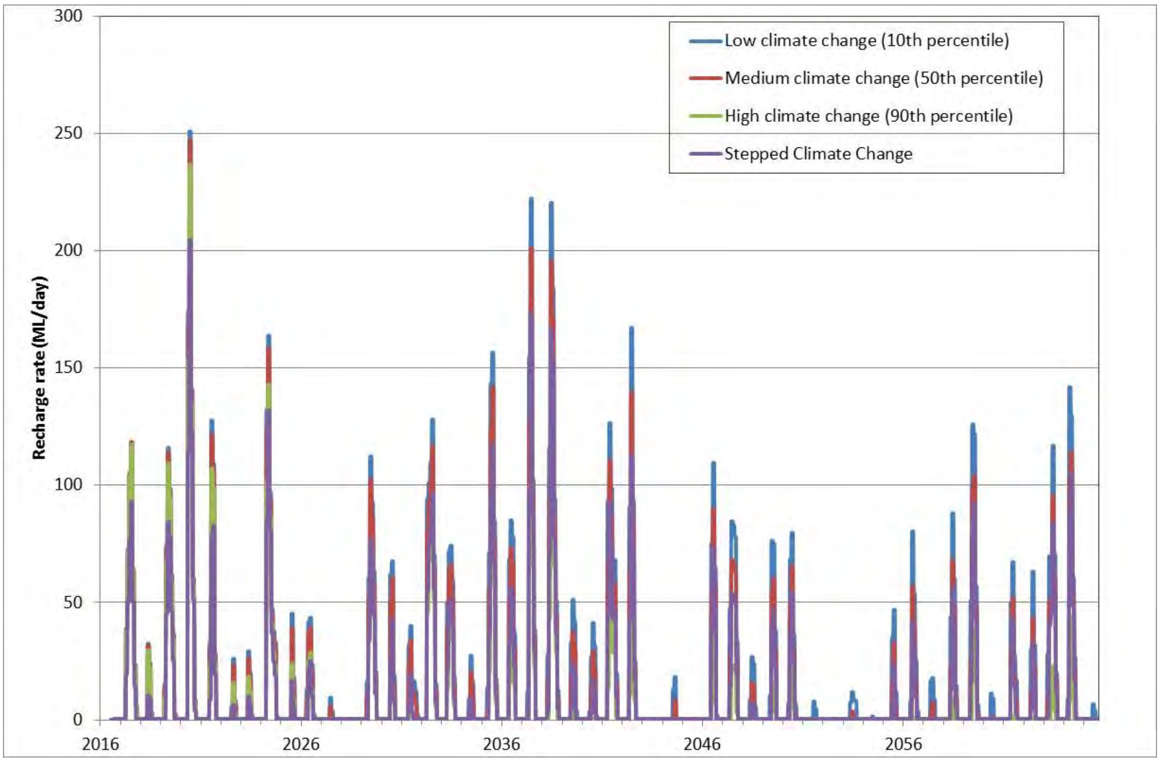
5.2 Recharge to the Lower Tertiary Aquifer

The average recharge to the LTA over the last 30 years is estimated to be 5,900 ML/year. Recharge to the aquifer is predominantly where the aquifer outcrops at the Barongarook High, in the Boundary Creek catchment. Table 5-2 outlines the recharge to the LTA under the four different climate change scenarios. With the exception of the low climate change scenario, recharge is expected to decline.

Table 5-2: Estimated recharge to the Lower Tertiary Aquifer under different climate scenarios over 50 years

Climate change scenario	Groundwater recharge over LTA Outcrop (ML/year)	Comment
Current	5,835	Average recharge in the calibration model (30 years)
Low	6,336	This is an increase of 8% compared to average over last 30 years
Medium	5,371	This is a reduction of 8% compared to average over last 30 years
High	4,410	This is a reduction of 25% compared to average over last 30 years
Stepped	4,145	This is a reduction of 29% compared to average over last 30 years

Figure 5-1 : Recharge rate variability on the outcropping LTA



5.3 Model scenarios

Two potential future operating (pumping) scenarios were run, a constant rate pumping scenario and an intermittent pumping scenario.

An additional two model scenarios were also run to estimate the cumulative and incremental impacts of historical and future pumping. One scenario assumes no future pumping to estimate how the aquifer would behave if no further pumping occurred. Another scenario assumes no historical or future pumping to provide a baseline to estimate predicted impacts. These are described in detail in the following sections.

5.3.1 No pumping scenarios

Null case, or no pumping scenarios, were used for comparative purposes so that impacts associated with groundwater pumping can be distinguished from natural groundwater variability and trends due to future climate assumptions. The process involves subtracting predicted impacts for the no pumping scenarios from the pumping scenario to generate the predicted impacts due to the assumed pumping.

In addition to distinguishing the effects of borefield pumping from those of climate, impacts have also been estimated in terms of both cumulative and incremental effects. Cumulative impacts include the remnant impacts of previous operations superimposed on the impacts that may arise from future borefield pumping. Incremental impacts are those that can be attributed to future borefield operations alone and ignore the impacts that have already occurred and that will continue to be felt for some time. In order to be able to delineate both cumulative and incremental impacts two different null case scenarios have been formulated and run as follows:

- **Model scenario 0** is run for 87 years starting from 1980 (i.e., before the onset of large scale pumping from the borefield). It assumes initial conditions as the pre-development or “natural” state. The scenario simulates how the aquifers would have responded had there been no pumping from the borefield at any time. This is the null case that is used to identify the cumulative impacts of the borefield operations.
- **Model scenario 1** is run for 50 years from the present day. It assumes initial conditions as those prevailing in the aquifers as observed today (i.e. with residual drawdown and residual impacts from earlier borefield pumping). This scenario simulates how the aquifer will recover in future should there be no pumping from the borefield. This is the null case that can be used to extract incremental impacts of future borefield operations.

Both no pumping scenarios have been run with all four future climate conditions (low, medium high and step change scenarios).

5.3.2 Pumping scenarios

Two pumping scenarios were formulated and run as follows:

- **Pumping Scenario 2** includes borefield pumping at a constant rate of 4,000 ML/year (regardless of climate, i.e. even in a wet year, the model assumes that the borefield will extract 4,000 ML/year). It has been run from 2017 to 2067 and has been run with all four future climate assumptions. The 4,000 ML/year was selected based on the long term sustainable average extraction rate based on a study completed by the Department of Natural Resources and Environment (Witebsky et al, 1995). Witebsky et al., (1995) acknowledged that this extraction rate was likely to impact on flows in Boundary Creek and that this could be managed through by offsetting the impact when it was realised.
  - The Community Reference Group requested this scenario to understand whether a sustained pumping regime at a lower rate would produce less impacts than intermittent pumping.
- **Pumping Scenario 3** assumes intermittent groundwater extraction similar to how the borefield has been operated in the past. For the given climate scenarios, the model predicts that the borefield is not required for up 25 years because of the rainfall and drought sequence used.

The cumulative pumping volume for each scenario is shown in Figure 5-2.

For Scenario 3 the pumping rates included in the groundwater model were obtained from a water demand model (provided by Barwon Water from their internal SOURCE-Rivers model) that estimates the required timing and pumping rates from the borefield in order to meet the predicted water demand under the four future climate assumptions. This scenario has been run from 2017 to 2067 and has been run with all four future climate assumptions.

It should be noted that because the different climate assumptions produce different water demands (more water is pumped from the borefield in the drier climate scenarios) the assumed extraction from the borefield is different for each climate case.

The timeframe for when the borefield is required also changes for each climate scenario. For example:

- Under a low climate change scenario, the borefield is required first in 2045,
- Under a moderate climate change scenario, the borefield is required first in 2045 but for a shorter duration compared to the low climate change scenario,
- Under a high climate change scenario, the borefield is required first in 2028, and
- Under a step-change climate change scenario, the borefield is first required in 2027.

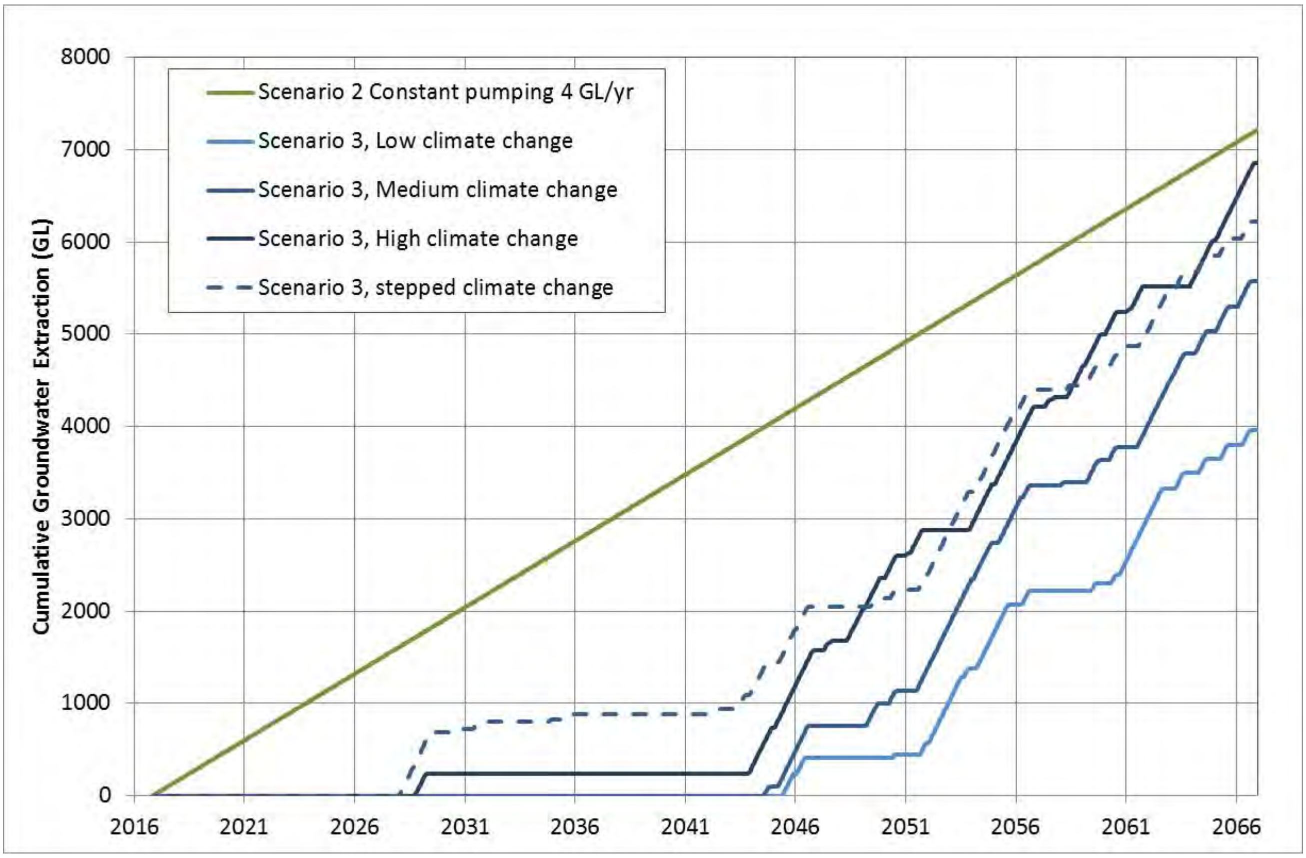
The four different pumping schedules included in this scenario are illustrated in Table 2-4 as pumping rates and cumulative extraction respectively. The constant pumping rate assumed for all climates in Scenario 2 is also presented on these figures. It is important to note that the intermittent pumping rates used in Scenario 3 include much higher extraction rates than those used in Scenario 2 and that most of the pumping occurs late in the simulation period. Overall there is more water extracted in Scenario 2 than in Scenario 3.

A summary of the model scenarios is provided in Table 5-3.

Table 5-3 Overview of the model scenarios

Model Scenario	Pumping (ML/year)	Scenario description
Scenario 0	0	Assumes **no historical or future pumping** and forms the basis for estimating cumulative impact of historical and future pumping from the bore field.
Scenario 1	0	Assumes **no future pumping** and predicts how the aquifer would recover under different climate scenarios if pumping ceased immediately.
Scenario 2	Constant pumping 4,000ML/year	Assumes a **constant groundwater extraction rate** over the next 50 years and predicts the aquifer response under different climate scenarios.
Scenario 3	Max Yearly Rate: 12,000 ML Max 15 year limit: 60,000 ML	Assumes an **intermittent groundwater extraction rate** which is similar to how the borefield has been operated historically but with a reduction in volumetric entitlements.

Figure 5-2 Cumulative groundwater extraction rate for Scenario 2 and 3



5.3.3 Model results

The model predicts the drawdown for each model scenario (climate and pumping scenarios). The predicted drawdown is used to assess the risk to the aquifer and environmental receptors at the surface from potential future operation of the Barwon Downs borefield. The results are discussed in the following chapters.

The modelling results are described in detail in Jacobs (2018).

6. Potential impact on the Lower Tertiary Aquifer

This section of the report directly addresses the assessment needed to meet the requirements of the Water Act (1989), specifically section 40 (D) which requires that any adverse effect of allocation or use will have on an aquifer be considered.

Based on the technical work that has been completed and summarised in this report, we have reached the conclusion that there is no adverse effect on any aquifer likely to arise from the allocation or use as proposed under the licence application.

The potential adverse effects of the groundwater extraction from the Barwon Downs borefield on the Lower Tertiary Aquifer (LTA) or any other aquifer has been considered in terms of the following:

- Groundwater mining leading to long term loss of groundwater storage from the resource as a whole,
- Degradation of the aquifer through irreversible alteration of the aquifer matrix, and
- Loss of beneficial uses due to degradation in water quality.

These effects are discussed in the following the sections.

6.1 Groundwater mining

There has been some community concern that the aquifer is being mined. Groundwater mining refers to operations where over the long term, groundwater extraction rates exceed recharge rates, so groundwater levels decline over the long term (50 to 100 years). Groundwater levels would be expected to continuously decline leaving the aquifer depleted for the foreseeable future. In reality, groundwater mining which is ceased does not necessarily lead to a permanent loss of groundwater storage as groundwater levels will eventually recover to pre-development levels after the extraction is ceased (albeit over a long time frame). In the case of Barwon Downs, the proposed extraction rates do not exceed recharge and the rate of decline in groundwater levels will stabilise slowly over time. When pumping ceases, groundwater levels will recover and the aquifer will eventually return to its pre-development condition.

The maximum proposed 15 year extraction limit is 60,000 ML. Using the assumed climate sequence adopted in the groundwater model, recharge from rainfall infiltration over the next 15 years is assumed to range from 95,000 ML for the low climate change scenario to 62,000 ML for the step change climate change scenario. It should be noted that this recharge does not include additional recharge from rivers or from inflows from surrounding formations.

The predicted recharge rates and the proposed extraction rates as a percentage of the recharge is shown in Table 6 1. Based on the assumptions used in the groundwater model, the percentage of recharge proposed to be extracted ranges between 63% and 97%. Irrespective of the balance between recharge and long term groundwater extraction while the borefield is operational, groundwater levels will always be lower than pre-pumping groundwater levels. This is a feature of all groundwater extractions in all aquifers. The fact that drawdown occurs during periods of groundwater extraction does not indicate that the extraction is not sustainable nor is it an indication of groundwater mining. Aquifers are replenished when pumping ceases and groundwater levels recover with time.

Table 6 1: Recharge rates compared to proposed extraction limit

Climate change scenario	Groundwater recharge to LTA (ML/year)	15 year recharge rate (ML)	Proposed extraction rate of 60,000 ML
Low	6,336	95,040	63% of recharge
Medium	5,371	80,565	76% of recharge
High	4,410	66,150	90% of recharge
Stepped	4,145	62,175	97% of recharge

6.2 Irreversible changes to the aquifer matrix

It is acknowledged that in certain circumstances, groundwater extraction and drawdown can reduce pressures in confined aquifers to a level that will induce settlement in the aquifer itself that could permanently diminish its ability to transmit and store water. While land subsidence has been identified in a number of areas of high groundwater extraction, there are few, if any, examples (in Australia and internationally) of compaction occurring in an aquifer that has led to damage to the aquifer itself. In most instances of reported land subsidence arising from groundwater extraction, the compaction has occurred in clay rich aquitards that bound the productive aquifers.

In the context of the Barwon Downs borefield, there has been no indication that historic groundwater extraction has caused damage to the LTA aquifer. In addition to this, the drawdown effect is significantly less than other Victorian aquifers which also have no evidence of adverse effect. Given that the proposed future extraction rates (and expected levels of drawdown) are not greater than historic rates, it is difficult to conceive that the proposed extraction will damage the aquifer

As noted above, historic groundwater extraction and drawdown has not led to a measurable degradation of the aquifer function. The historic pumping has given rise to a maximum of about 60 m of drawdown within the borefield area. It can be concluded that this level of drawdown in the future will not cause an adverse effect on the aquifer matrix.

There is currently no formal policy or guideline outlining a framework that determines the risk or impact to an aquifer. However, a framework was developed in the Water Science Studies to determine impacts that may arise as a consequence of onshore gas development (DELWP & GSV, 2015). The Water Science Studies impact assessment framework included impacts to rivers, water bodes and aquifers resulting from aquifer depressurisation.

The impact, or effect, was defined based on the criteria outlined in Table 6 2. This framework has been adopted to determine the impact of drawdown from the Barwon Downs borefield on the aquifer.

Table 6 2: Framework to assess impacts to aquifers from drawdown (DELWP & GSV, 2015)

GW level drawdown	Unconfined aquifer	Confined aquifer
Low effect	Drawdown is small with respect to aquifer ability to supply. Drawdown < 2 m after 30 years.	Drawdown is small with respect to aquifer ability to supply. Drawdown < 10 m after 30 years.
Moderate effect	Extraction impacts measurably with respect to aquifer ability to supply, but can potentially be mitigated by deepening of boreholes/pumps. Drawdown between 2 m and 15 m after 30 years.	Extraction impacts measurably with respect to aquifer ability to supply, but can potentially be mitigated by deepening of boreholes/pumps. Drawdown between 10 m and 75 m after 30 years.
High effect	Extraction is large with respect to aquifer ability to supply. Drawdown > 15 m after 30 years.	Extraction is large with respect to aquifer ability to supply. Drawdown > 75 m after 30 years.

6.2.1 Predicted drawdown in the LTA

The predicted drawdown results for the LTA where the aquifer is confined and unconfined has been classified into the relevant categories presented in Table 6 2 and shown in Figure 6.1 to 6-4.

These figures highlight the following:

- There is very little difference between the maximum drawdown impacts between the constant and intermittent pumping scenarios for areas of confined and unconfined LTA.
- Predicted drawdown for both constant and intermittent pumping is expected to be similar to observed historical drawdown.
- The maximum predicted drawdown at the borefield is 60 m around the borefield. This impact is classified as a moderate effect as the bores have been designed to accommodate this drawdown and do not need to be augmented as a result. Consequently, there is low risk of harm to the aquifer. Figure 6.1 and Figure 6.2 shows that the model predicts more than 75 m drawdown immediately around the extraction bores. This is a modelling artefact as the regional model is not capable of predicting drawdown in a well accurately.
- Away from the borefield, where the LTA is confined, the predicted drawdown is between 10 and 75 m, which is classified as a moderate impact on the aquifer. This is described as '*the extraction impacts measured with respect to the aquifer's ability to supply, but this can be mitigated with augmentation of the production bores'*. This level of extraction has not adversely impacted the aquifer's ability to supply water historically as bore yields have remained constant. Barwon Water licence accounts for the full PCV under the current licence, so there are no other users in the aquifer that could be adversely impacted by this level of drawdown. Future users will need to take into account the projections of effects that are described in this report.
- The drawdown throughout the remainder of the confined aquifer is less than 10 m and is therefore predicted to have a low effect on the aquifer.
- Where the LTA is unconfined, the model predicts more than 15 m drawdown in some areas on the Barongarook High. While this is classified as a high impact on the aquifer, there is no evidence that historical drawdown of this magnitude has had any impact on the aquifer's capacity to transmit and store water. Drawdown in the unconfined region near Boundary Creek Reach 2 has had undesirable impacts on the creek and these are considered in detail in the risk assessment.

Figure 6.1: Contours of predicted drawdown in the confined LTA for the intermittent pumping scenario (moderate climate change)

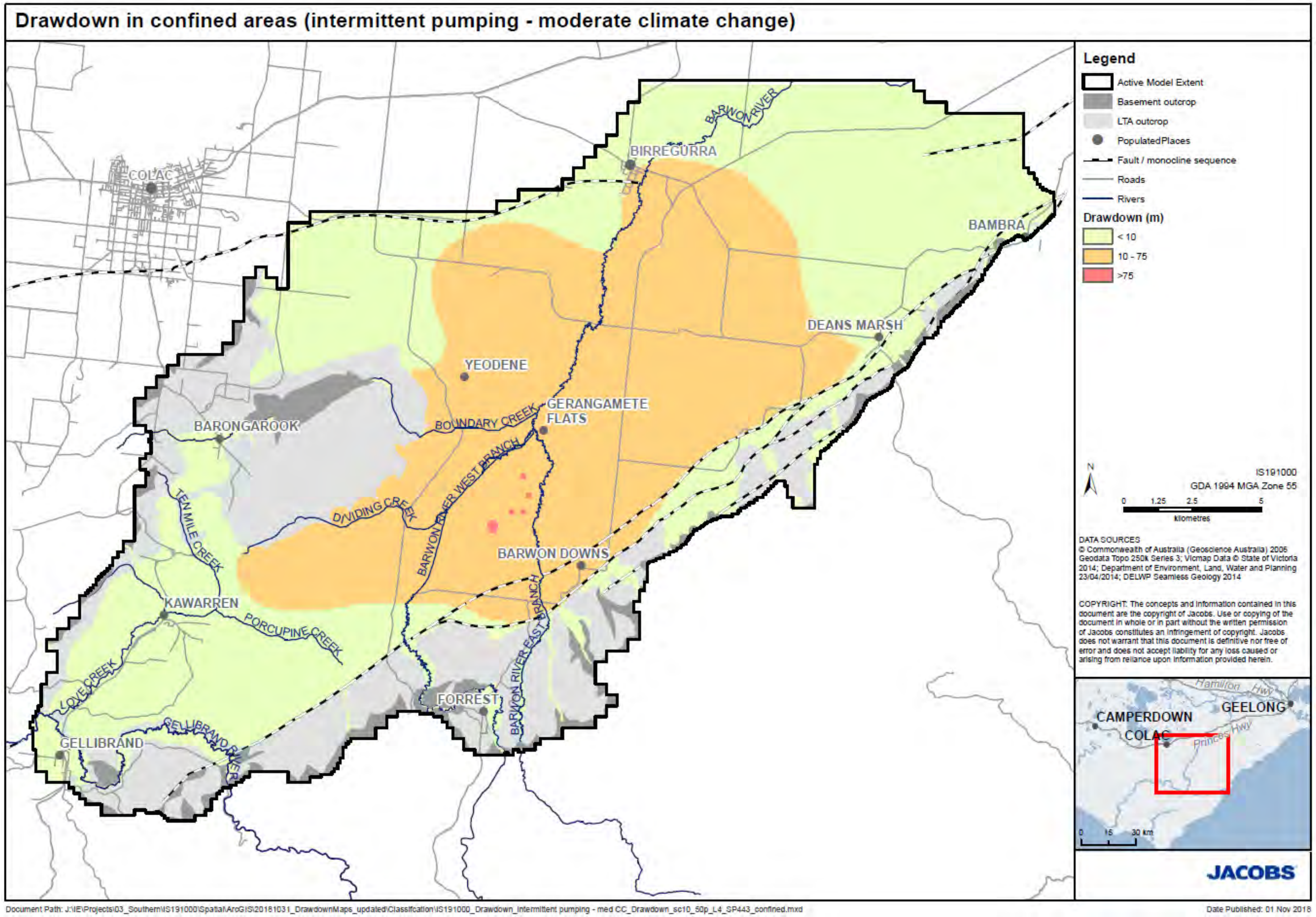


Figure 6.2: Contours of predicted drawdown in the confined LTA for the constant pumping scenario (moderate climate change)

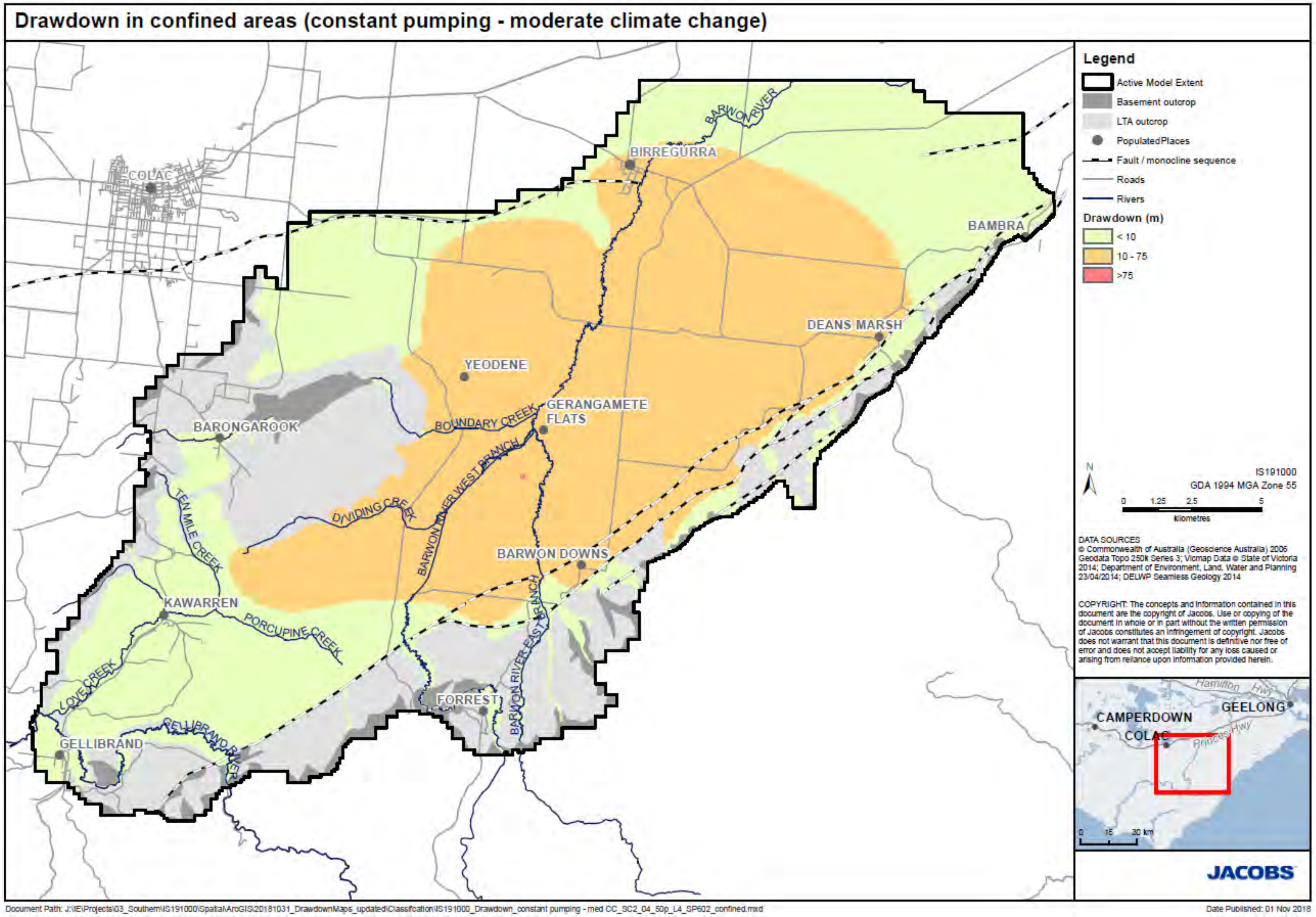


Figure 6.3: Contours of predicted maximum drawdown in the unconfined LTA for the intermittent pumping scenario (moderate climate change)

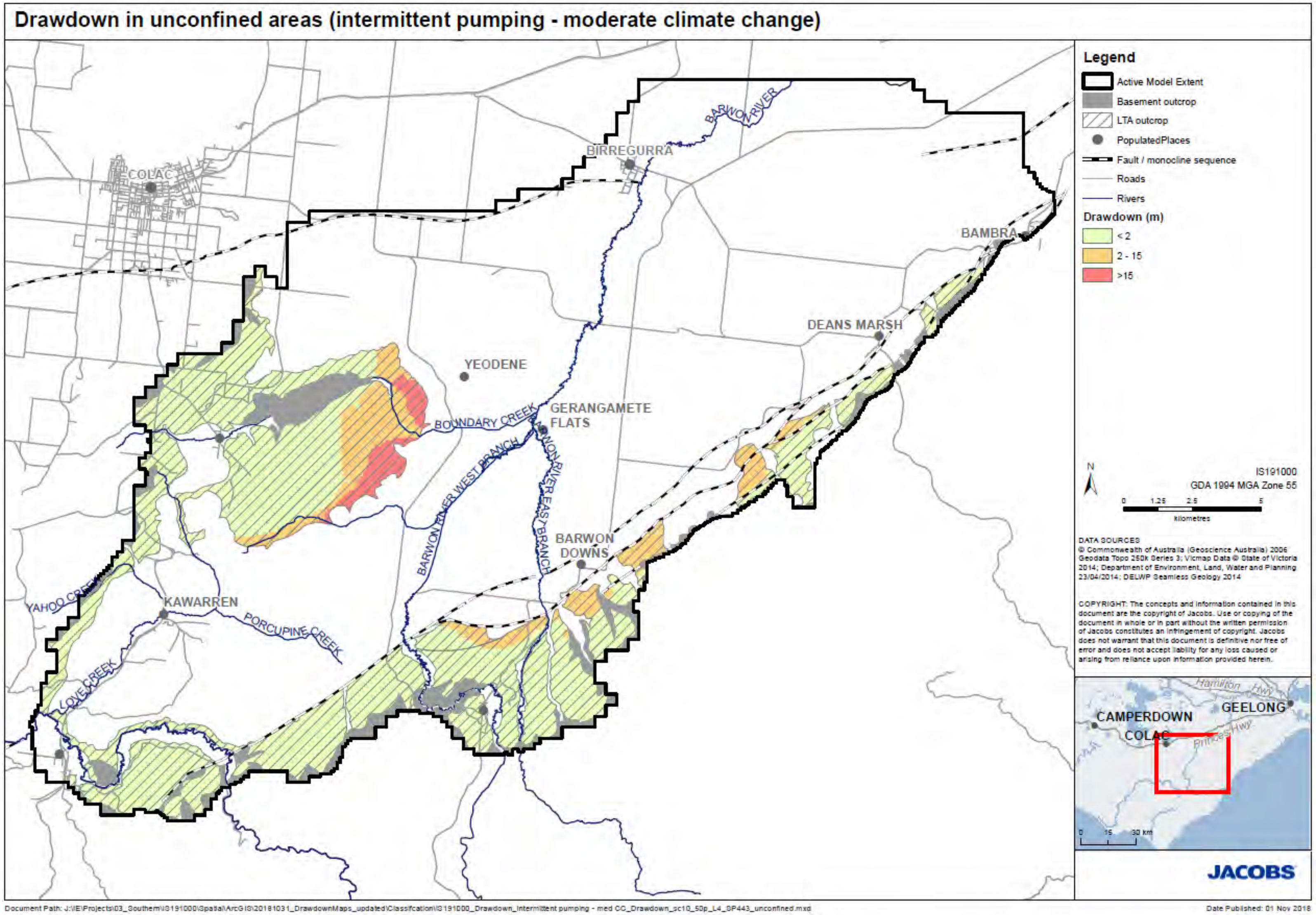
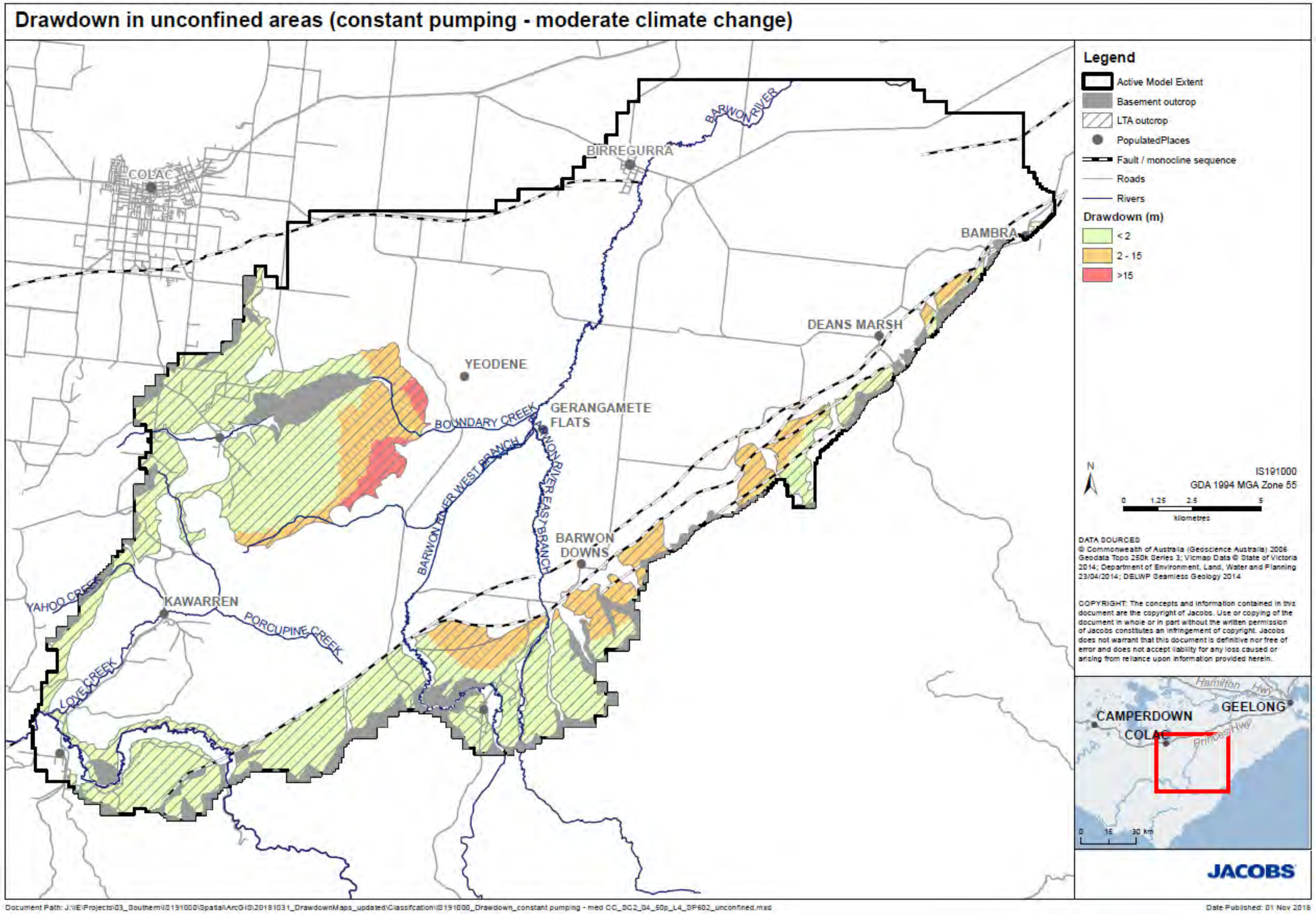


Figure 6.4: Contours of predicted maximum drawdown in the unconfined LTA for the constant pumping scenario (moderate climate change)



6.2.2 Water level recovery in the Lower Tertiary Aquifer

The groundwater model was also used to understand how groundwater levels in the regional aquifer would recover if there was no future pumping from the borefield and to demonstrate that the aquifer is not being mined. The scenario uses the water levels from the end of the calibration model, assumed to represent the current day, and predicts the rate of recovery under different climate scenarios. The drawdown is calculated as the difference between water levels predicted in Scenario 0 and Scenario 1.

An aquifer is typically considered to have recovered when the water level recovers to 90% of pre-pumping water level, as the remaining 10% of recovery can take significantly longer to realise and is a small enough proportion of the storage to overlook. That is, if the drawdown is 10 meters, 90% recovery would be constitute a groundwater level rise of 9 meters.

Groundwater levels close to the borefield will have more drawdown but will also recover faster. Groundwater levels further away from the borefield will have less drawdown, but will take longer to recover, especially in the unconfined part of the aquifer. Figure 6-5 shows the predicted recovery of groundwater levels in selected bores around the model domain.

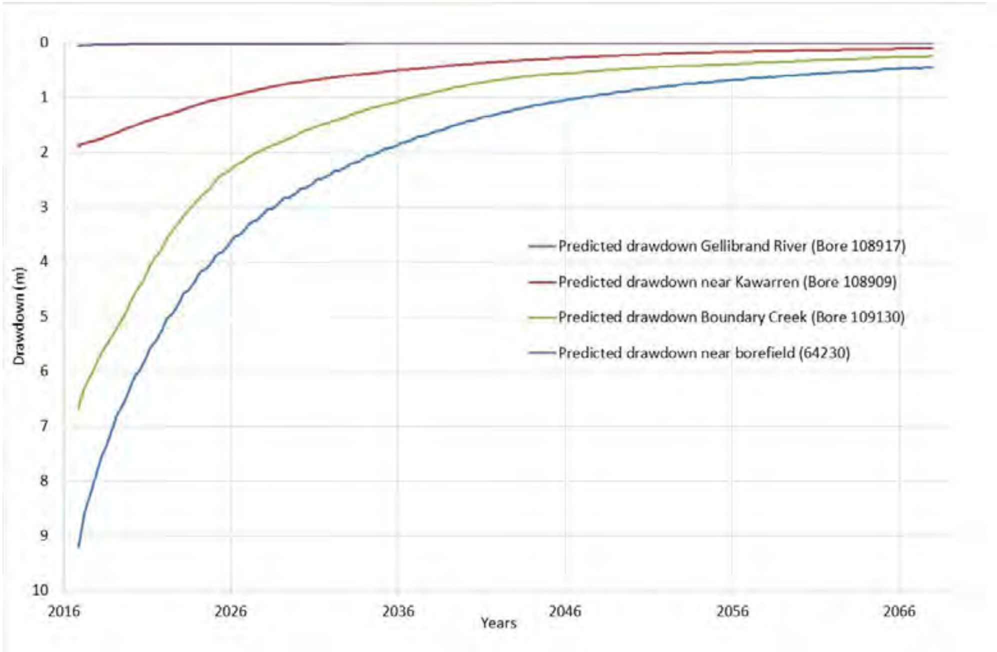
Water levels near the borefield (Bore 64230) show that the residual drawdown in 2016 was around 10 m. The maximum drawdown in this bore from historical pumping was 58 m, which highlights that the water levels had recovered over 80% in 2016. The aquifer is expected to have recovered to 90% (5-6 m drawdown) after around 5 years of no more pumping.

The drawdown in the regional aquifer near Boundary Creek is currently around 7 meters (Bore 109130). The maximum historical drawdown in response to pumping was 10 m, which indicates the aquifer is around 30% recovered in this location. The aquifer is predicted to be 90% recovered (1 m drawdown) after 20 years of no more pumping.

The drawdown predicted at Kawarren (Bore 108909) is significantly less, but the rate of recovery is slower. The maximum historical drawdown in response to pumping was 3 m and the drawdown is currently 2 m, or 30% recovered. The aquifer is predicted to be 90% recovered in around 2050 after 30 to 40 years of no more pumping.

The future climate will also influence the rates of recovery. The climate regime assumed for the predicted model includes a period of above average rainfall at the start of the climate sequence, which will increase the rate of recovery. In contrast, below average rainfall conditions would decrease the rate of recovery. Given the recovery rates presented in here are based on a climate sequence with above average rainfall conditions, they represent a best case scenario. If rainfall over the next 10-15 years is below average, recovery rates would be slower than predicted here.

Figure 6-5 Predicted water level recovery from 2016 assuming no future pumping for the moderate climate change scenario



6.3 Effect on groundwater quality

As outlined in Section 3.5, the groundwater salinity in the LTA has been measured in 48 bores, however these are typically single measurements taken when the bore was constructed. With the exception of the requirements of the existing groundwater licence to monitor the salinity in three bores, there is very limited data to demonstrate if and how salinity may have changed over time.

The groundwater salinity has been monitored annually in three bores since 2004 in accordance with Schedule 2.1 in the current groundwater extraction licence. The groundwater salinity has been measured annually since 2004 and the results are shown in Figure 6.6. This graph also shows the data that is available for the same bores on WMIS, together with the data collected by Barwon Water.

The graph shows that groundwater salinity decreased from between 2004 and 2014. Although the data on WMIS has more variability, the same downward trend is observed. All bores recorded higher salinities in 2015 and the reason for this is not known. The salinity was lower in 2016 and has generally increased slightly since then. The groundwater salinity ranges between 300 and 1,100 µS/cm EC (195 and 715 mg/L TDS), which is within the typical range of the LTA.

Although it not clear what factors are driving the variability in groundwater salinity, operating the borefield has not had an adverse impact on the groundwater quality with respect to salinity. If anything, the groundwater salinity has decreased in all bores since monitoring commenced. The range of salinities recorded is within the typical range expected for the LTA.

Figure 6.7 shows the salinity data available on WMIS in two of the groundwater extraction bores 64229 and 64236. The salinity in these bores shows a similar trend over the period the data was collected.

Figure 6.6: Groundwater salinity measurements in bores monitored as a condition of the current licence

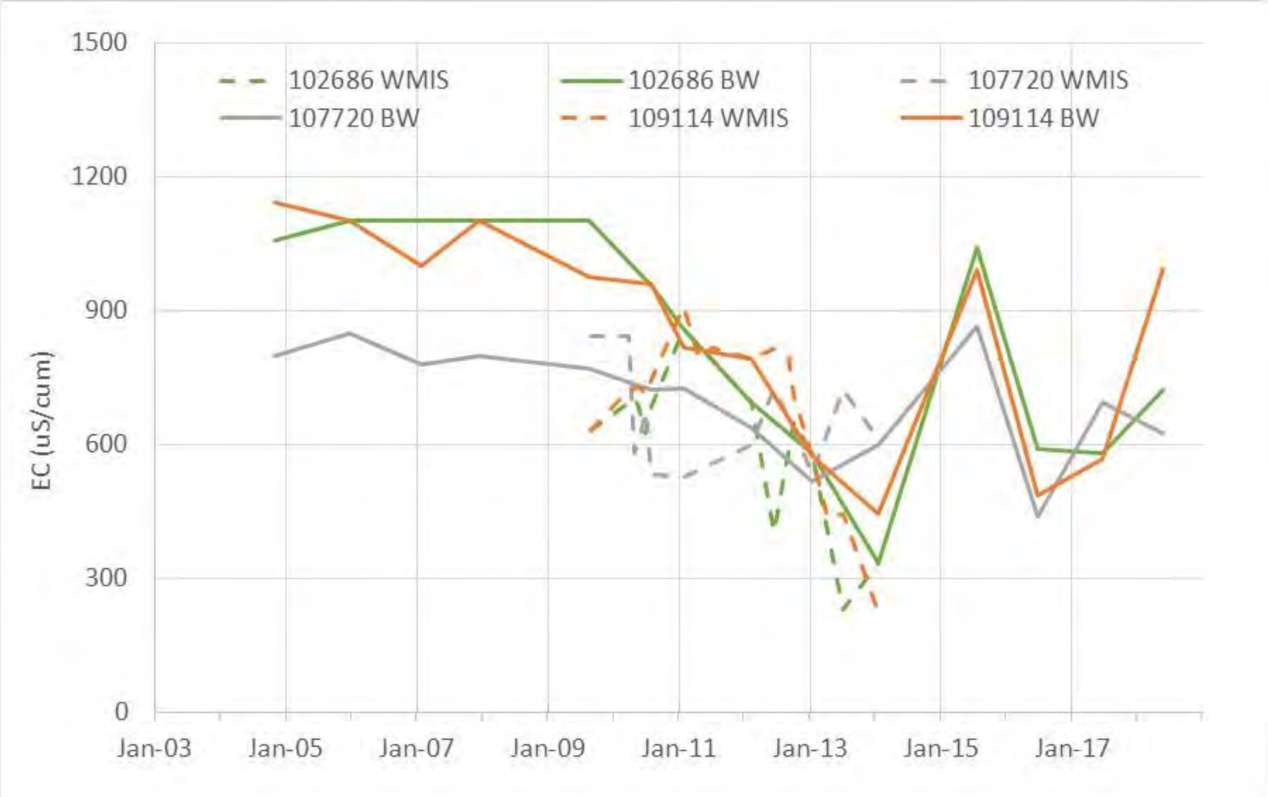
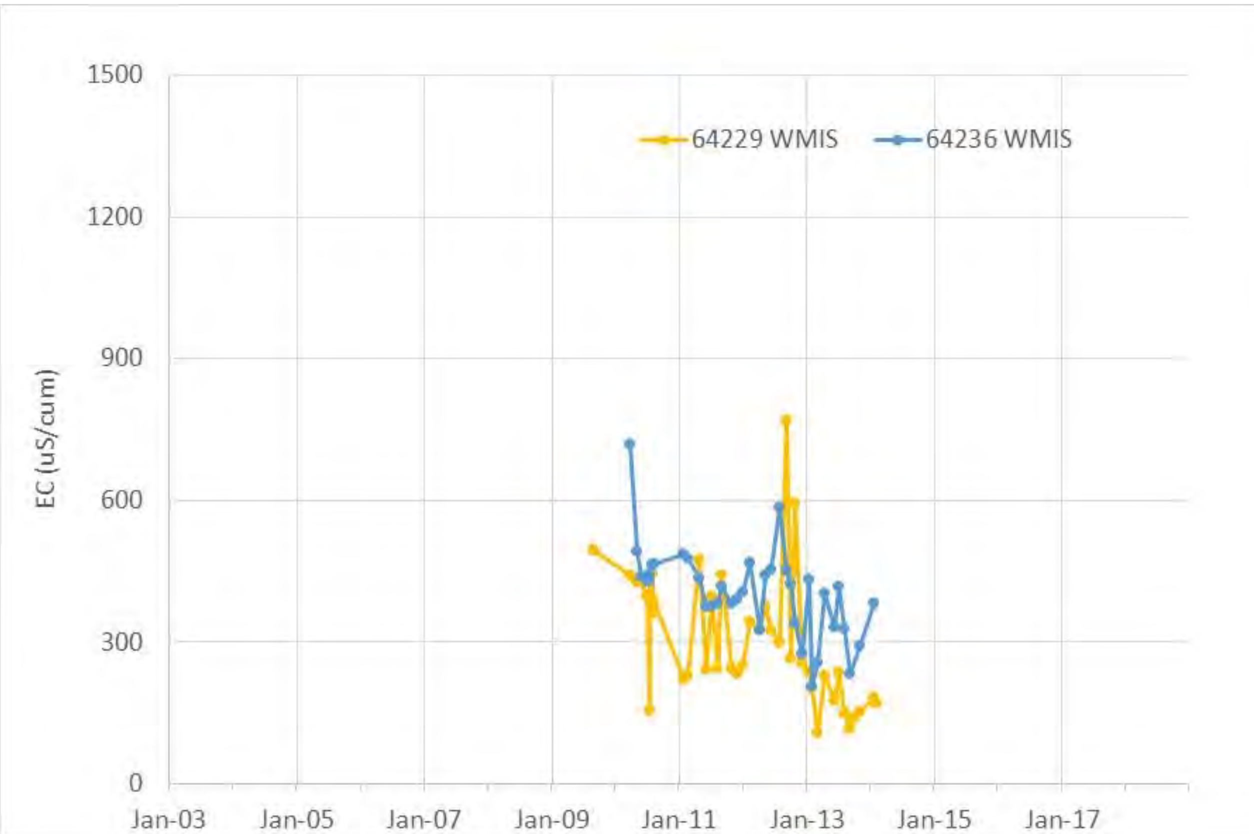


Figure 6.7: Groundwater salinity measurements from WMIS



6.4 Effect on land subsidence

Land subsidence can occur in response to drawdown, however subsidence generally relates to the compaction of clays in the overlying aquitards rather than the aquifer itself. For this reason, subsidence is not expected to adversely impact the LTA.

Land subsidence has been monitored in accordance with the existing licence conditions. This historical impact of land subsidence has also been well within the existing trigger limits of 200 mm. Given the predicted groundwater level drawdown is within the range of both historical impacts and the current groundwater level triggers, it is highly likely that the potential future subsidence will also be similar to historical observations and therefore within the trigger levels.

Ongoing monitoring of land subsidence is recommended, and the existing triggers levels are recommended for the future licence.

6.5 Summary

The technical works completed to date demonstrate that there is no adverse effect on the LTA likely to arise from the allocation or use as proposed under the licence application. The potential adverse effects of the groundwater extraction from the Barwon Downs borefield on the LTA or any other aquifer was considered in terms of the following:

- Groundwater mining leading to long term loss of groundwater storage from the resource as a whole,
- Degradation of the aquifer through irreversible changes of the aquifer matrix, and
- Loss of beneficial uses due to degradation in water quality.

There has been some community concern that the aquifer is being mined. This refers to operations where groundwater extraction rates exceed recharge rates, so groundwater levels decline over the long term (50 to 100 years). In the case of Barwon Downs, the proposed extraction rates do not exceed recharge. In addition to this, the rate of decline in groundwater levels is predicted to stabilise slowly over time. When pumping ceases, groundwater levels have recovered in the past, and are predicted to recover in the future. The aquifer will return to its pre-development condition when pumping ceases.

It is acknowledged that in certain circumstances, groundwater extraction and drawdown can reduce pressures in confined aquifers to a level that will induce settlement in the aquifer itself that could permanently diminish its ability to transmit and store water. In most instances of reported land subsidence arising from groundwater extraction, the compaction has occurred in clay rich aquitards that bound the productive aquifers. For this reason, groundwater extraction is not likely to impact on the aquifer matrix.

Groundwater salinity has been monitored in accordance with the groundwater extraction licence and while there has been some variability in groundwater salinity, operating the borefield has not had an adverse impact on the groundwater quality.

In summary, the proposed groundwater extraction rates are not expected to cause adverse impacts to the LTA.

7. Risk assessment framework for receptors

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.

7.1 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:
    - 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:
    - 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

These are described in more detail below.

7.1.1 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 Table 7-1):

- 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 7.1 shows the spatial representation of the likelihood of river being connected to the regional groundwater system.

Table 7-1 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	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	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	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

7.1.2 Consequence

The **consequence** of pumping has been considered using both measures outlines in Table 7-2:

1. Percentage reduction in low flows (10th 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 (see Table 7-2).

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 7.2.

Table 7-2 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 7.1: Likelihood of surface water connection to groundwater

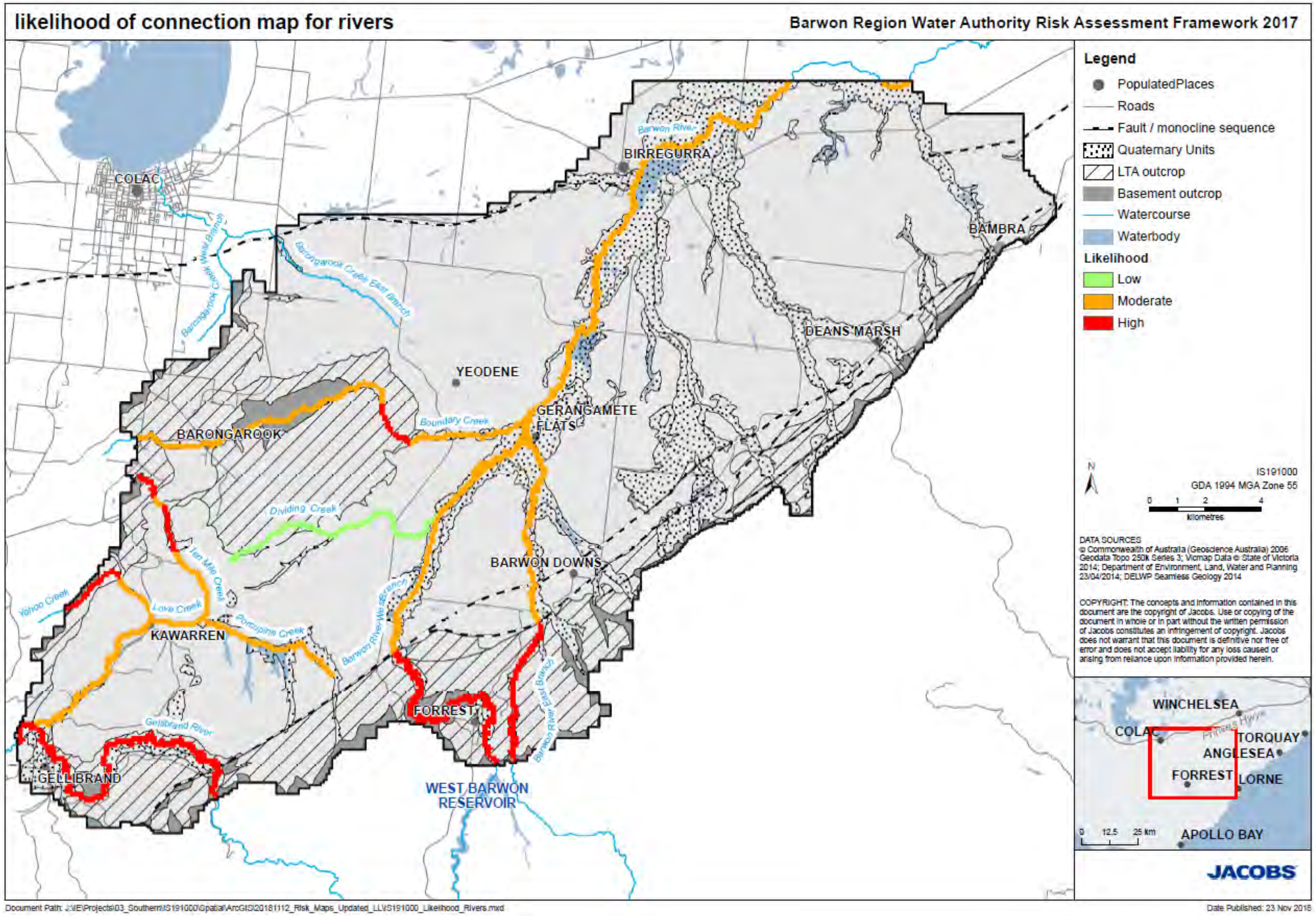
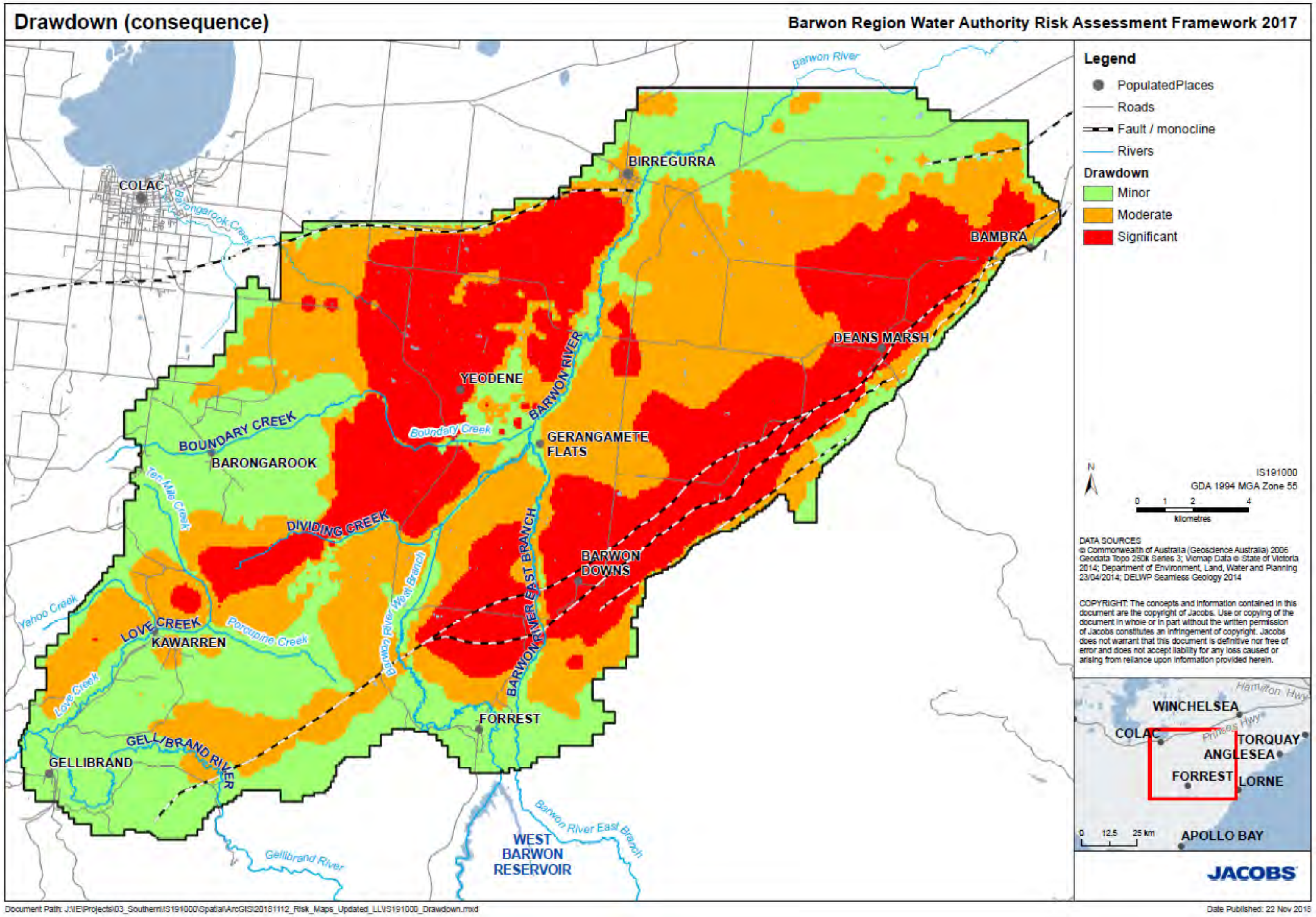


Figure 7.2: Drawdown in the model watertable aquifers as a measure of consequence of impact of the borefield



7.1.3 Risk

The risk assessment framework is shown in Table 7-3.

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 aquifer and the regional aquitard, that essentially mitigate the risk the drawdown. Consequently, risk of groundwater extraction to creeks and rivers has been considered in terms of potential unmitigated and mitigated risk where:

- **Unmitigated risk** is based on the likelihood of connection and drawdown predicted in the groundwater model.
- **Mitigated risk** considers the physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in real world, but not well represented or include significant levels of predictive uncertainty in the model. These include the presence of alluvial aquifers and the regional aquitard. The Technical Works Monitoring Program has confirmed that alluvial aquifers are present in many areas and have not been influenced by drawdown and, drawdown in the regional aquitard near the surface is less than predicted by the model. Drawdown takes time to propagate through the aquitard to the surface. However, the model calculates drawdown at the centre of each formation, including the aquitard. As such, the model over predicts water table drawdown during the model time frame where the aquitard outcrops.

Table 7-3 Risk assessment framework

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

7.2 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 7-4)
- **Consequence** of the proposed groundwater extraction on the feature defined by the drawdown in the regional aquifer (see Table 7-5)
- **Risk** is considered in terms of low, medium, high risk using the following equation (see Table 7-6):
  - Likelihood x Consequence = Risk

Table 7-4 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 7-5 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

Table 7-6 Risk assessment framework

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

8. Potential risk to rivers

In some areas, groundwater baseflow to rivers is an important component of the river flow, particularly during low flow periods (i.e. summer months). Declining groundwater levels have the potential to reduce the amount of baseflow in rivers and, if significant, groundwater level declines can result in the river changing from gaining to losing, also impacting on river flows.

Changes in groundwater contributions to rivers has been estimated for the historic and predicted model scenarios for the following rivers:

- Boundary Creek – including Reaches 1, 2 and 3
- Barwon River – including the West Branch, East Branch and downstream of the confluence between the two branches.
- Dividing Creek
- Gellibrand River – including tributaries Porcupine Creek, Ten Mile Creek, Yahoo and Loves Creek
- Barongarook Creek.

The location of the river reaches is shown in Figure 8.1.

The predicted impacts of potential drawdown from future groundwater pumping on groundwater baseflow to rivers in the model domain is described in the following sections. The risk assessment framework outlined in the Ministerial Guidelines for High Value GDEs was used to determine the risk. The risk framework and the implications of drawdown on groundwater surface water interactions across the catchment is also described in the following sections.

Section 8.2.2 deals specifically with the requirement of clause 9.4b in the current licence to provide "…… *a report containing an assessment of the loss of flow in the East Barwon River between the stream gauge referred to in sub-clause 9.1 and the aqueduct crossing on the East Barwon River east of Yaugher due to pumping under this licence.*

8.1 Available surface water flow monitoring data

Streamflow monitoring data varies across the model domain. Table 8-1 summarises the streamflow data and the location of the streamflow monitoring gauges is shown in Figure 8-2.

There is very limited flow data available for Ten Mile Creek, Yahoo Creek and Barongarook Creek. Rather than rely solely on the available flow data for these creeks to determine the consequence of the predicted reduction in groundwater contribution on river flows, the predicted drawdown has also been used to inform the risk of groundwater pumping to these creek (see Table 7-2 in Section 7.1.2).

Table 8-1 : Stream flow gauges on rivers in model domain

Gauge	Description	Active/ Inactive	Record length	Confidence rating
Boundary Creek catchment				
bw763	Boundary Creek Release flow meter	Active	March 2015 to present	High
233273A	Boundary Creek at Barongarook	Active	June 2014 to present	Low (before Aug 2016) Moderate (after Aug 2016)
233231A	Boundary Creek Upstream Macdonald's Dam	Active	Dec 1989 to Feb 1994 June 2014 to present	High
233229A	Boundary Creek Downstream Macdonald's Dam	Active	Dec 1989 to Feb 1994 June 2014 to present	Moderate
233228A	Boundary Creek at Yeodene	Active	June 1979 to present	High
Barwon River catchment				
233224	Barwon River at Ricketts Marsh	Active	July 1971 to present	High
233247	Barwon River at Kildean Lane	Active	June 1993 to present	High
Gellibrand catchment				
235227	Gellibrand River at Bunkers Hill	Active	March 1970 to present	High
235228	Gellibrand River at Gellibrand	Inactive	April 1970 to May 1989	Low
235202	Gellibrand River at Upper Gellibrand	Active	August 1949 to present	High
235239	Ten Mile Creek at Kawarren	Inactive	April 1985 to July 1995 April 2008 to July 2009	Low
235240	Yahoo Creek at Kawarren	Inactive	March 1985 to July 1995	Low
235241	Porcupine Creek at Kawarren	Inactive	April 1985 to July 1995 April 2008 to July 2009	Low
235234	Loves Creek at Gellibrand	Active	May 1979 to present	High
Barongarook Creek catchment				
234210	Barongarook Creek at Lake Colac	Inactive	Oct 1975 to Jan 1981	Low

Figure 8.1: Location of river reaches in the model

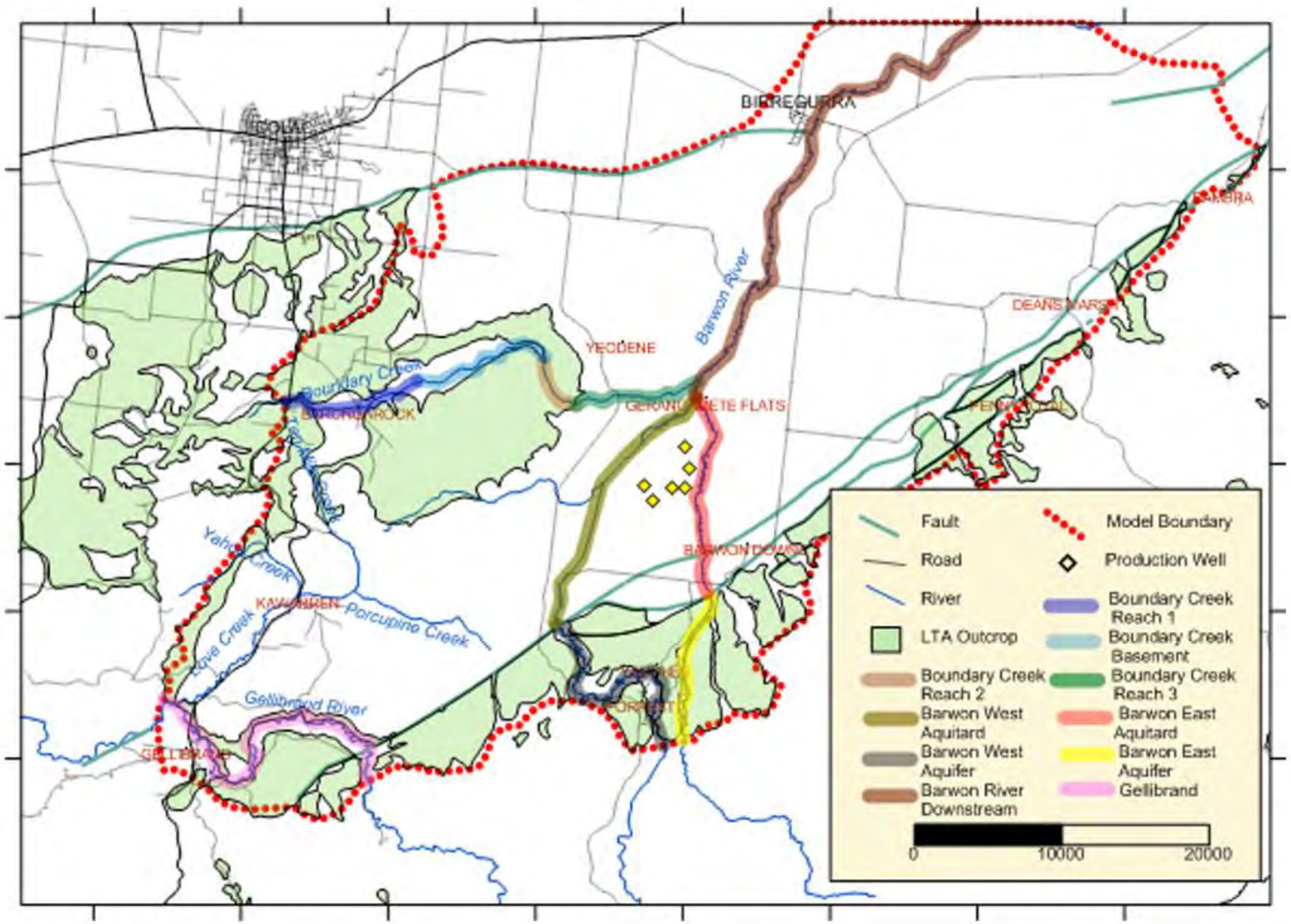
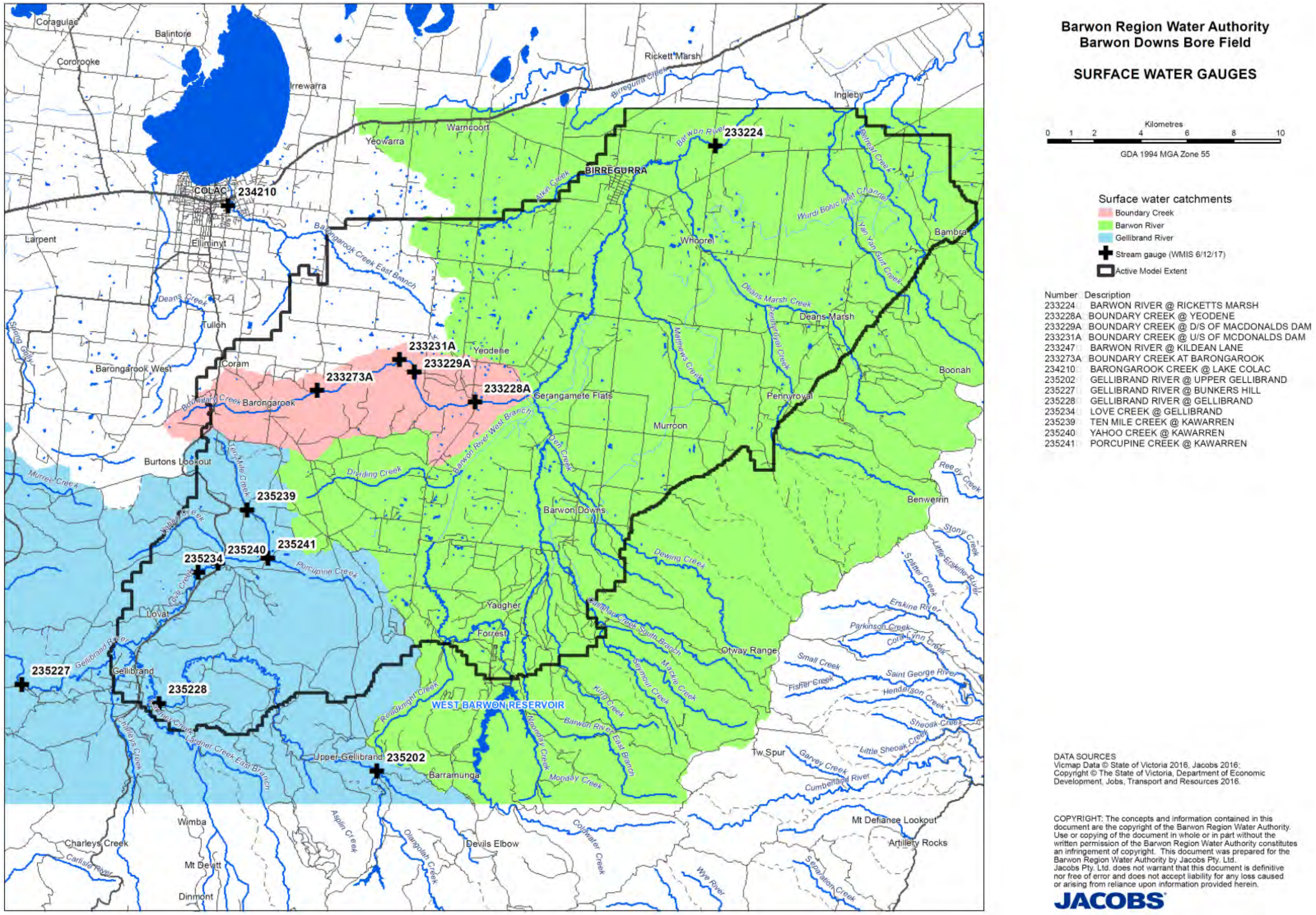


Figure 8-2 Location of relevant streamflow monitoring gauges in the model domain



8.2 Risk of groundwater pumping on rivers

The major river systems in the study area are the Barwon Catchment and the Gellibrand Catchment. The interaction between these rivers (and tributaries) and the groundwater system, particularly the Lower Tertiary Aquifer (LTA), varies significantly spatially and temporarily. Jacobs (2017a) describes the current understanding of where groundwater discharges to rivers and where rivers recharge the groundwater system and how these interactions have changed over time.

The exchange of water between the groundwater system and the rivers is a key feature of the groundwater model. The groundwater model predicts changes to groundwater levels in response to climate and pumping which in turn alters the baseflow contributions to river. In some cases, groundwater levels may decline significantly and lead to a gaining river becoming a losing river.

The groundwater model can be used to quantify the reduction in groundwater baseflow to rivers. The subsequent impacts that this reduction in groundwater baseflow has on the flow regime and the ecological values of the river need to be determined by site specific studies.

The Ministerial Guidelines for High Value GDEs provide a risk assessment framework to characterise the risk of groundwater baseflow reduction using the percentage of low flow as the key indicator. Where the risk is considered to be medium to high, further work may be required to understand the impact of the baseflow reduction on the flow regime and ecological values of the river or creek.

The predicted impacts of groundwater pumping on each river and creek is described in the following sections. Each section describes the predicted reduction in baseflow contribution to the rivers as a result of groundwater pumping, which is calculated using the numerical groundwater model. The predicted impact is then compared to low flow volume (low flow) using available streamflow monitoring data. The subsequent risk of groundwater pumping to the river or creek is assessed using the risk assessment framework outline in Section 7.1.

The change in groundwater contribution is determined using the groundwater contribution to rivers assuming there has been no pumping in the past to determine the baseline baseflow contributions without the influence/impact of pumping. The baseline baseflow contribution is then used to calculate the difference between future scenarios for the next 50 years of no pumping, constant pumping and intermittent pumping.

The result is compared to low flow volume (flow) at the end of each scenario sequence in accordance with the risk assessment framework outlined in the Ministerial Guidelines, to determine level of risk.

The baseflow contributions is described for three scenarios:

- No pumping – predicted maximum impact associated with no future pumping. This is basically the impact of historical pumping in 2017-2018 as groundwater levels will continue to recover with no future pumping.
- Constant pumping – the maximum predicted impact of pumping the borefield at a constant rate of 4 GL/year, which occurs at the end of the model timeframe
- Intermittent pumping – the maximum predicted impact of pumping the borefield intermittently at high rates.

The impact of pumping is then used to assess the risk to river flows. The **unmitigated risk** for all rivers is shown in Figure 8-3. Figure 8-4 shows the **mitigated risk** considers the physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in real world, but not represented well in the model. As outlined in Section 4.4 these include the presence of alluvial aquifers, the regional aquitard and in the case of rivers, the river bed sediments that can impede groundwater surface water interaction.

The individual risks are discussed in the following sections. Appendix A shows the predicted groundwater contribution to the rivers for both the calibration and predicted models to provide context of the predicted historical impacts with the predicted future impacts. This shows changes in groundwater contribution and whether the river is gaining or losing to groundwater.

Figure 8-3 Spatial representation of the unmitigated risk to creek or river based on drawdown

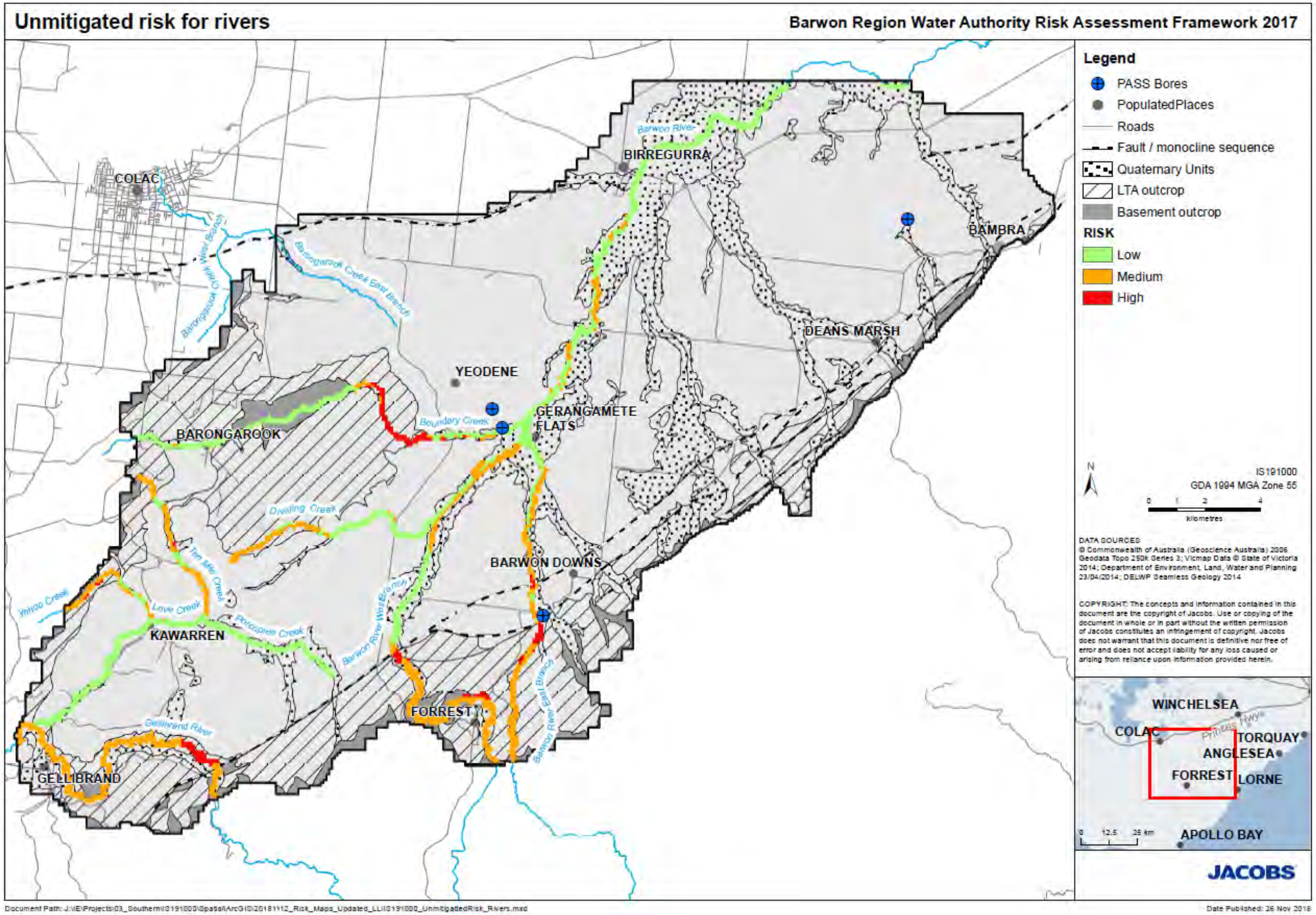
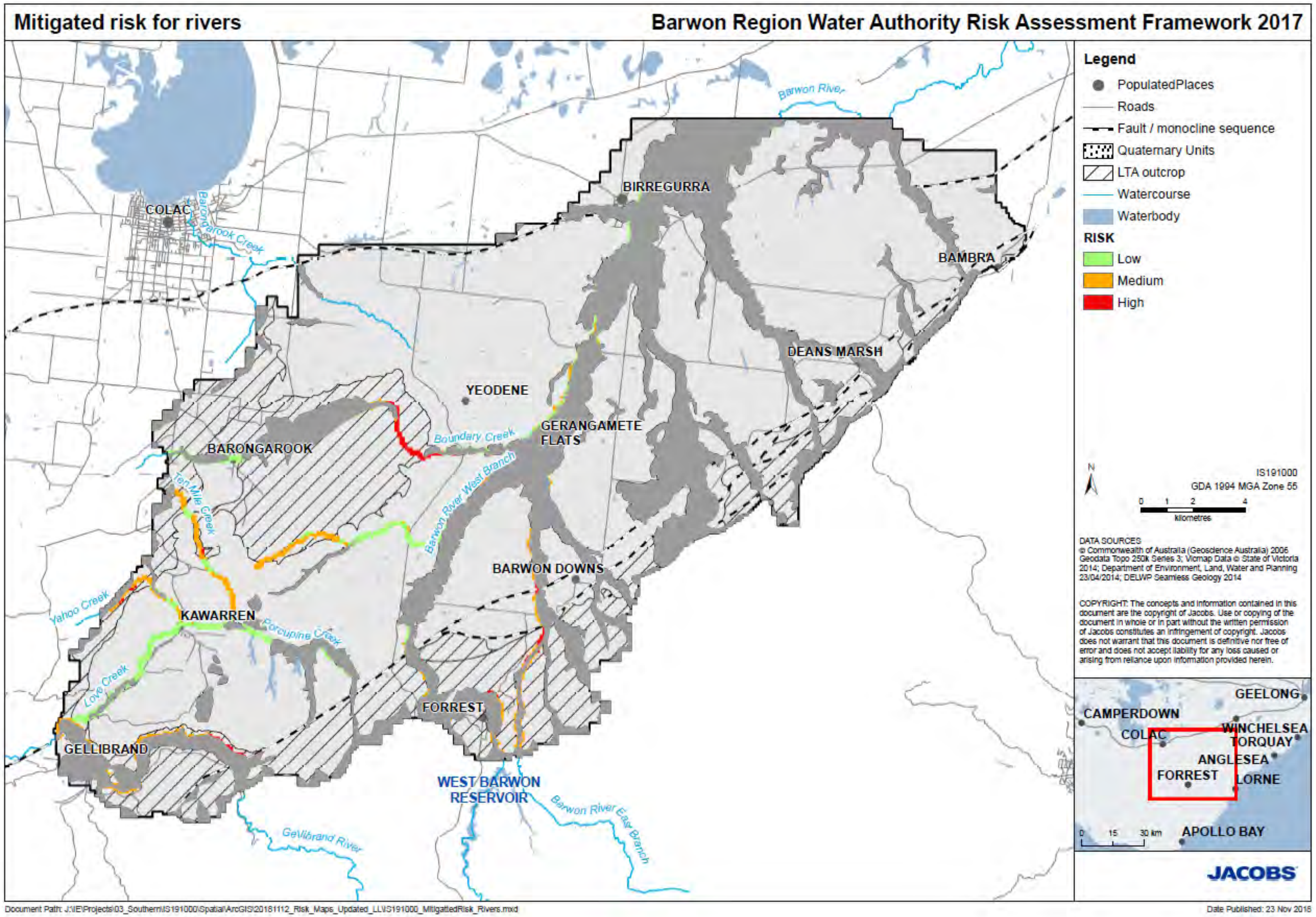


Figure 8-4 Spatial representation of the mitigated risk to creek or river based on drawdown



8.2.1 Boundary Creek

The predicted change in groundwater contributions to Reach 2 of Boundary Creek for both the calibration and predictive models assuming intermittent pumping and moderate climate change is shown in Figure 8-5.

Figure 8-5 shows that groundwater pumping has had a maximum historical impact of a 30 to 35 L/sec (2.5-3.0 ML/day) reduction in baseflow to Reach 2 of Boundary Creek. For more information on other downstream impacts, refer to the Yeodene Swamp Study report (Jacobs, 2018b).

Modelling indicates that predicted impact with constant pumping to Reach 2 of Boundary Creek will be similar to past impacts. The impact of intermittent pumping is predicted to be slightly less than this, with an impact of 25 to 30 L/sec (2.0-2.5 ML/day) predicted. These findings are consistent with observations and impacts of pumping from the borefield as documented in Jacobs (2018b).

Table 8-2 summarises the unmitigated and mitigated risk to the Boundary Creek reaches. Reach 1 is classified as low risk, Reach 2 is classified as high risk and Reach 3 has a moderate risk. Overall the risk to the creek is considered to be high due to the direct hydraulic connection with the LTA in Reach 2.

Figure 8-5 Predicted change in groundwater contribution to Boundary Creek for the calibration and predicted model assuming intermittent pumping and moderate climate change

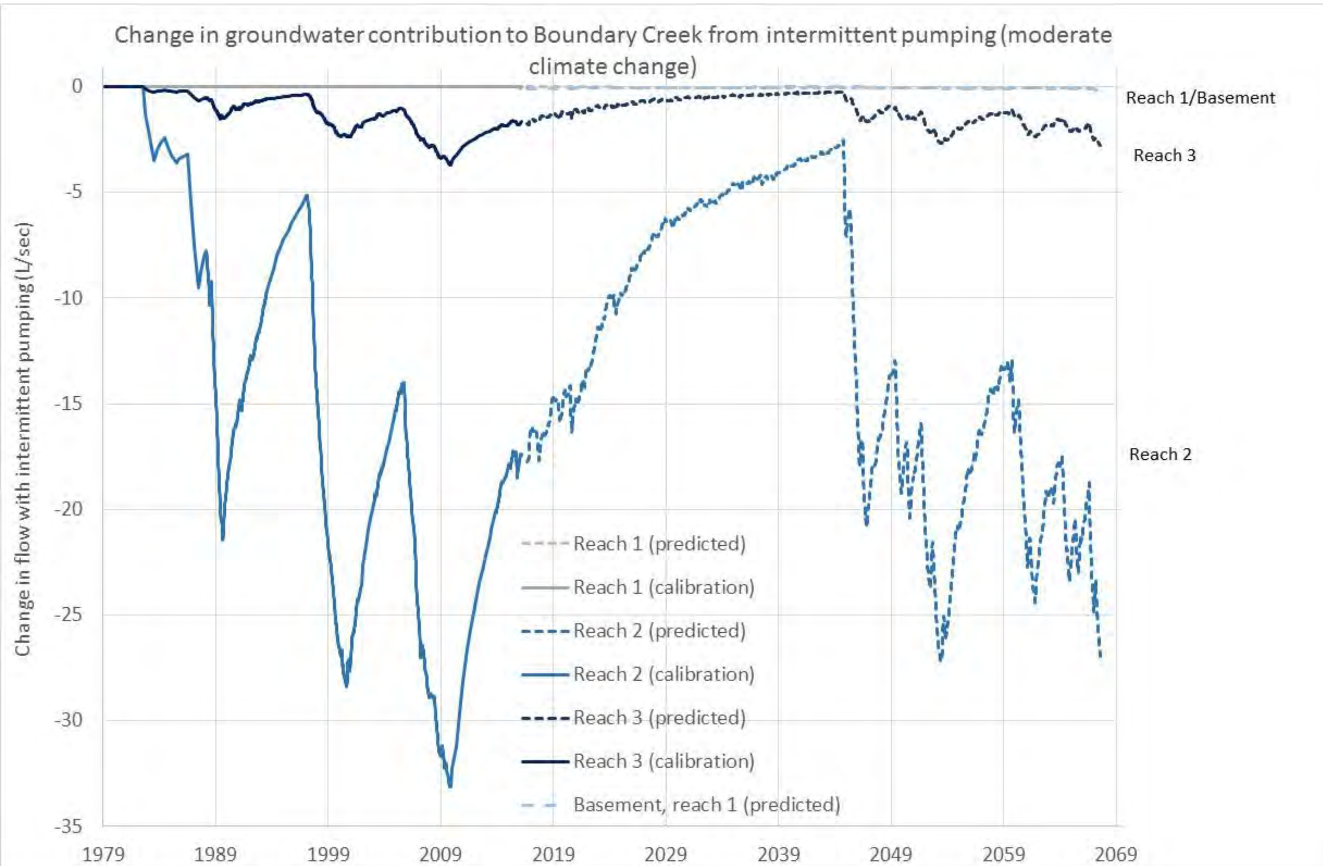


Table 8-2 Risk to Boundary Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Reach 1 Boundary Creek	• Reach 1 of Boundary Creek would continue to lose to groundwater over model timeframe. • The predicted maximum impact in Reach 1 is 0.01 ML/day.	• Reach 1 of Boundary Creek would continue to lose to groundwater over model timeframe. • The predicted maximum impact in Reach 1 is 0.02 ML/day.	• Reach 1 of Boundary Creek would continue to lose to groundwater over model timeframe. • The predicted maximum impact in Reach 1 is 0.02 ML/day	Low	**Low**
Reach 2 Boundary Creek	• Reach 2 of Boundary Creek would continue to lose to groundwater for 20 to 25 years. • The predicted maximum impact in Reach 2 is 1.5 ML/day.	• Reach 2 of Boundary Creek would continue to lose to groundwater over model timeframe. • The predicted maximum impact in Reach 2 is 2.7 ML/day.	• Reach 2 of Boundary Creek would continue to lose to groundwater over model timeframe. • The predicted maximum impact in Reach 2 is 2.3 ML/day.	High	**High**
Reach 3 Boundary Creek	• Reach 3 of Boundary Creek would become weakly gaining seasonally. • The predicted maximum impact in Reach 3 is 0.2 ML/day.	• Reach 3 of Boundary Creek would continue to lose to groundwater over model timeframe (50 years). • The predicted maximum impact in Reach 3 is 0.2 ML/day.	• Reach 3 of Boundary Creek would continue to lose to groundwater over model timeframe (50 years). • The predicted maximum impact in Reach 3 is a 0.5 ML/day.	Medium	**Medium**
Total impacts	• The total impact of historical pumping on flows is 1.7 ML/day which is 100% of low flows.	• The total impact on flow from constant pumping is 3.0 ML/day which is 100% of low flows.	• The total impact on flow from intermittent pumping is 2.6 ML/day which is 100% of low flows.		High

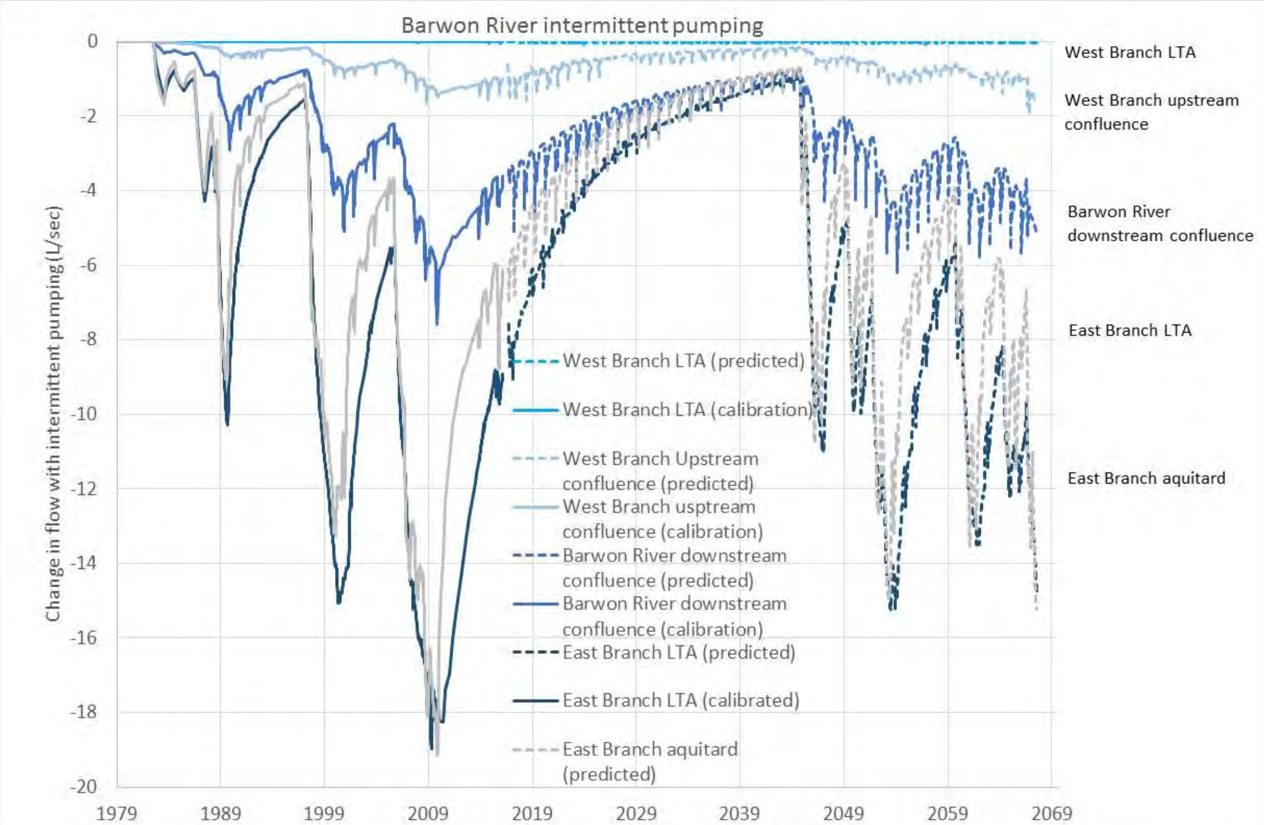
8.2.2 Barwon River

The predicted change in groundwater contributions to the Barwon River for both the calibration and predictive models is shown in Figure 8-6. This illustrates the impacts of historical and potential future pumping, assuming moderate climate change and a constant pumping regime.

Figure 8-6 shows that the potential impact of pumping on groundwater contributions to the Barwon River are greatest in the East Branch, with maximum predicted impacts of 10 to 15 L/sec (~1 ML/day), less than historical impacts of 15 to 20 L/sec (~1.5 ML/day). The modelled impacts on the West Branch are significantly less, with both historical and predicted impacts estimated to be <2 L/sec (<0.2 ML/day). The modelled impact on the Barwon River downstream of the confluence between the East and West branches is ~7.5 L/sec (0.7 ML/day), which is similar to historical impacts.

Assuming intermittent pumping, the predicted impacts are variable over time and in the different reaches. Impacts on the Barwon River West Branch are similar to those predicted for constant pumping. The effects on the Barwon River East Branch are predicted to be slightly greater (~15 L/sec or ~1.3 ML/day), while effects downstream of the confluence of the two branches will be slightly less (~6 L/sec or 0.5 ML/day) that the constant pumping scenario.

Figure 8-6 Change in groundwater contribution to Barwon River (calibrated and predicted for intermittent pumping and moderate climate change)



Alluvial aquifers are present along both the West and East Branches of the Barwon River, which have the capacity to store groundwater and further mitigate borefield effects. The presence of these alluvial aquifer have been considered to be mitigating factors with respect to the potential impacts of pumping on the Barwon River. Given this, the unmitigated and mitigated risk classification for the Barwon River by reach has been summarised in Table 8-3 and is as follows:

- The Barwon River East Branch is at a medium risk where it flows over the aquifer. The predicted reduction in flow is over 1 ML/day and more than 20% of the low flow. While this represents a high risk, this is mitigated by the presence of alluvial aquifer, resulting in a medium risk.
- The Barwon River East Branch is at a medium risk where it flows over the aquitard. The predicted reduction in flow is over 1 ML/day and more than 20% of the low flow. While this represents a high risk, the branch is unlikely to be in direct connection with the regional aquifer and impacts will be mitigated by the presence of the alluvial aquifer, resulting in a medium risk.
- The Barwon River West Branch is at a low risk where it flows over the aquifer. The predicted reduction in flow is 0.01 ML/day which is <1% of the low flow, resulting in a low risk.
- The Barwon River West Branch is at a low risk where it flows over the aquitard. While the predicted reduction in flow is 0.02 ML/day and 7% of the low flow (a moderate consequence), it is not in direct connection with the aquifer and impacts are mitigated by the presence the alluvial aquifer, resulting in a low risk.
- The Barwon River is at a high risk downstream of the East Branch/West Branch confluence as the estimated impact of pumping is greater than 10% of the low flow. However the reach is unlikely to be in connection with the regional aquifer and impacts are likely to be mitigated by the presence the alluvial aquifer, resulting in a medium risk.

Table 8-3 Risk to the Barwon River from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Barwon River East (overlying the LTA)	• Barwon River East (overlying the LTA) becomes seasonally gaining and losing. • The maximum impact is 0.8 ML/day, which is 100% of low flows in the upper reach and 16% of low flow downstream of the confluence.	• Barwon River East (overlying the LTA) remains a dominantly losing system with brief gaining periods. • The maximum impact is 1.2 ML/day, which is 100% of low flows in the upper reach and 25% of low flow downstream of the confluence.	• Barwon River East (overlying the LTA) becomes seasonally gaining and losing. • The maximum impact is 1.3 ML/day, which is 100% of low flows in the upper reach and 27% of low flow downstream of the confluence.	High	**Medium**
Barwon River East (overlying the MTD)	• Barwon River East (overlying the MTD) recovers and becomes seasonally gaining and losing. • The maximum impact is 0.6 ML/day, which is 100% of low flow in the upper reach and 12% of low flow downstream of the confluence.	• Barwon River East (overlying the MTD) remains a losing system with some change to groundwater fluxes from pumping. • The maximum impact is 1.1 ML/day, which is 100% of low flows in the upper reach and 22% of low flow downstream of the confluence.	• Barwon River East (overlying the LTA) remains a losing system with some change to groundwater fluxes from pumping. • The maximum impact is 1.3 ML/day, which is 100% of low flow in the upper reach and 27% of low flow downstream of the confluence.	High	**Medium**
Barwon River West (overlying the LTA)	• Barwon River West (overlying the LTA) remains a mostly losing river with minimal change to groundwater fluxes from pumping. The modelled maximum impact is <0.01 ML/day, which is <1% of low flow in the upper reach or downstream of the confluence.	• Barwon River West (overlying the LTA) remains a mostly losing river with minimal change to groundwater fluxes from pumping. • The modelled maximum impact is 0.01 ML/day, which is <1% of low flow in the upper reach or downstream of the confluence.	• Barwon River West (overlying the LTA) remains a mostly losing river with minimal change to groundwater fluxes from pumping. • The modelled maximum impact is 0.01 ML/day, which is <1% of low flow in the upper reach or downstream of the confluence.	Low	**Low**
Barwon River West (overlying the MTD)	• Barwon River West (overlying the MTD) remains a losing river with minimal change to groundwater fluxes from pumping. • The modelled maximum impact is 0.1 ML/day, which is 5% of low flow in the upper reach and 3% of low flows	• Barwon River West (overlying the MTD south) remains a losing river with minimal change to groundwater fluxes from pumping. • The modelled maximum impact is 0.2 ML/day, which is 6% of low flow in the upper reach and 3% of low flows	• Barwon River West (overlying the MTD) remains a losing river with minimal change to groundwater fluxes from pumping. • The modelled maximum impact is 0.2 ML/day, which is 7% of low flow in the upper reach and 5% of low flows downstream of the confluence.	Medium	**Low**

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
	downstream of the confluence.	downstream of the confluence.			
The Barwon River (downstream confluence)	• The Barwon River (downstream of confluence) remains a seasonally gaining and losing river. • The modelled maximum impact is 0.4 ML/day, which is 9% of low flow.	• The Barwon River (downstream of confluence) becomes a mostly losing river. • The modelled maximum impact is 0.6 ML/day, which is 13% of low flow.	• The Barwon River (downstream of confluence) remains a seasonally gaining and losing river for 35 years before becoming a mostly losing river. • The modelled maximum impact is 0.5 ML/day, which is 11% of low flow.	High	**Medium**

8.2.3 Dividing Creek

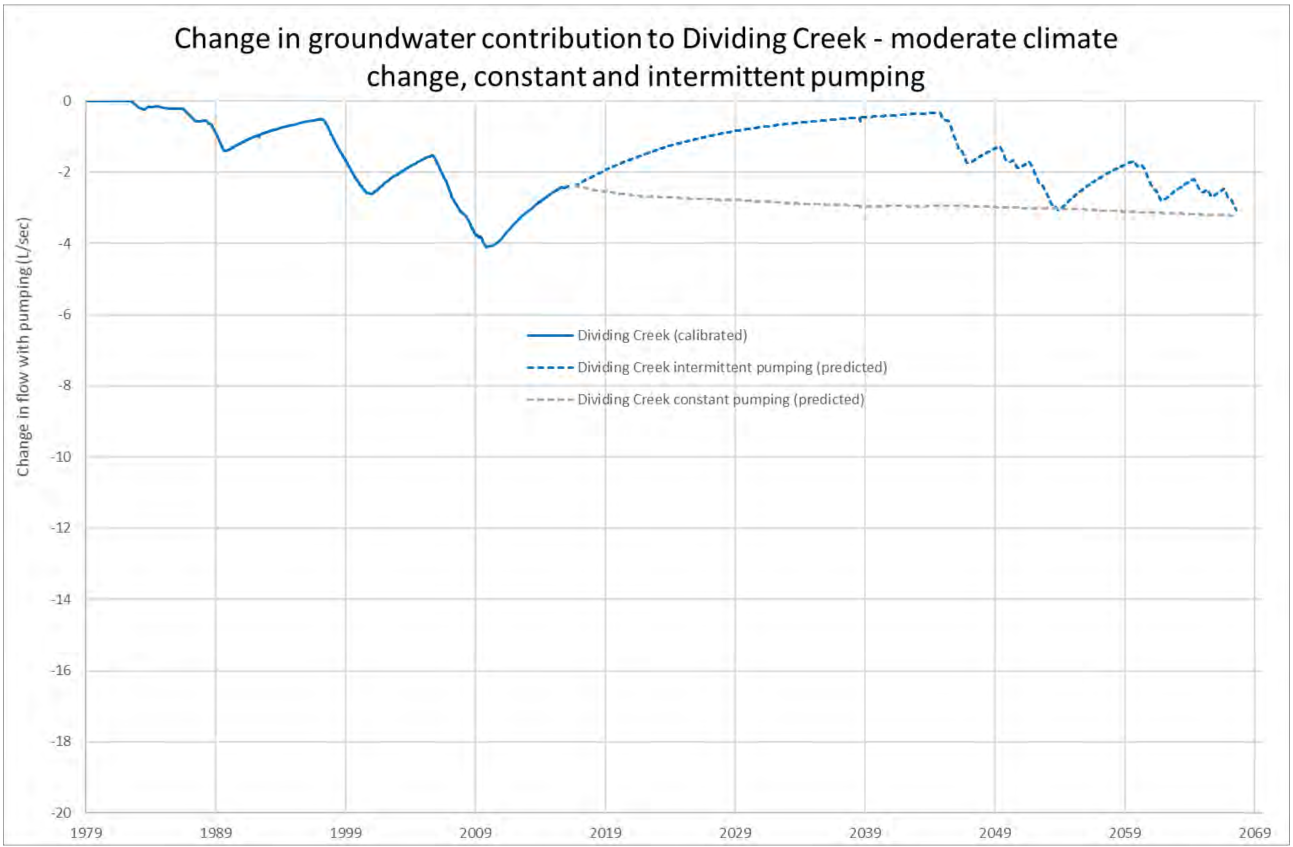
The predicted change in groundwater contribution to the Dividing Creek is shown in Figure 8-7 for both the calibration and predictive models. This shows that the predicted maximum impact of future pumping is ~3 L/sec (0.3 ML/day), which is slightly less than the maximum historical impact ~4 L/sec.

As there is no flow data for Dividing Creek, the risk assessment has been based on drawdown. More than 2 m of drawdown is predicted along the upper sections of the creek, with <0.1 m predicted along lower sections of the creek. The lower reaches of Dividing Creek flow through aquitard and are unlikely to be in connection with the regional aquifer. Likewise, where the aquifer outcrops on Dividing Creek, the groundwater levels are tens of meters below the ground surface and thus, the creek is unlikely to be in connection with the aquifer. Given this, the creek is at a medium risk from borefield operation.

Table 8-4 Risk to the Dividing Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Dividing Creek	• Dividing Creek remains a losing system with some impacts from historical pumping. • Maximum impact is 0.6 ML/day	• Dividing Creek remains a losing system with some impacts from pumping • The total impact on flow from constant pumping is 0.3 ML/day	• Dividing Creek remains a losing system with some impacts from pumping • The total impact on flow from intermittent pumping is 0.3 ML/day.	Medium	Medium

Figure 8-7 Change in groundwater contribution to Dividing Creek (calibrated and predicted for intermittent pumping and moderate climate change)



8.2.4 Gellibrand River

The predicted change in groundwater contribution to the Gellibrand River for both the calibration and predictive models is shown in Figure 8-8. This shows that the predicted maximum impact of future pumping ranges between 3 and 4 L/sec (0.2-0.4 ML/day), which is similar to the maximum historical impact ~4 L/sec (0.4 ML/day).

The predicted impact represents 3% of the low flow for the Gellibrand River, which is equates to a high risk given the connection to the regional aquifer. However, groundwater storage in the alluvial aquifer along much of the rivers flow path with mitigate the risk of drawdown. The Gellibrand River is therefore at a medium risk from potential future pumping. It should be noted there are small areas of high risk that may exist where there are no alluvial aquifers present (see Figure 8-4).

Figure 8-8 Change in groundwater contribution to Gellibrand River (calibrated and predicted for moderate climate change with constant and intermittent pumping)

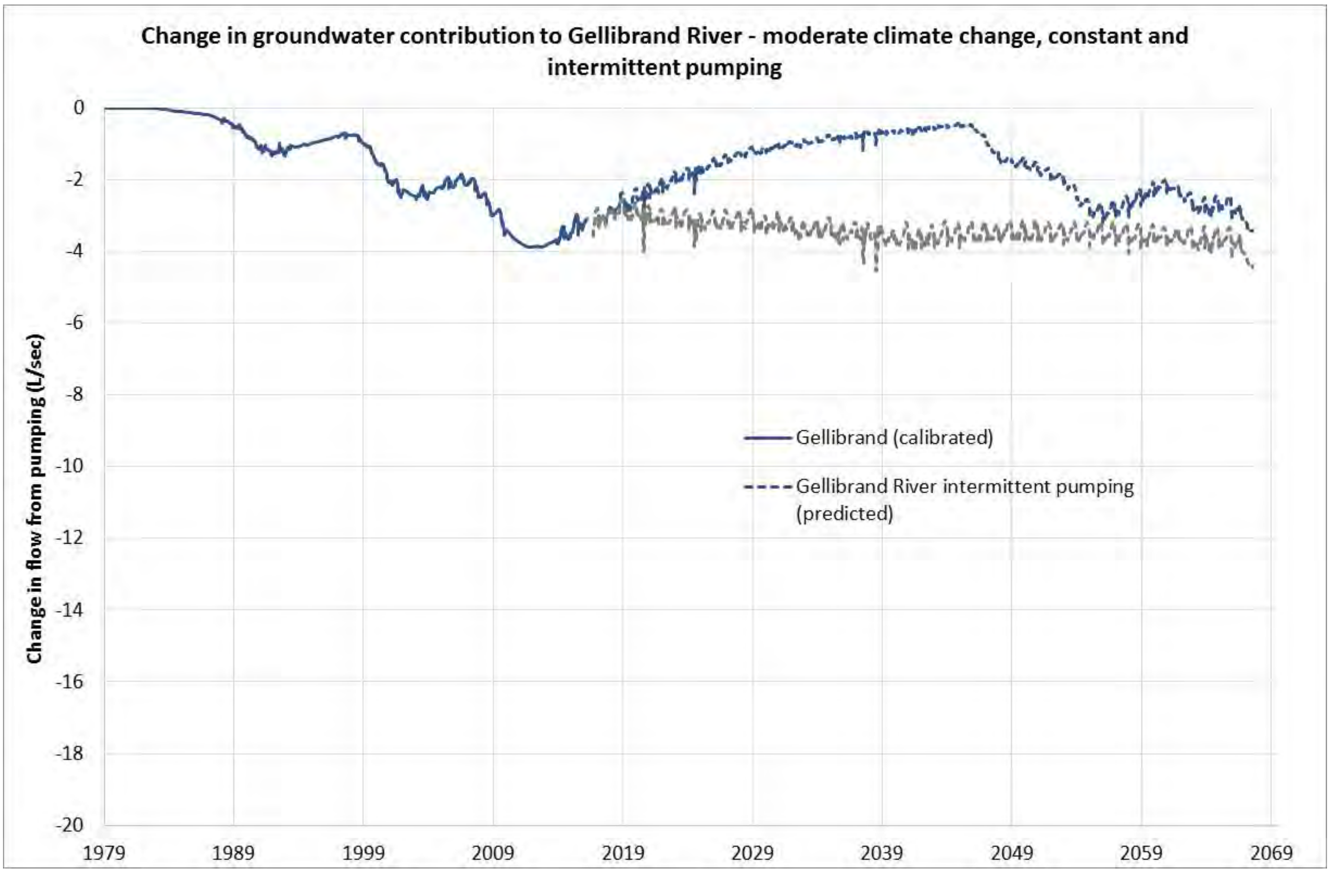


Table 8-5 Risk to the Gellibrand River from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Gellibrand River	• Gellibrand River remains a gaining river with minimal change to groundwater fluxes from historical pumping. • The total impact on flow from historical pumping is 0.3 ML/day which is 3% of low flow.	• Gellibrand River remains a gaining river with minimal change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.4 ML/day which is 3% of low flow.	• Gellibrand River remains a gaining river with minimal change to groundwater fluxes to the river. • The total impact on flow from intermittent pumping is 0.3 ML/day which 3% of low flow.	High	Medium

8.2.5 Porcupine Creek

The predicted change in groundwater contributions to Porcupine Creek for both the calibration and predictive models is shown in Figure 8-9. This shows that the predicted maximum impact of future pumping is <0.2 L/sec (0.02 ML/day), which is similar to maximum historical impacts.

The predicted maximum impact represents 5% of the low flow for Porcupine Creek. This represents a low risk as the creek is unlikely to be in connection with the regional aquifer. Further, impacts on Porcupine Creek are mitigated by the presence of alluvial aquifers along significant portions of the creeks flow path. Given this, the creek is considered to be at a low risk from potential future pumping.

Figure 8-9 Change in groundwater contribution to Porcupine Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

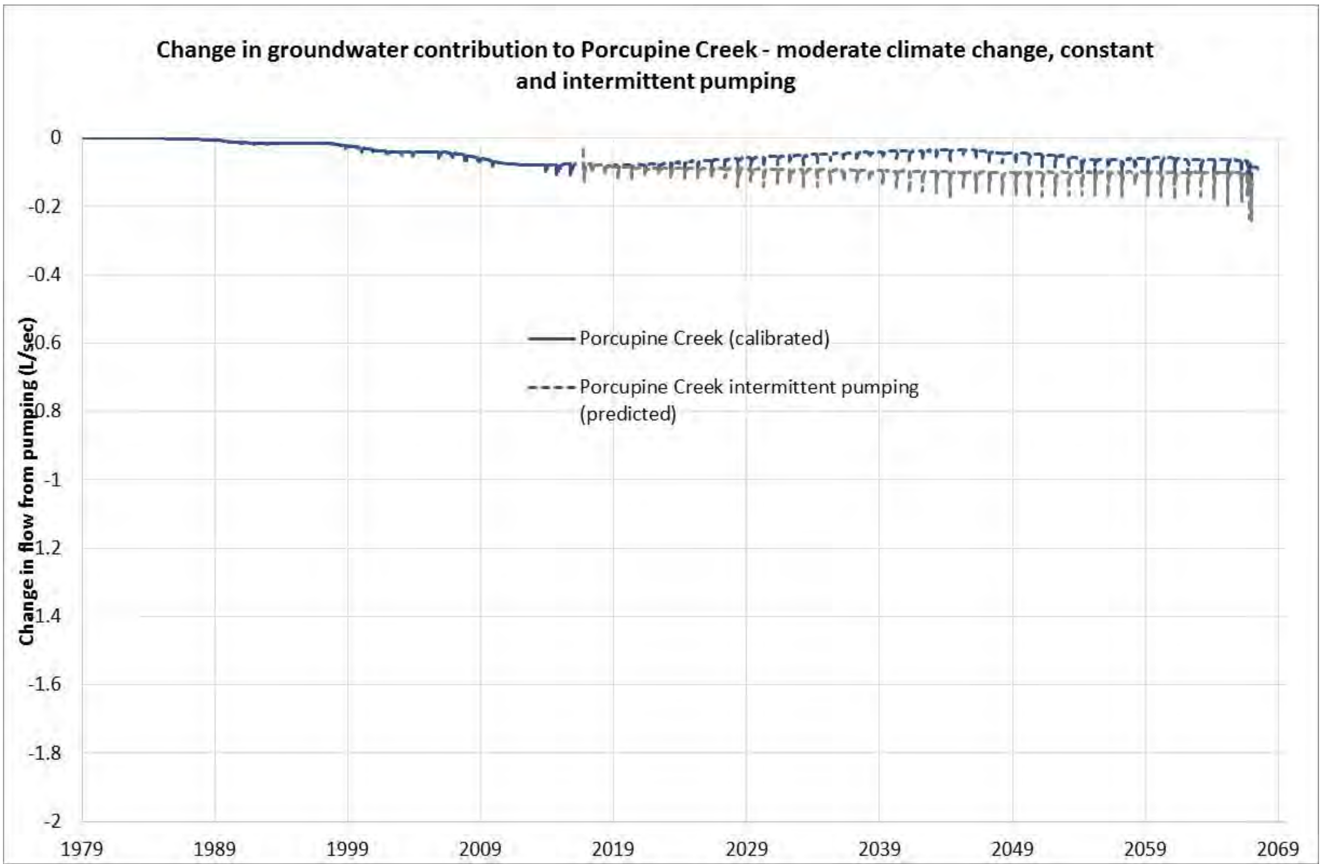


Table 8-6 Risk to Porcupine Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Porcupine Creek	• Porcupine Creek remains a weakly losing creek with minimal change to groundwater fluxes from historical pumping. • The total impact on flow from historical pumping is 0.01 ML/day which is 3% of low flow.	• Porcupine Creek remains a weakly losing creek with minimal change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.02 ML/day which is 5% of low flow.	• Porcupine Creek remains a weakly losing creek with minimal change to groundwater fluxes from pumping. • The total impact on flow from intermittent pumping is 0.02 ML/day which is 6% of low flow.	Low	Low

8.2.6 Ten Mile Creek

The predicted change in groundwater contributions to Ten Mile Creek for both the calibration and predictive models is shown in Figure 8-10 below. This shows that the predicted maximum impact of future pumping is ~2 L/sec (0.2 ML/day), which is similar to maximum historical impacts. However, as there is limited flow data for Ten Mile Creek after 1995, risk has been assessed based on predicted drawdown (see Table 7-2).

Drawdown is generally estimated to be <0.1 m in the upper reaches of Ten Mile Creek which are in good connection with the regional aquifer, resulting in a medium risk. In the lower reaches drawdown is estimated to be between 0.1 and 2 m, however in these reaches the creek is not in good connection with the regional aquifer, resulting in a low risk. Accordingly, future pumping presents a medium risk to the upper reaches of Ten Mile Creek and a low risk to the lower reaches.

Figure 8-10 Change in groundwater contribution to Ten Mile Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

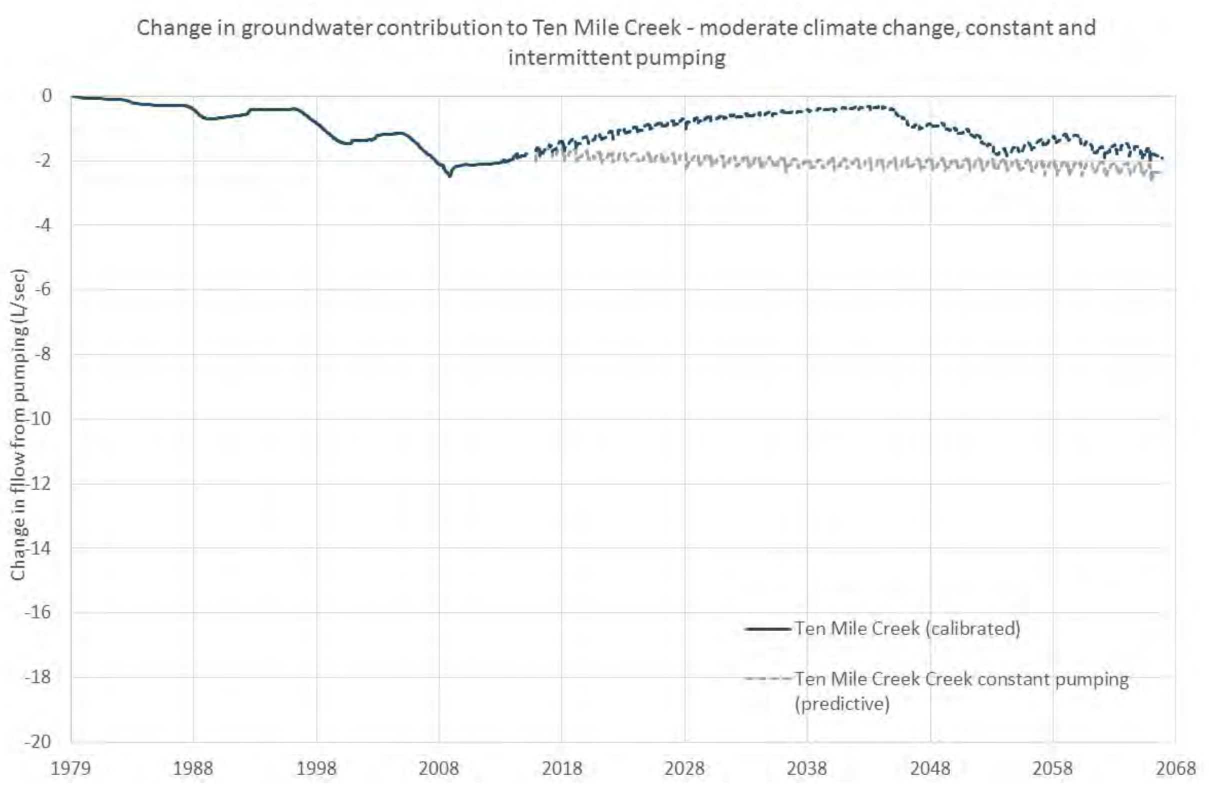


Table 8-7 Risk to Ten Mile Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Ten Mile Creek	• Ten Mile Creek would recover from weakly losing seasonally to gaining perennially after 15 years. • The total impact on Ten Mile Creek from historical pumping is 0.2 ML/day which is 12% of low flow based on the available flow data.	• Ten Mile Creek becomes a seasonally losing creek as a result of pumping. • The total impact on Ten Mile Creek from constant pumping is 0.2 ML/day which is 13% of low flow based on the available flow data.	• Ten Mile Creek becomes a seasonally losing creek as a result of pumping. • The total impact on Ten Mile Creek from intermittent pumping is 0.2 ML/day which is 13% of low flow based on available flow data.	Medium to low	Medium to low

8.2.7 Yahoo Creek

The predicted change in groundwater contributions to Yahoo Creek for both the calibration and predictive models is shown in Figure 8-11 below. This shows that the predicted maximum impact of future pumping is ~1.5 L/sec (0.13 ML/day), which is similar to the maximum historical impacts.

The predicted impact represents up to 13% of the low flow for Yahoo Creek. This represents a high risk to Yahoo Creek along its upper reaches where the creek is in good connection with the regional aquifer. However, this represents a relatively small proportion of the creeks flow path. The lower reaches of the creek are not in good connection with the regional aquifer, yielding a medium risk from pumping. Further, alluvium through the middle reaches of the creek may mitigate the effects of pumping. Giving this, Yahoo Creek is at a medium risk from potential future pumping.

Figure 8-11 Change in groundwater contribution to Yahoo Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

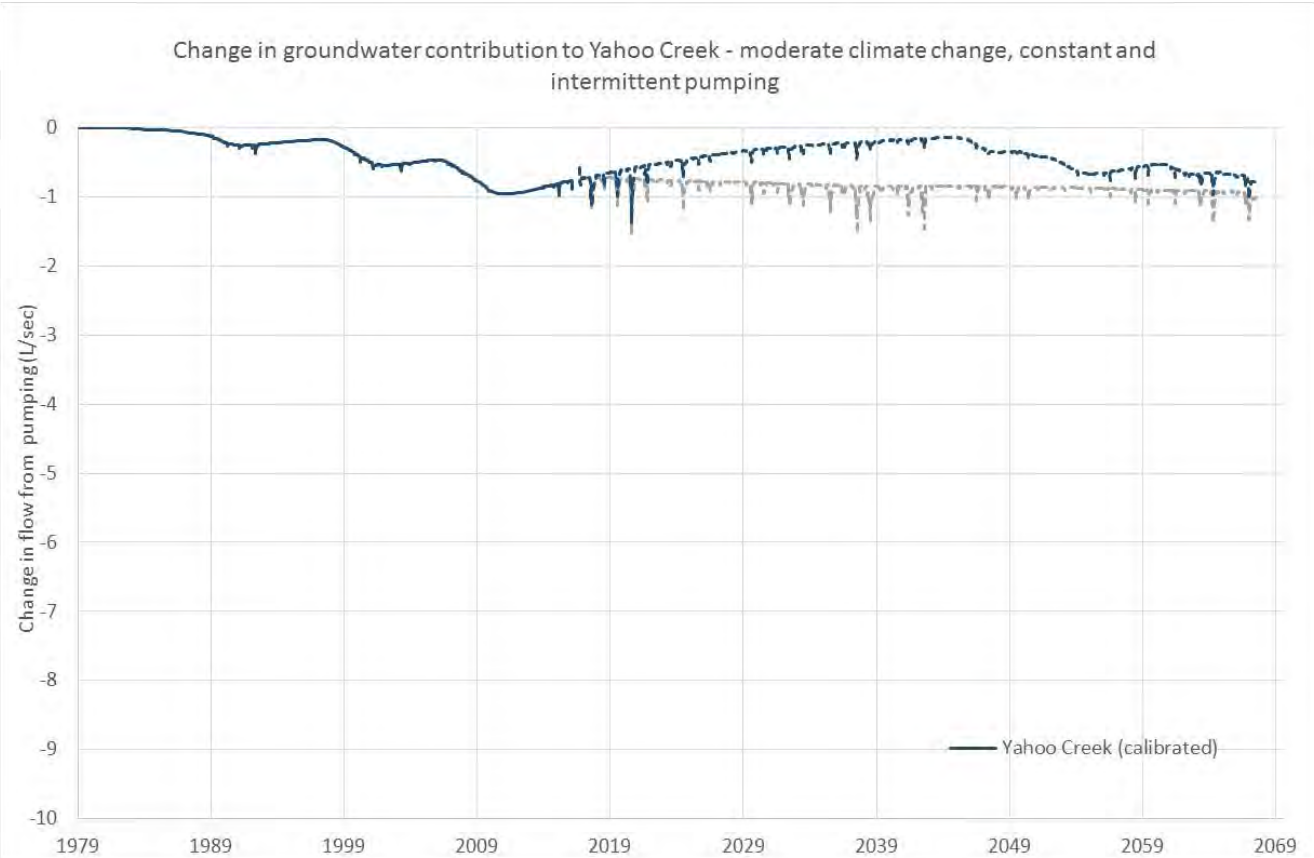


Table 8-8 Risk to Yahoo Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Yahoo Creek	• Yahoo Creek remains a losing creek with some change to groundwater fluxes from pumping. • The total impact on flow from historical pumping is 0.1 ML/day which is 11% of low flow.	• Yahoo Creek remains a losing creek with some change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.1 ML/day which is 13% of low flow.	• Yahoo Creek remains a losing creek with some change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.1 ML/day which is 11% of low flow.	Medium-High	Medium

8.2.8 Loves Creek

The predicted change in groundwater contributions to Loves Creek for both the calibration and predictive models is shown in Figure 8-12 below. This shows that the predicted maximum impact of future pumping is up to 0.3 L/sec (~0.03 ML/day), which is similar to maximum historical impacts.

The predicted impact represents up to 2% of the low flow for Loves Creek. This represents a moderate consequence however the majority of the creek is underlain by aquitard and unlikely to be in connection with the regional aquifer. This yields a low risk. Further, where the creek does flow over the regional aquifer, alluvial aquifers are present that mitigate against the risk of pumping.

Given the above factors, Loves creek is considered to be at a low risk from pumping.

Figure 8-12 Change in groundwater contribution to Loves Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

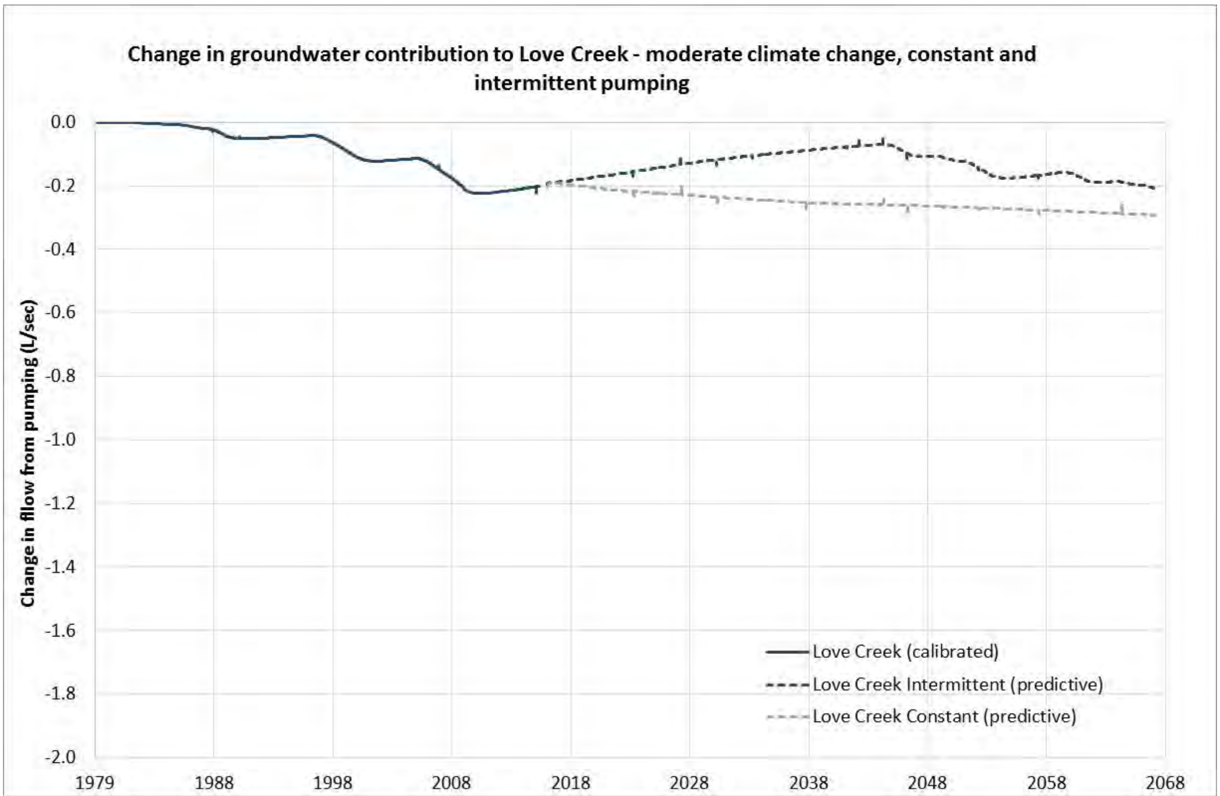


Table 8-9 Risk to Loves Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Loves Creek	• Loves Creek remains a mostly losing creek with minimal change to groundwater fluxes from historic pumping. • The total impact on flow from historical pumping is 0.02 ML/day which is 1% of low flow.	• Loves Creek remains a mostly losing creek with minimal change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.03 ML/day which is 2% of low flow.	• Loves Creek remains a mostly losing creek with minimal change to groundwater fluxes from pumping. • The total impact on flow from intermittent pumping is 0.02 ML/day which is 1% of low flow.	Medium	Low

8.2.9 Barongarook Creek

Barongarook Creek was not included in the calibration model or the pumping scenarios described in Chapter 5. Additional scenarios (no pumping and pumping) model runs were completed with the creek in the model to quantify the impacts. The additional model runs are described in detail in Jacobs (2018c).

The predicted change in groundwater contributions to Barongarook Creek for the predictive model scenarios is shown in Figure 8-13 below. This shows that the predicted maximum impact of future pumping is up to 1.0 L/sec (~0.1 ML/day). The predicted impact represents up to 4% of the low flow for Barongarook Creek and given the creek is unlikely to be in connection with the regional aquifer, this indicates a medium risk from pumping. Further, the lower reaches of the creek flow through an alluvial aquifer which will mitigate this risk. The upper reaches of Barongarook Creek are considered to be at a medium risk from pumping, with the lower reaches at a low risk from pumping.

Figure 8-13 Change in groundwater contribution to Barongarook Creek (predicted for moderate climate change with constant and intermittent pumping)

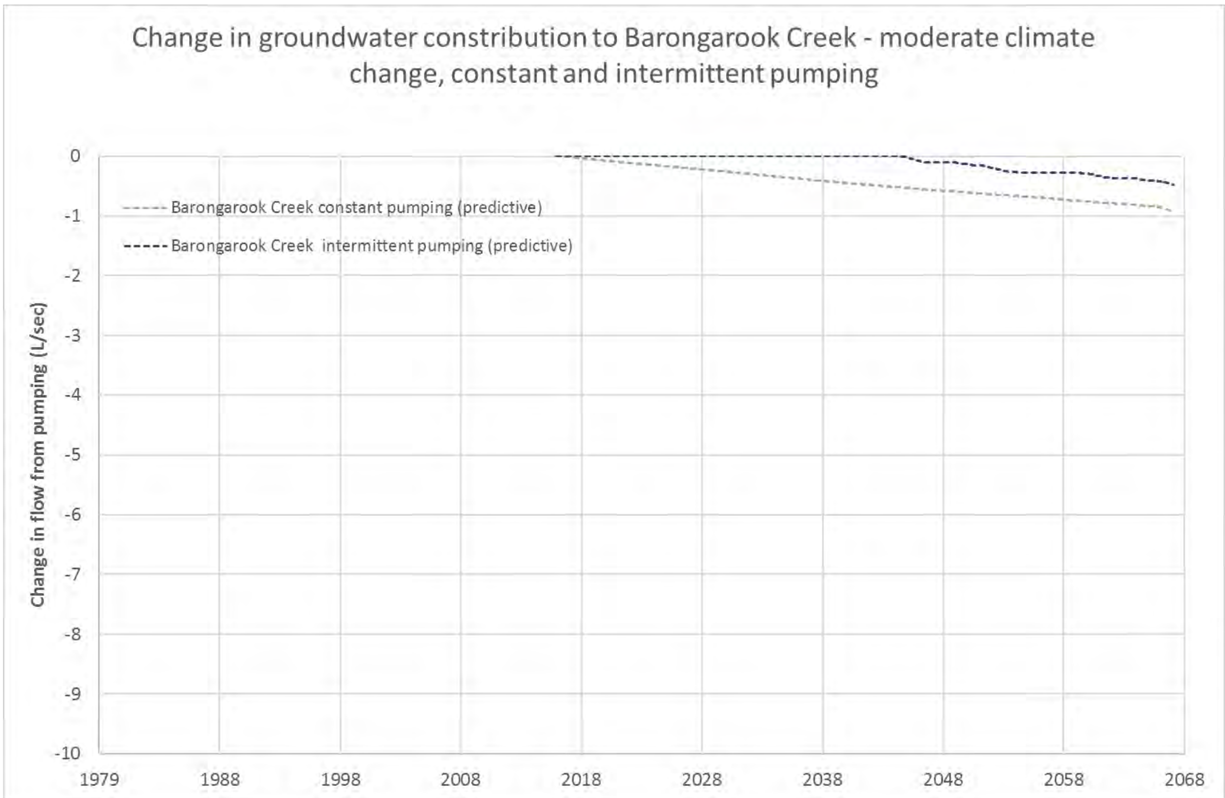


Table 8-10 Risk to Barongarook Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

River	Impacts of no pumping	Impacts of constant pumping	Impacts of intermittent pumping	Unmitigated risk	Mitigated risk
Barongarook Creek	• The Barongarook Creek remains a gaining creek with groundwater fluxes declining from 0.6 to 0.9 ML/day in response to climate.	• The Barongarook Creek remains a gaining creek with minimal change to groundwater fluxes from pumping. • The total impact on flow from constant pumping is 0.08 ML/day which is 4% of low flow.	• The Barongarook Creek remains a gaining creek with minimal change to groundwater fluxes from pumping. The total impact on flow from constant pumping is 0.04 ML/day which is 2% of low flow.	Medium	Medium to Low

8.3 Summary of risk to rivers

A summary of the risk to each river reach is outlined in Table 8-11.

River reaches that are classified as having a low risk are Reach 1 of Boundary Creek, Barwon River West Branch, Porcupine Creek and Loves Creek. Rivers classified as medium risk include Reach 3 Boundary Creek, BArwon River East Branch and downsteam of the confluence, Dividing Creek, Gellibrand River, Ten Mile Creek, Yahoo Creek and Barongarook Creek.

There is only one river reach classified as a high risk and that is Reach 2 of Boundary Creek. This is consistent with previous studies and an offset measure was established to mitigate any adverse impacts. It has been acknowledged that this offset has not been implemented effectively and the impacts of this are discussed in Jacobs (2018b). Barwon Water are currently working to ensure the supplementary flow is delivered to Reach 2.

Table 8-11 Key findings of predicted impacts to rivers as a result of groundwater pumping

Environmental receptors	Risk assessment outcomes	Residual risk ranking
Boundary Creek flows reach 1	Reach 1 is a low risk classification as this reach is not directly connected to the regional aquifer.	Low
Boundary Creek flows reach 2	Reach 2 of Boundary Creek, where the creek flows over the regional aquifer between McDonalds Dam and Yeodene Swamp, is considered to be at high risk of potential impact. The predicted reduction in groundwater contribution to the river is around 2 ML/day which is more than 100% of low flows. The risk associated with potential future pumping is predicted to be marginally less than historical pumping. Regardless of future pumping, reach 2 of Boundary Creek is predicted to take 20-30 years to recover from historic pumping in terms of baseflow contribution if remediation works is not undertaken.	High
Boundary Creek flows reach 3	Reach 2 is a medium risk classification as this reach is not directly connected to the regional aquifer.	Medium
Barwon River (east branch)	Barwon River East branch is thought to be gaining in some sections where it flows over the Lower Tertiary Aquifer to the south east of the borefield. The model over predicts drawdown due to the presence of the fault, the aquitard and local alluvial aquifers. This means that model predictions are conservative and most likely an overestimate. Predictive scenario modelling indicates that the greatest risk of impact to the Barwon East Branch will occur to the south of the intersection between the river and the Birregurra-Forrest Road. Given the potential physical mitigating factors, the Barwon River is classified as potential medium risk where the East Branch flows over the aquifer and aquitard. The model has highlighted there could be a potentially significant impact to surface flows in the East Branch during low flow periods.	Medium
Barwon River (west branch)	The mitigated risk to the West Baron River is considered to be low risk where it flows over the aquifer and aquitard due to the presence of alluvial aquifers.	Low
Barwon River (confluence)	Downstream of the confluence the mitigated risk is considered to be low as alluvial aquifers are present.	Low
Dividing Creek	Dividing Creek is a losing creek that is disconnected from the regional aquifer.	Medium

Environmental receptors	Risk assessment outcomes	Residual risk ranking
	The risk classification for Dividing Creek is medium because although there is a low likelihood that the stream is connected to the regional aquifer, more than 2 m of drawdown is predicted.	
Gellibrand River	The Gellibrand River is a key discharge feature for the regional aquifer. Alluvial sediments are present in the floodplain and this local aquifer will be buffered from drawdowns predicted in the regional aquifer. The risk to the Gellibrand River is considered to be medium given the presence of an alluvial aquifer. However, are some small areas of high risk where the alluvial aquifer may not be present and the Lower Tertiary Aquifer outcrops at the surface.	Medium
Porcupine Creek	Porcupine Creek flows over the aquitard and into Loves Creek which is a tributary of the Gellibrand River. The risk to the creek is considered to be low given the potential physical mitigating factors such as the presence of alluvial aquifers that buffer the impact from pumping.	Low
Ten Mile Creek	Ten Mile Creek is a tributary of Loves Creek and flows over a small outcrop of the Lower Tertiary Aquifer. The creek is considered to be a gaining creek where it flows over the aquifer. Modelling predicts that there is a low to medium risk to the creek, given the physical mitigating factors such as the presence of alluvial aquifers.	Medium
Yahoo Creek	Yahoo Creek is also a tributary of Loves Creek and similar to Ten Mile Creek, the creek flows the regional aquifer in the upper reaches. Given the physical mitigating factors such as the presence of alluvial aquifers, the modelling predicts that there is a low risk to majority of the creek and small areas of medium risk.	Medium
Loves Creek	Loves creek predominantly flows over the aquitard, however the aquifer outcrops near the confluence with the Gellibrand River, where drawdown is predicted to be minor (less than 0.1 m). Given the presence of mitigating factors such as the presence of alluvial aquifers, the risk is considered to be low as a result of low connectivity with the regional aquifer.	Low
Barongarook Creek	Barongarook Creek is located north of Boundary Creek and flows north west to Lake Colac. The creek flows over the aquitard and modelling predicts that there is a medium risk in the upper reaches of Barongarook Creek and a low risk for the lower reaches.	Medium to Low

9. Potential risk to terrestrial groundwater dependent ecosystems

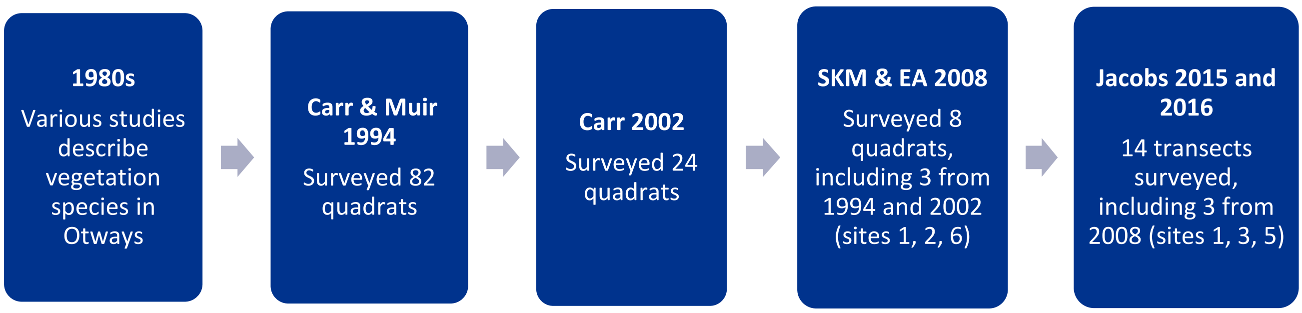
Vegetation that relies on groundwater seasonally or episodically are referred to as terrestrial groundwater dependent ecosystems (GDE). Terrestrial GDEs are often found in riparian zones of ephemeral and perennial streams, near water bodies such as lakes and swamps or in areas of shallow watertable. Vegetation across the Barwon Downs study area has been monitored over several years to determine the potential impact of extraction from the Barwon Downs borefield on vegetation.

9.1 Overview of vegetation monitoring program

Vegetation across the Otway region was first described in the 1980s and vegetation monitoring has occurred regularly since 1994 (e.g. 1994, 2002, 2008/09 and 2014/15, see references in Figure 9-1). The current vegetation monitoring network comprises 14 sites (T1 to T14) which are located in topographic depressions associated with drainage lines and creek. The sites were last surveyed in 2016 (Jacobs, 2017b).

An overview of vegetation monitoring in the study area is provided in Figure 9-1. The number of quadrats surveyed reduced from 82 to 8 sites between 1994 and 2008. Of the 8 sites, 3 sites were monitored in 1994, 2002 and 2008. In 2014, the vegetation monitoring network was expanded to 14 sites representing areas where the aquifer was confined and unconfined and inside and outside the zone of influence of the Barwon Downs borefield. One site (site 1) has been monitored since 1994 and is currently now referred to as T2.

Figure 9-1 Overview of vegetation surveys in the Otways region



9.2 Risk of groundwater pumping on vegetation

The groundwater model was used predict drawdown in the upper most active layer in the model, which is either the regional aquifer where it is unconfined, or the regional aquitard where the aquifer is confined. The predicted drawdown from the groundwater model was used together with the depth to watertable to determine the level of risk using the risk assessment framework outline in Section 7.2.

Drawdown takes time to propagate to the surface. The time required for this to occur is longer where the aquitard overlies the aquifer and less where the regional aquifer outcrops at the surface. The maximum drawdown in the watertable is therefore experienced at different times around the study area.

The maximum drawdown in the watertable varies significantly for the intermittent pumping scenario depending on when the borefield is turned on. In addition to this, some areas may continue to experience drawdown after the borefield has been turned off. Because of the issues associated with drawdowns being realised at different times at different locations, it is not possible to estimate the maximum drawdown across the whole study area for a single timeframe for the intermittent pumping scenario. Therefore, the maximum risk to vegetation across the study area was assessed using the drawdown at the end of the constant rate pumping scenario.

The difference between the maximum impact between constant and intermittent pumping scenarios was assessed for each of the vegetation monitoring sites (see Appendix C). This illustrates that with the exception of sites T1 and T2, the constant rate pumping scenario had the same or a slightly higher drawdown than the intermittent scenario. Even so, the resulting consequence and risk ratings at T1 and T2 were not affected by the difference in the two scenarios. The constant rate scenario therefore provides a valid representation of the maximum risks to vegetation in the study are. Consequently, the risk to the vegetation across the catchment has been assessed using the drawdown for the constant rate scenario.

The following sections outline the risk assessment results for vegetation across the study area and at the individual monitoring locations.

9.2.1 Vegetation across the study area

The **unmitigated risk** for vegetation across the study area is shown in Figure 9-2. The majority of the watertable aquifer (62%) across study is at a low risk from groundwater pumping. High risk areas are shown on the edges of the graben where regional aquifer is closer to the surface and the aquitard is thin, which makes up 23% of the study area.

Figure 9-3 shows the **mitigated risk** which considers the physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in real world, but not represented well in the model. As outlined in Section 7.2, these include the presence of alluvial aquifers and the regional aquitard. The high risk areas at the edges of the graben are reduced by the presence alluvial aquifers.

The aquitard outcrops across much of the high risk area and observation data indicates that the aquitard further mitigates drawdown. Figure 9-4 shows the mitigated risk to vegetation, excluding areas where the aquitard is present. Accordingly, approximately 2% of the study is at a high risk. The highest risk is along Reach 2 of Boundary Creek where the regional aquifer outcrops (site T2). Other high risk areas are present where the aquifer outcrops around the Bambra Fault, particularly around the Barwon River East Branch. Small areas along Gellibrand River are also potentially high risk.

In summary over the majority of the study area vegetation is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. Small areas of high risk are located along Reach 2 of Boundary Creek, Barwon River East Branch and the Gellibrand River.

9.2.2 Vegetation monitoring sites

The location of the 14 vegetation monitoring sites is shown in Figure 9-4. Vegetation monitoring of the 14 sites has demonstrated that most of these sites have local alluvial aquifers that are buffered from impacts from drawdown induced by groundwater pumping (Jacobs 2017a, Jacobs 2017b). The exception to this is T2, which is located in Reach 2 of Boundary Creek where groundwater levels have declined in response to pumping.

The drawdown predicted in the watertable by constant pumping and intermittent pumping at vegetation monitoring sites is similar and is generally less than drawdown from historical pumping (see Appendix c). That is, according to ministerial guidelines, there is no difference in the risk to vegetation from the different pumping scenarios.

There is no evidence from observed data that drawdown in the regional aquifer as a result of historic pumping has propagated to the shallow alluvial aquifer at any other monitoring sites (i.e. than T2). The risk of drawdown affecting groundwater dependant vegetation is mitigated in many areas by the presence of the aquitard, shallow alluvial aquifers and the Bambara Fault. This yields a mitigated risk of low for all sites except T1 (which is medium) and T2 (which is high).

A brief description of the predicted drawdown at each on the vegetation monitoring sites is provided in Appendix C.

Figure 9-2 Unmitigated risk to vegetation across the model domain based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)

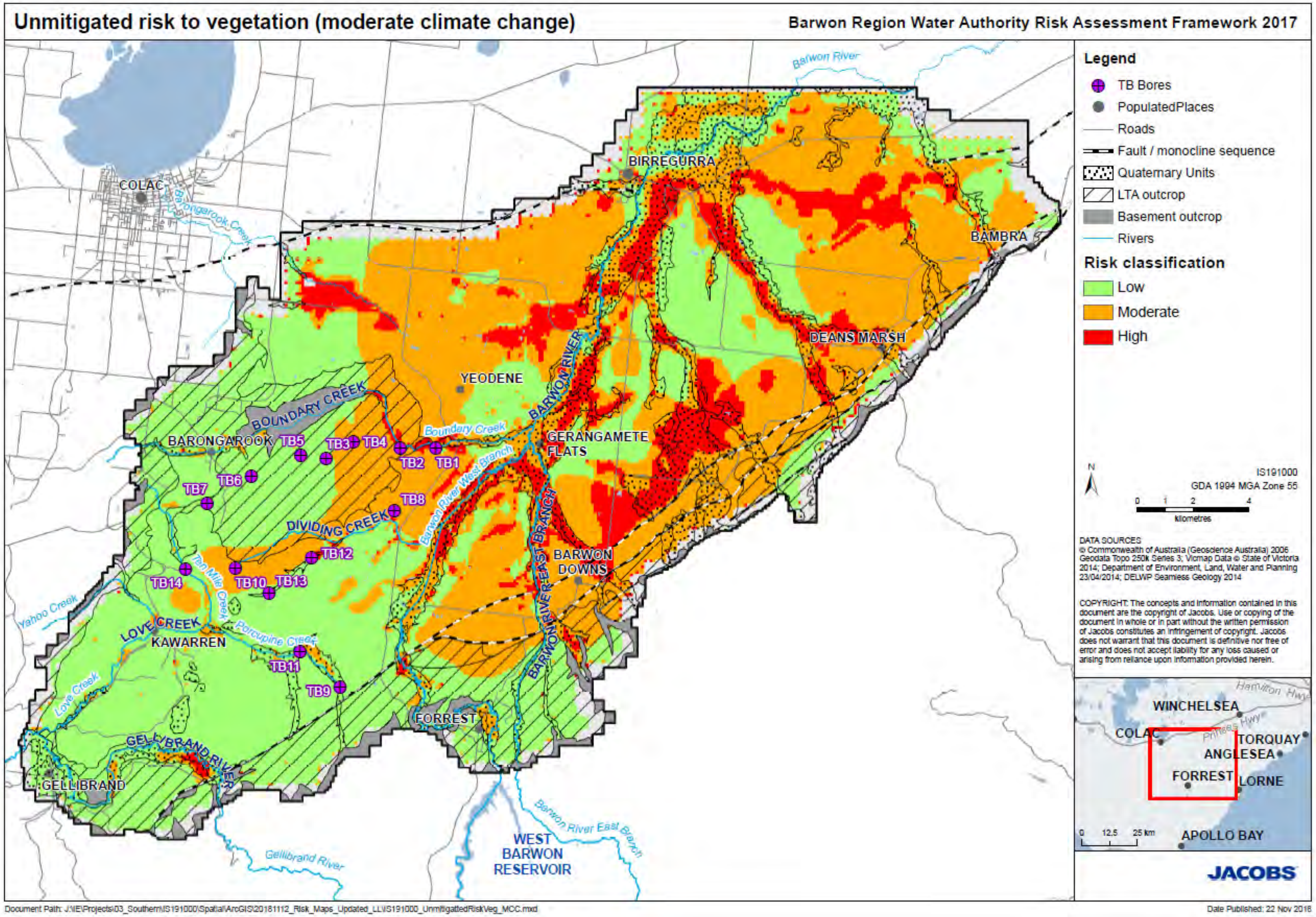
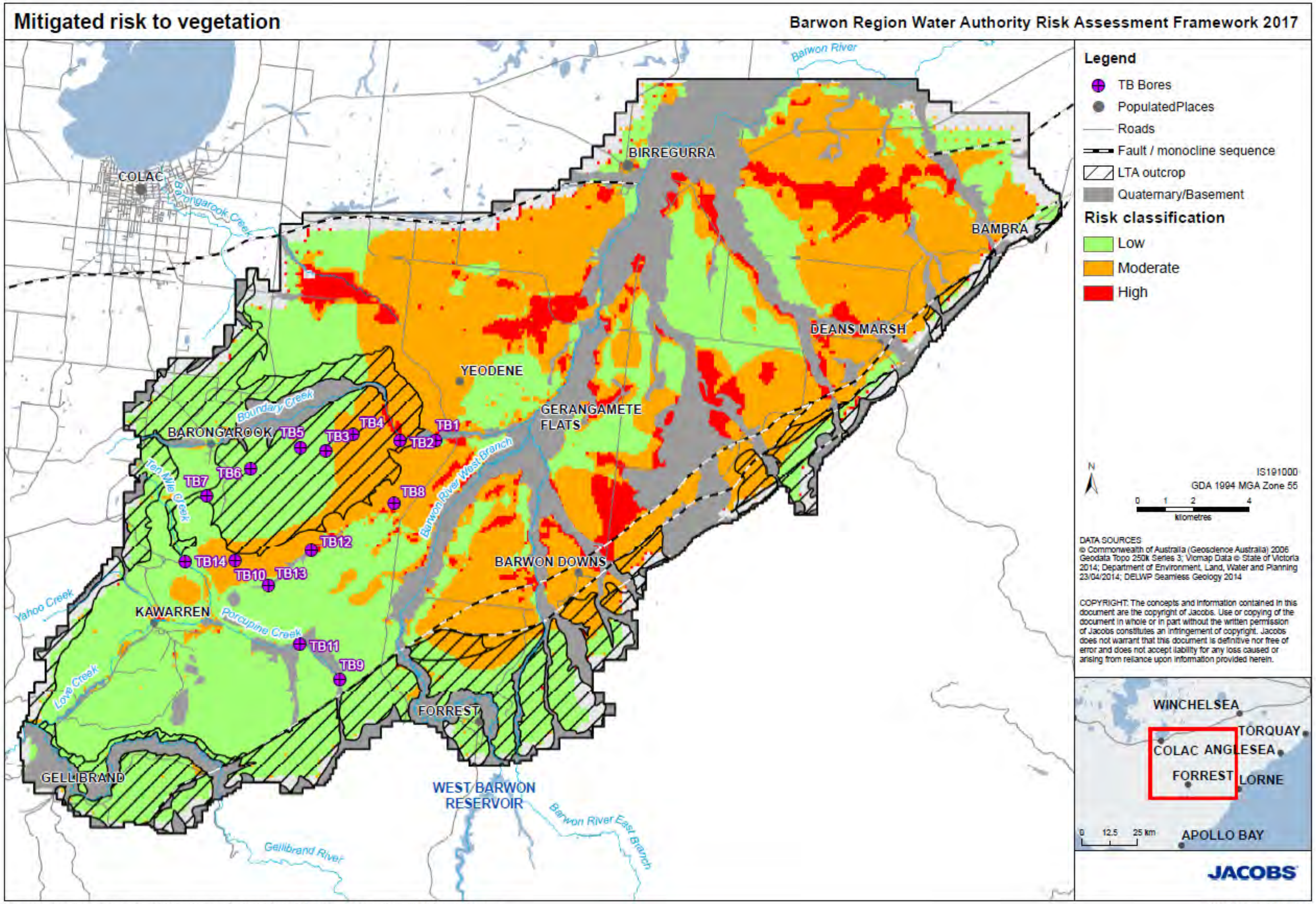


Figure 9-3 Mitigated risk to vegetation across the model domain considering physical mitigating factors (moderate climate change)



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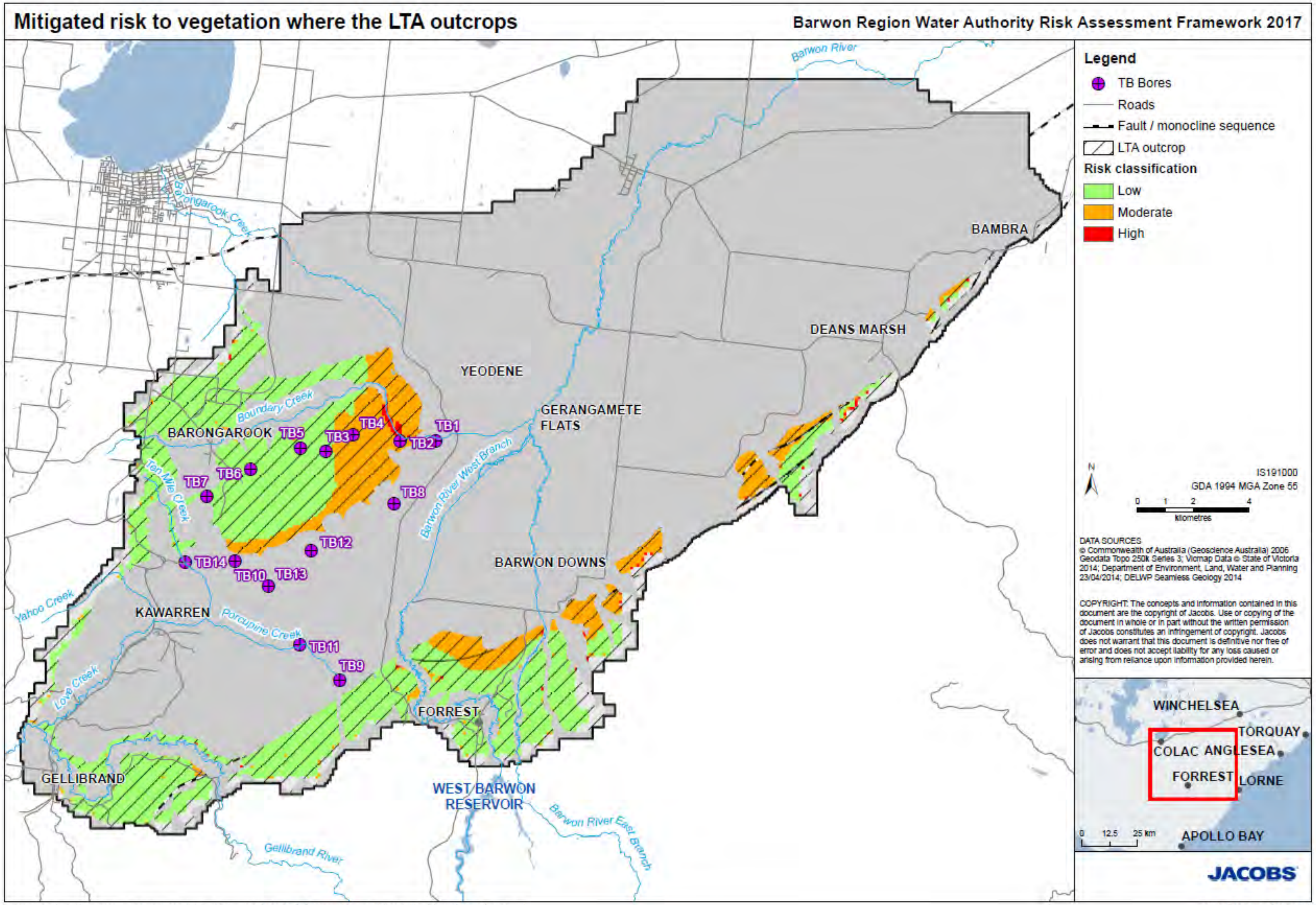
Date Published: 23 Nov 2018

Figure 9-4 Mitigated risk to vegetation where the LTA outcrops considering physical mitigating factors (moderate climate change)



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Date Published: 23 Nov 2018

9.3 Summary of risk to groundwater dependent vegetation

A summary of the risk to groundwater dependent vegetation is outlined in Table 9-1.

Table 9-1 Key findings relating to predicted impacts to vegetation

Environmental receptors	Risk assessment outcomes	Residual risk ranking
Vegetation across the catchment	• Vegetation monitoring of 14 sites has demonstrated that most of these sites have local alluvial aquifers that are buffered from impacts from drawdown induced by groundwater pumping. • The exception to this is site T2, which is located in Reach 2 of Boundary Creek where groundwater levels have declined in response to pumping, which is discussed in Table 3. • There is no evidence from observed data that predicted drawdown in the regional aquifer as a result of historic pumping has propagated to the shallow alluvial aquifer at any other monitoring sites. • Over the majority of the study area, vegetation is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. • Areas of high risk exist where the regional aquifer outcrops and there are no alluvial aquifers. For example, on the Barongarook High, along Reach 2 of Boundary Creek and small areas along the Gellibrand River. • In summary groundwater dependent vegetation across 98% of the study area is classified as low residual risk and 2% is classified as high residual risk. Vegetation dependent on groundwater in the regional aquifer in the areas of high risk has the potential to be impacted by drawdown from the borefield.	High risk in small areas where the regional aquifer outcrops and there are no local alluvial aquifers.

10. Potential risk to PASS

Acid sulfate soils (ASS) are naturally present within the Barwon River catchment. ASS refers to soils that contain pyrite, which forms under waterlogged conditions where there is little or no oxygen available. When saturated, these soils remain stable and are referred to as potential acid sulfate soils (PASS), posing little environmental concern. If these soils are exposed to air (oxygen) as a result of declining groundwater levels or excavation, a natural chemical reaction takes place that produces sulphuric acid and can mobilise heavy metals. The end result is actual acid sulfate soils (AASS). There are several naturally occurring areas in the Barwon River catchment with AASS. The most well-known of these is Yeodene (Big) Swamp, which causes water quality issues in the lower reach of Boundary Creek.

The objective of this risk assessment is to use the framework outlined in the Ministerial Guidelines for High Value GDEs to understand the risk of pumping on PASS. Although PASS are not technically a high value GDE, they are similar to groundwater dependent vegetation, in that they can be dependent on groundwater to remain saturated and prevent the soils becoming acidic. Given PASS have the potential to be influenced by groundwater drawdown via the same process as groundwater dependent vegetation, the ministerial guidelines have been adapted to determine the risk of groundwater pumping to PASS.

10.1 Overview of PASS monitoring program

A review of flora and groundwater levels recommended that a study be undertaken to determine whether acid sulfate soils are present in the catchment and assess the effect that drying conditions may have on these soils and the associated surface water systems (i.e. wetlands and streams) (SKM and EA, 2008-09). There has also been increasing community interest about the potential environmental impacts of the Barwon Downs borefield. One of these areas of interest has included potential for acid sulfate soils and their subsequent impacts.

Figure 10-1 below illustrates the progressive stages of how the PASS program has evolved and is described in detail below. In 2013 a desktop study and field inspection identified nine sites for more detailed sampling and analysis. An additional five sites were identified by the Barwon Downs Community Reference Group, and these were also recommended for more detailed sampling and analysis. Access was granted to six of the identified sites and of these, four sites considered to be at the highest risk was recommended for ongoing monitoring.

More detail on the PASS monitoring program is provided in Jacobs (2017c).

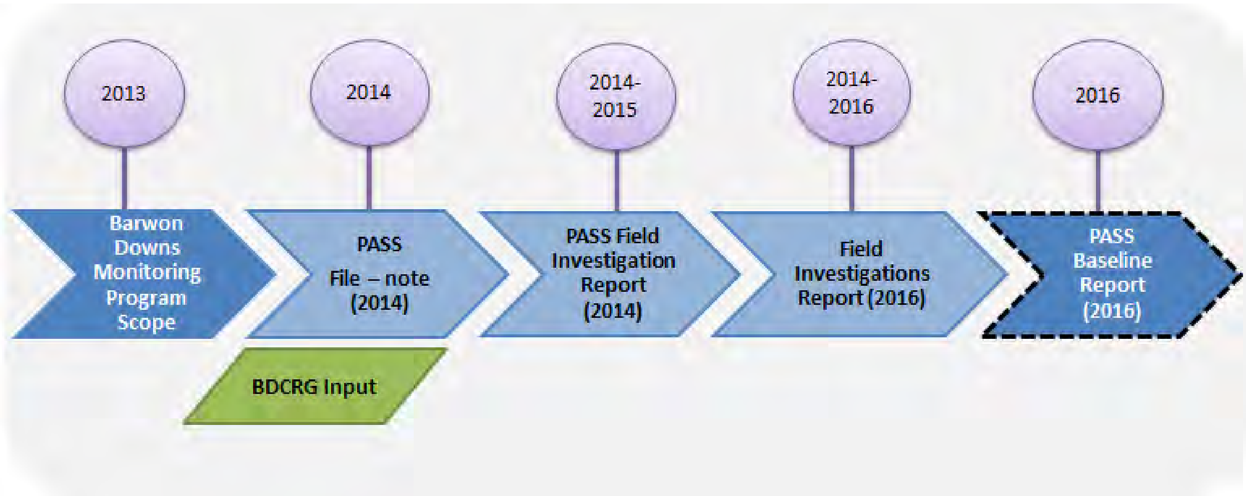


Figure 10-1 : Overview of the PASS program

10.2 Risk of groundwater pumping on PASS

The risk posed to PASS 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 groundwater model was used predict drawdown in the upper most active layer in the model and the corresponding risk to PASS was assessed according to the ministerial guidelines discussed in 7.2.

Similar to determining the risk to vegetation, the risk to PASS is defined by the drawdown in the watertable. Due to variations in the time lag between pumping and drawdown propagating to the watertable aquifer, the intermittent scenario yields maximum drawdowns for different locations at different times, making it difficult to compare impacts across the study area. However, the constant pumping scenario typically yields greater maximum impacts than the intermittent scenario.

The difference in the maximum impact between constant and intermittent pumping scenarios was assessed for each of the PASS monitoring sites (Appendix D). This illustrates that with the exception of site PASS2, the constant rate pumping scenario has a higher drawdown than the intermittent scenario. Even so, the resulting consequence and risk rating at PASS2 is not affected by the difference in drawdown predicted by the two scenarios. Therefore, the constant rate scenario is considered to provide an accurate and valid representation of the potential impacts and associated risk to PASS in the study area.

10.2.1 PASS across the study area

The risk to PASS sites was assessed using the same risk assessment framework for vegetation. The mitigated risk to PASS sites is shown in Figure 10.2 for all the PASS sites that have been investigated around the catchment (Jacobs, 2015). This map shows the mitigated risk, which considers the physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in real world, but not represented well in the model. As outlined in Section 7.2, these include the presence of alluvial aquifers and the regional. The high risk areas at the edges of the graben are reduced by the presence of the alluvial aquifers.

Figure 10.2 highlights that with the exception of the sites around Reach 2 of Boundary Creek, the risk to PASS is mitigated by the presence of alluvial aquifers. The inset on the map shows that risk to Yeodene Swamp is predicted to be mitigated by the presence of the alluvial aquifer, however monitoring has demonstrated that the alluvial aquifer has been influenced by pumping through the effect of reduced inflows from the regional aquifer further upstream of the swamp.

There are two PASS sites located on the Barwon River East Branch and there is limited information to confirm the influence of pumping on the alluvial aquifers in this region. Further site specific studies are recommended to confirm the presence of the alluvial aquifers and if they are at risk from effects of groundwater pumping.

The aquitard outcrops across much of the high risk area and is likely to further mitigate the drawdown. Figure 10.3 shows the mitigated risk to PASS, excluding areas where the aquitard is present. PASS sites located in Reach 2 of Boundary Creek are at a high risk from effects of groundwater pumping.

In summary over the majority of the study area PASS is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. Small areas of high risk are located along Reach 2 of Boundary Creek and Barwon River East Branch where PASS are found to be present.

Figure 10.2: Mitigated risk to PASS across the model domain based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)

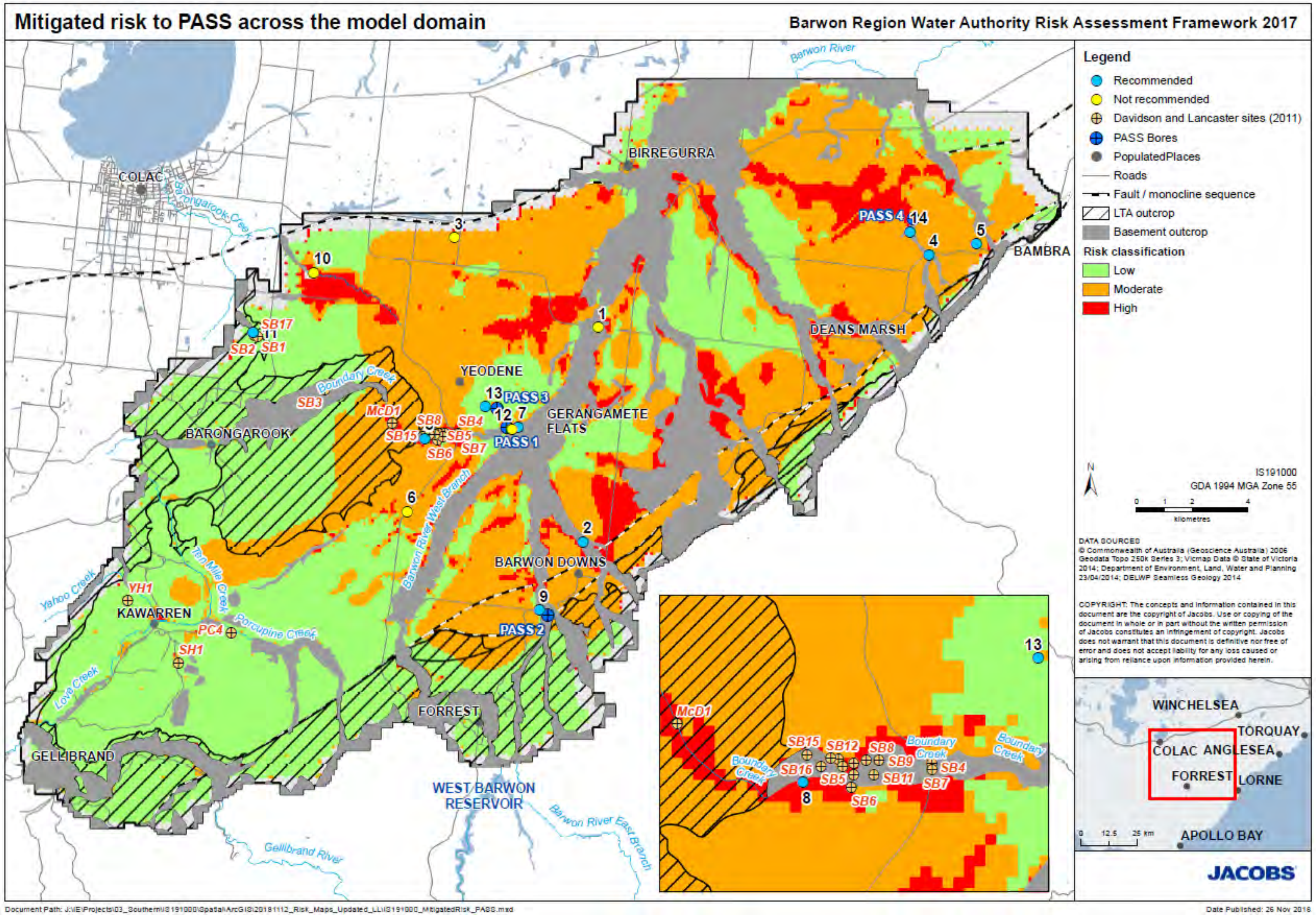
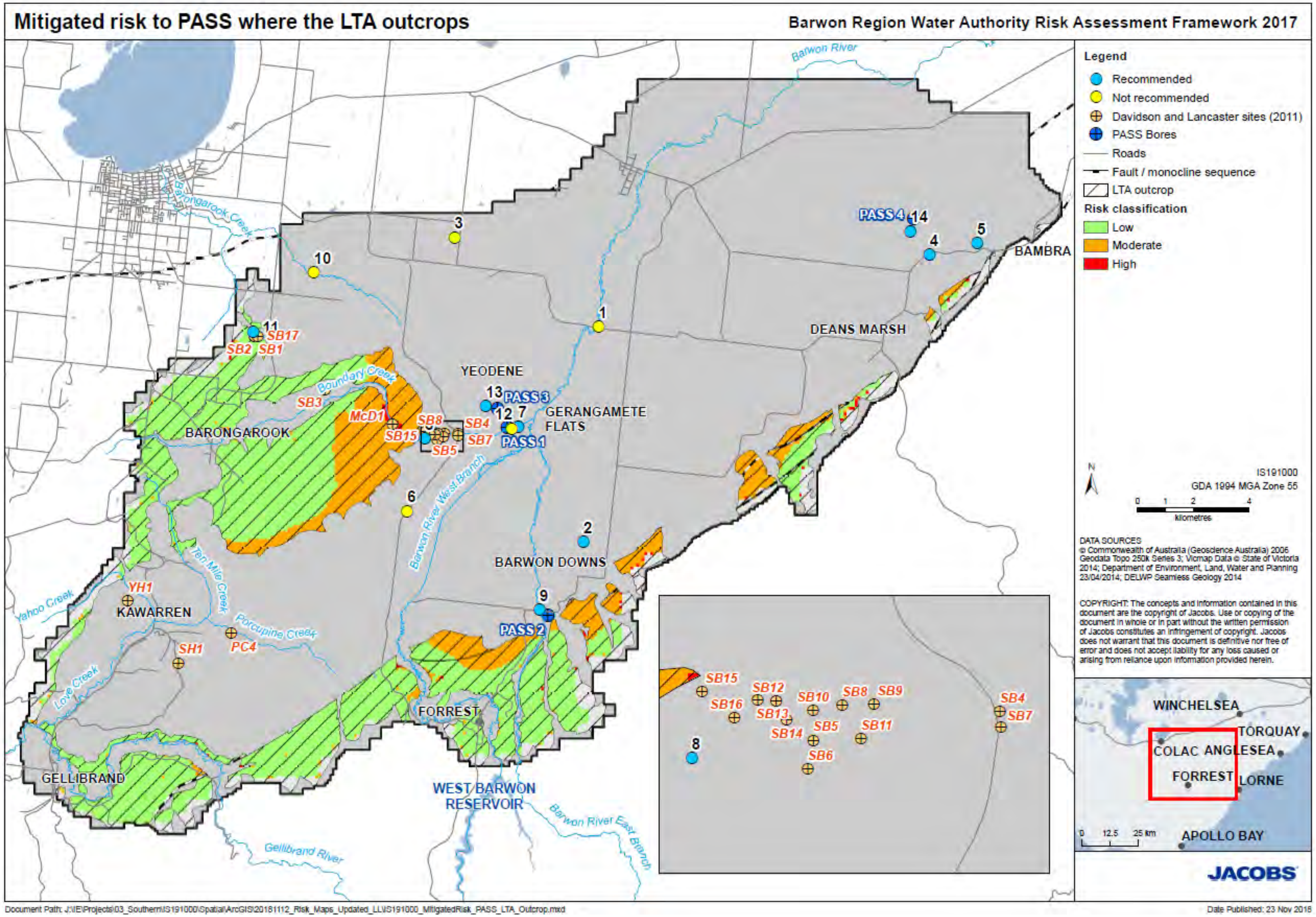


Figure 10.3: Mitigated risk to PASS where the LTA outcrops based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)



10.2.2 PASS at monitoring sites

Site specific investigations at the PASS monitoring sites indicate that all sites have a local shallow alluvial aquifer overlying the regional aquitard. This local alluvial aquifer is not represented in the groundwater model as it is highly variable and discontinuous. The local alluvial aquifers provide an additional water store and consequently, the groundwater model will overestimate the impacts at the surface from groundwater pumping as this additional local water store is not taken into account in the regional model. In addition to this, drawdown in the top of the regional aquifer and aquitard is buffered by lower permeability layers in the regional units that mean drawdown does not propagate to the surficial hydrogeological layers. The potential risk to PASS has therefore be considered using the model predictions, together with the observation data.

Appendix D shows the risk assessment applied to the PASS monitoring sites. The unmitigated risk is presented together with the mitigated risk, which is considered low for all sites, due to the presence of the alluvial aquifers and aquitard at all sites.

The monitoring site PASS 1 is located on the northern floodplain of Boundary Creek, approximately 1 km upstream of its confluence with the Barwon River where the alluvial aquifer overlies the regional aquitard. Drawdown is predicted in the regional aquitard, however observations indicate that this has not propagated to the alluvial aquifer. The overall risk classification is considered to be low at this location.

PASS 2 is located to the east of the Barwon River East Branch approximately 7 km upstream of its confluence with the Barwon River West Branch where the alluvial aquifer overlies the regional aquitard. Similar to PASS 1, drawdown is predicted in the regional aquitard, but observations suggest that this has not influenced groundwater levels in the alluvial aquifer. The overall risk classification is considered to be low at PASS 2.

PASS 3 is located along a tributary to Boundary Creek, approximately 1 km to the north west of the confluence with the Barwon River. The site has a local alluvial aquifer overlying the regional aquitard. The overall risk classification is considered to be low, assuming a low likelihood of the site being connected to the regional aquifer, a moderate predicted drawdown (consequence) and mitigation via the alluvial aquifer.

PASS 4 is located on the eastern floodplain of Yan Yan Gurt Creek, approximately 4 km north of the Deans Marsh town centre. The site has a local alluvial aquifer overlying the regional aquitard. Although drawdown is predicted to have occurred, observations indicate that this has not influenced groundwater levels in the local alluvial aquifer. The overall risk classification is considered to be low at PASS 4.

11. Key findings of impact and risk assessment

The key findings for the impacts and risk assessment are:

1. Groundwater levels in the LTA will be lower than pre-pumping levels as long as the borefield is operational. The proposed extraction limit of 60,000 ML over 15 years ranges between 63% and 97% of the predicted recharge rate to the LTA over the same timeframe, depending on the climate scenario.

2. The aquifer is not being mined. Modelling has demonstrated that the rate of decline in groundwater levels in response to pumping stabilises slowly over time and when pumping ceases, groundwater levels rise. The rate of recovery may be slow (i.e. 20-50 years) in some areas, however the aquifer is predicted to recover to near pre-pumping groundwater levels.

3. There is no comparable difference in overall risk between operating the borefield at a constant rate of 4 GL/year compared to intermittent pumping (for the same total volume extracted over 15 year the licence period).

4. Groundwater modelling and risk assessment indicate that operating the borefield according to the intermittent pumping scenario can be considered to be sustainable, providing the current trigger levels are maintained and additional site-specific studies are completed in areas identified as high risk, to confirm that high value GDEs are either not present or not impacted by pumping.

5. The predicted impacts associated with operating the borefield are either similar to, or less than, the impacts that have occurred historically. That is, predicted drawdown is typically less than what was observed during the Millennium Drought and is not predicted to be any worse.

6. The proposed groundwater extraction rates are not expected to cause adverse impacts to the LTA in terms of aquifer mining, changes to the aquifer matrix or groundwater salinity.

7. Where the LTA is unconfined, the model predicts more than 15 m drawdown in some areas on the Barongarook High. While this is classified as a high impact on the aquifer, the impact can be offset by the provision of the supplementary flow to Boundary Creek.

8. It is acknowledged that the same area (Reach 2 of Boundary Creek) was highlighted as a potential high impact area to the aquifer and Boundary Creek in the previous licence, and a supplementary flow was recommended to offset the impacts. Barwon Water have provided the supplementary flow according to the licence conditions, however there have been issues with the supplementary water being released downstream of McDonalds Dam during the summer months. These issues and their effect have been described in detail in Jacobs (2018b).

9. The model over-predicts drawdown in many areas at the surface as a result of physical mitigation constraints that restrict groundwater flow (and therefore drawdown impacts) present in the real world, but not represented well in the model or include a higher degree of uncertainty. These include the presence of alluvial aquifers and the regional aquitard.

10. Most of the catchment will not be significantly impacted by pumping because of physical hydrogeological barriers that buffer drawdown in the regional aquifer at or near the surface.

11. While operating the Barwon Downs borefield is likely to reduce groundwater contribution to rivers and creeks, the risk associated with these impacts is typically low to medium. Further investigation of the high risk areas is warranted to determine the nature of the impact and if further mitigating measures are required. Exceptions to this are Reach 2 of Boundary Creek and potentially the middle reaches of the Barwon River East Branch, which are both classified as high risk.

12. The majority of the study area vegetation is considered to be at low risk from pumping due to the presence of physical mitigating factors such as the regional aquitard and alluvial aquifers. Approximately 2% of the area is at high risk in areas located along Reach 2 of Boundary Creek, Barwon River East Branch and the Gellibrand River. A study using NDVI to assess potential impacts from historical pumping on trees across the vegetation monitoring sites showed no evidence of impact on vegetation health.

13. The drawdown predicted at the PASS monitoring sites is within the range of drawdown experienced in the past and a baseline assessment in 2015 highlighted there was no evidence of drawdown from the borefield influencing PASS at these sites.

12. Proposed Management Plan

This chapter outlines the proposed management plan to monitor and address potential impacts to sensitive environmental receptors and the reporting requirements to Southern Rural Water, as the DELWP's delegate. The monitoring program is outlined in the following sections.

It is important to note that there are currently no other existing groundwater users in the GMA as the full PCV is currently allocated to Barwon Water. If there are other groundwater users in the GMA in the future, the impact to these would be considered when required.

12.1 Water level monitoring plan

There are 131 bores that have been monitored for water levels in the Barwon Downs graben and 89 bores are currently monitored. Of the 89 bores that are currently monitored, Barwon Water monitor 35 and the remaining 54 bores are monitoring by DELWP as part of the State-wide Observation Bore Network (SOBN).

All bores that are currently monitored are recommended for ongoing monitoring. The primary objective of monitoring these bores is to record accurate and timely observations of water level responses to pumping and climate variability. The water level data can also be used to evaluate and (if required) re-calibrate the groundwater model in the future.

Although there has been a rationalisation of the SOBN monitoring network, Barwon Water has also expanded the monitoring network to address key data gaps. The 89 bores that are currently monitored are listed by aquifer in Table 12 1 and their locations are shown in Figure 12.1.

The primary objective of these bores is to monitor water levels in the different hydrogeological units. In summary, there are:

- 5 bores monitoring the Quaternary Alluvial aquifers
- 5 bores monitoring the Gellibrand Marl (MTD)
- 3 bores monitoring the Clifton Formation (LMTA)
- 11 bores monitoring the Narrawaturk Marl (MTD)
- 44 bores monitoring the Mepunga and Dilwyn Formations (LTA)
- 16 bores monitoring the Pebble Point Formation (LTA)
- 5 bores monitoring the Basement.

Until recently there were no monitoring bores in the Quaternary Alluvial aquifer, the Gellibrand Marl or the Narrawaturk Marl. Barwon Water commissioned the installation of 21 monitoring bores in these formations, which were installed in 2014.

The Quaternary Alluvial aquifers, Gellibrand Marl and Narrawaturk Formations have 4 years of monitoring record. The bores monitoring the Clifton Formation aquifer were installed in the 1970s and 1980s and have long term water level trends.

The monitoring network for the LTA is reasonably comprehensive. The majority of bores have long term monitoring records in the Mepunga and Dilwyn Formations. Barwon Water also commissioned the installation of 5 additional monitoring bores in the Mepunga and Dilwyn Formations. The underlying Pebble Point Formation has 16 monitoring bores and most of these bores have long monitoring records.

Until recently there was one bore monitoring the Basement aquifer. Four additional monitoring bores have been installed in the aquifer to monitoring groundwater levels since 2014.

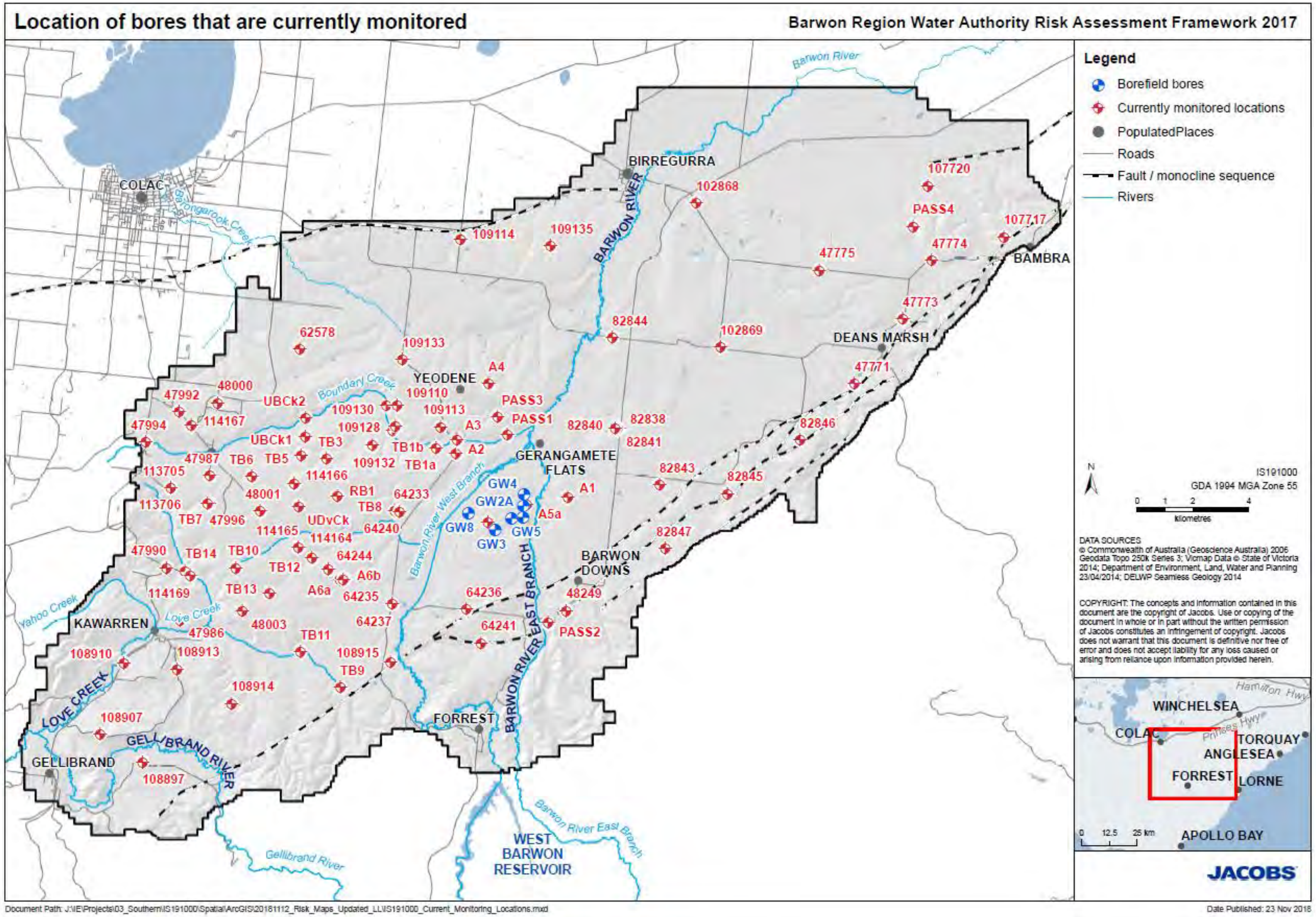
Most bores that have been installed recently are monitoring groundwater levels with a data logger that is recording levels at a twice daily frequency and downloaded regularly. The remaining bores are monitored manually on a quarterly basis.

The existing monitoring network is sufficient to monitor groundwater levels across the study area. More information on each of these bores, including the monitoring frequency is provided in Appendix E. Annual reporting of groundwater levels is recommended.

Table 12 1: Bores recommended for ongoing water level monitoring

Layer	Model layer	Number of obs bore monitored currently	Bore recommended for ongoing monitoring
Quaternary alluvium	*	5	TB1a, TB9, TB10, TB11, TB13
Gellibrand Marl	1	5	A1, A5a, A5b, A6a, A6b
Clifton Formation	2	3	64234, 64235, 82838
Narrawaturk Marl	3	11	PASS1, PASS2, PASS3, PASS4, TB1b, TB8, TB12, TB14, A2, A3, A4
Mepunga/Dilwyn Formations	4	44	TB1c, TB6, TB7, 47771, 47773, 47774, 47775, 47986, 47987, 47990, 47992, 47996, 48003, 48249, 64233, **64236**, 64237, 64240, 64244, 82841, 82843, **82844**, 82845, 82846, 82847, 102868, 102869, 107717, 107720, 108897, 108907, 108910, 108913, 108914, 108915, 109112, 109128, 109130, 109131, 109133, 109135, 114165, 114167, 114169
Pember Mudstone	5	0	
Pebble Point	6	16	TB3, TB5, 47994, 48000, 48001, 62578, **64229**, 64241, 82840, 109110, 109113, 109114, 109132, 113706, 114164, 114166
Basement	7	5	113705, RB1, UBCk, UBCk1, UBCk2

Figure 12.1: Location of bores that are currently monitoring and recommended for ongoing monitoring



12.2 Groundwater extraction monitoring program

In accordance with the existing groundwater licence conditions, the groundwater extraction rates from the Barwon Downs pumping bores has been monitored. Ongoing monitoring of the extraction rates is recommended in the future.

12.3 Groundwater salinity protection program

As outlined in Section 3.5, the groundwater salinity in the LTA has been measured in 48 bores, however these are typically single measurements taken when the bore was constructed. There is very limited data to demonstrate if and how salinity may have changed over time.

In accordance with the existing licence conditions, the groundwater salinity has been monitored in bores 109114, 107720 and 102868 (refer Section 6.2). The salinity has been monitored annually since 2004 and ongoing annual monitoring of the salinity in these bores is recommended in the future. The bore details are provided in Table 12 2.

Table 12 2: Bores recommended for ongoing monitoring of groundwater salinity

Bore ID	Depth	Aquifer monitored	Average salinity reading	Recommended monitoring frequency
102868	577 m	Mepunga/Dilwyn Formations	844 µS/cm	Annual
107720	259 m	Mepunga/Dilwyn Formations	702 µS/cm	Annual
109114	550 m	Pebble Point	853 µS/cm	Annual

12.4 Surface water flow monitoring

There are currently 12 relevant surface water gauges that are currently monitored:

- 5 gauges on Boundary Creek
- 4 gauges on the Barwon River
- 3 gauges on the Gellibrand River

Two additional gauges are recommended to be re-instated – one on Ten Mile Creek and one on Yahoo Creek.

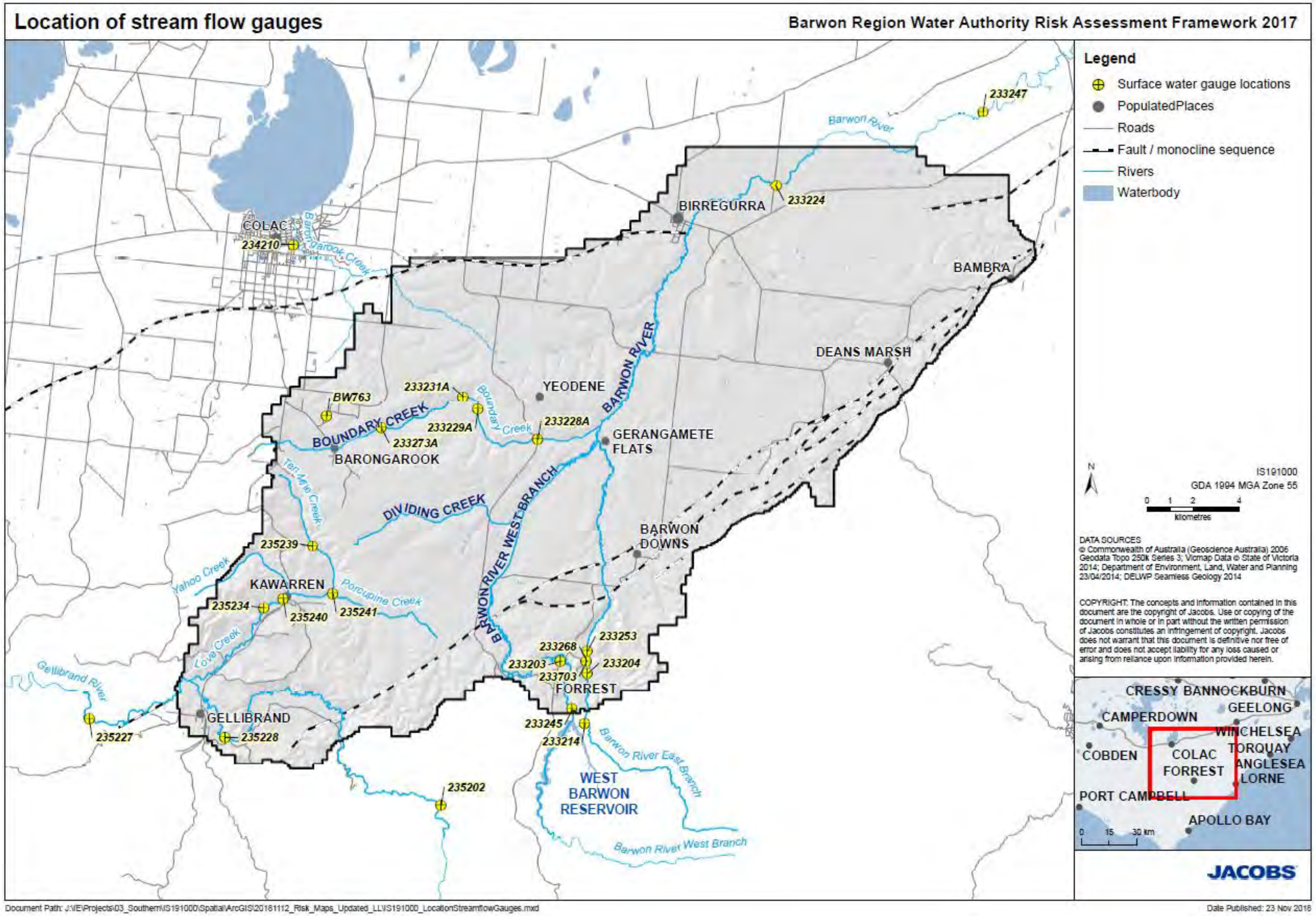
The gauges recommended for ongoing monitoring are listed in Table 12 3 and their locations are shown in Figure 12.2. Ongoing annual monitoring of the surface water gauges is recommended in the future.

Table 12 3: Stream flow gauges recommended for monitoring

Gauge	Description	Active/ Inactive	Record length	Recommendation
Boundary Creek catchment				
bw763	Boundary Creek Release flow meter	Active	March 2015 to present	Continue monitoring
233273A	Boundary Creek at Barongarook	Active	June 2014 to present	Continue monitoring
233231A	Boundary Creek Upstream Macdonald’s Dam	Active	Dec 1989 to Feb 1994 June 2014 to present	Continue monitoring

Gauge	Description	Active/ Inactive	Record length	Recommendation
233229A	Boundary Creek Downstream Macdonald's Dam	Active	Dec 1989 to Feb 1994 June 2014 to present	Continue monitoring
233228A	Boundary Creek at Yeodene	Active	June 1979 to present	Continue monitoring
Barwon River catchment				
233245	Barwon River West at Spillway	Active	Sep 2000 to present	Continue Monitoring
233214	Barwon River East at Forrest	Active	May 1955 to present	Continue Monitoring
233224	Barwon River at Ricketts Marsh	Active	July 1971 to present	Continue monitoring
233247	Barwon River at Kildean Lane	Active	June 1993 to present	Continue monitoring
Gellibrand catchment				
235227	Gellibrand River at Bunkers Hill	Active	March 1970 to present	Continue monitoring
235228	Gellibrand River at Gellibrand	Inactive	April 1970 to May 1989	
235202	Gellibrand River at Upper Gellibrand	Active	August 1949 to present	Continue monitoring
235239	Ten Mile Creek at Kawarren	Inactive	April 1985 to July 2009	Re-instate gauge
235240	Yahoo Creek at Kawarren	Inactive	March 1985 to July 1995	Re-instate gauge
235241	Porcupine Creek at Kawarren	Inactive	March 1986 to July 2009	
235234	Loves Creek at Gellibrand	Active	May 1979 to present	Continue monitoring
Barongarook Creek catchment				
234210	Barongarook Creek at Lake Colac	Inactive	Oct 1975 to Jan 1981	

Figure 12.2: Location of stream flow gauges recommended for ongoing monitoring



12.5 Vegetation monitoring

A condition of the existing licence specifies vegetation condition to be monitored at specific sites. As described in Section 9.1, the vegetation monitoring network was re-designed in 2014 and accepted by Southern Rural Water, to ensure the monitoring locations target areas that are groundwater dependent. Revision to the previous network was also aimed at establishing sites within the outcropping LTA and MTD that were truly reference (or 'control') sites, i.e. un-impacted by borefield pumping.

Accordingly, the revised list of vegetation monitoring sites recommended for on-going monitoring as part of this licence application, and corresponding monitoring bore details, is listed in Table 12 4 below. This takes into account a number of sites in which the LTA has been impacted by pumping, as well as a bores considered to be true reference (control) sites.

Table 12 4: Vegetation bores recommended for monitoring

Site	Bore ID	Easting	Northing	MZ	Elevation (mAHD)	Depth (m)	Screen top (m)	Screen bottom (m)	Unit
T1	TB1a	212070	5742075	55	144	12.9	8.7	11.7	QA
	TB1b	212070	5742077	55	144	19.0	19.0	17.5	MTD
	TB1c	212070	5742079	55	144	36.5	36.0	33.0	LTA
T2	TB2c	210820	5742222	55	153	2.8	2.8	1.5	LTA
T3	TB3	208134	5741691	55	226	39.5	31.5	37.5	LTA
T4	TB4a	210790	5742057	55	179	17.1	13.7	16.7	LTA
	TB4b	209100	5742281	55	179	7.7	4.2	7.2	QA
	TB4c	209112	5742281	55	179	31.0	27.5	30.5	LTA
T5	TB5	207224	5741809	55	229	32.6	29.0	32.0	LTA
T6	TB6	205447	5741049	55	243	22.0	17.9	20.9	LTA
T7	TB7	203872	5740074	55	224	9.4	5.2	8.2	LTA
T8	TB8	210575	5739808	55	151	27.0	23.0	26.0	MTD
T9	TB9	208632	5733485	55	156	12.0	7.7	10.7	QA
T10	TB10	204874	5737770	55	215	10.9	7.0	10.0	QA
T11	TB11	207199	5734762	55	134	10.9	7.0	10.0	QA
T12	TB12	207615	5738133	55	172	12.2	8.1	11.1	QA
T13	TB13	206082	5736875	55	189	13.2	9.0	12.0	QA
T14	TB14	203063	5737656	55	141	11.6	8.5	11.5	QA

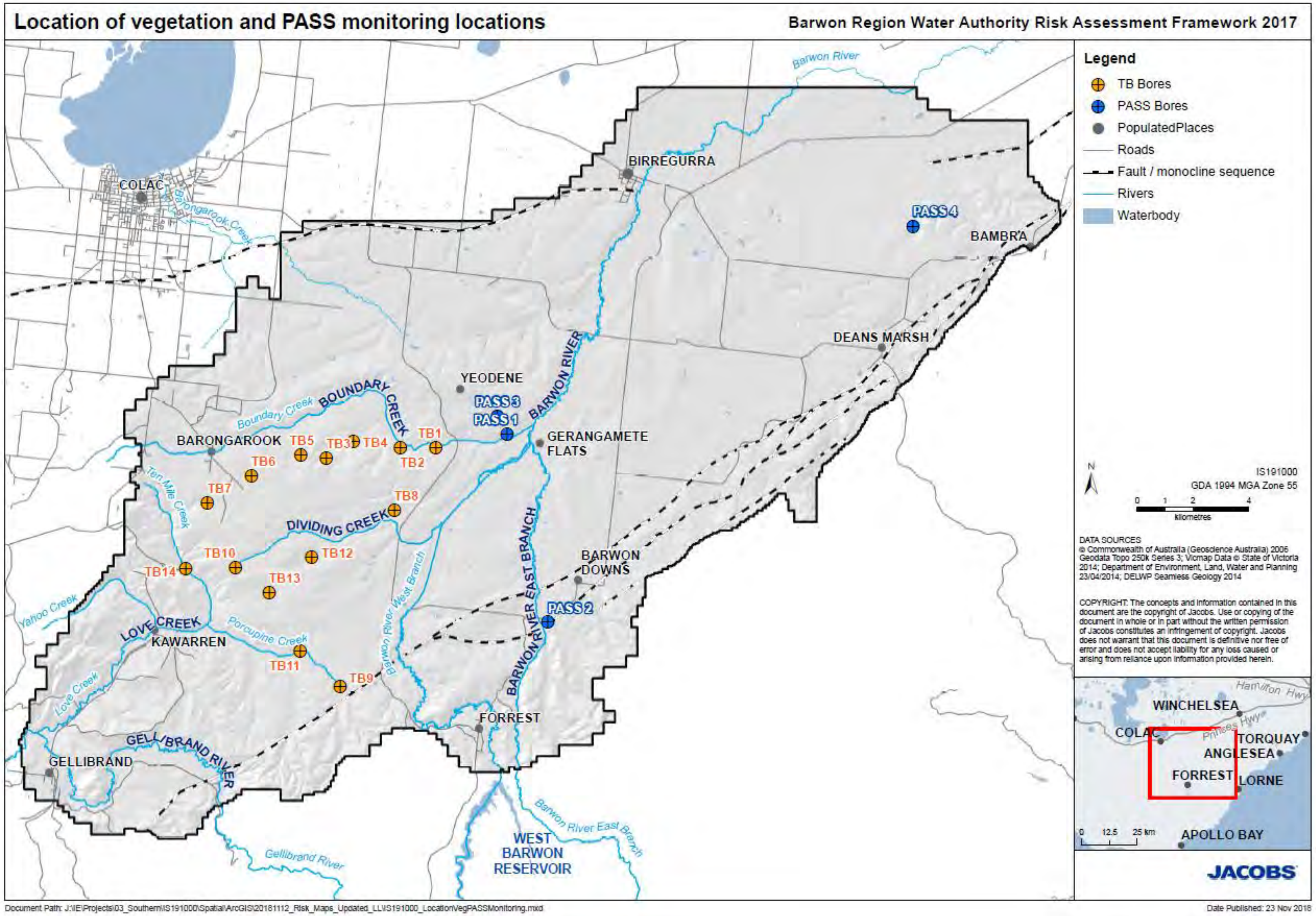
12.6 PASS monitoring

Monitoring of PASS is not a condition of the existing licence. As described in section 10, four PASS monitoring sites have been installed. Groundwater level loggers have been installed in the four bores listed in Table 12 5 below. It is recommended that ongoing monitoring of groundwater levels at these site is undertaken to inform potential borefield impacts on PASS.

Table 12 5: PASS bores recommended for monitoring

ID	Easting	Northing	MZ	Elevation	Depth (m)	Screen top (m)	Screen bottom (m)
PASS1	214626	5742548	55	122.2	10	4	9
PASS2	216082	5735799	55	136.88	9.8	4.8	8.8
PASS3	214267	5743206	55	143.89	10	4	9
PASS3	229173	5750021	55	137.52	8	2	7

Figure 12.3: Location of vegetation and PASS monitoring locations recommended for ongoing monitoring



13. Environment Protection Program

The purpose of the Environment Protection Program is to identify potential groundwater trigger levels for high value groundwater dependent receptors that have the potential to be impacted by future groundwater pumping from the Barwon Downs borefield.

The intent of a trigger level is to enable actions to be implemented that will protect sensitive receptors from adverse impacts generated by declining groundwater levels caused by the operation of the Barwon Downs borefield. When reached, the trigger level would trigger a management action or response which is designed to prevent or offset any adverse impacts. The management action may be to stop pumping, or it could be to provide an additional water source to the receptor.

13.1 What is a trigger level?

A trigger level – in this case of a groundwater level - is a level that when reached, triggers an action or response. Trigger levels are used as part of adaptive management in conjunction with an appropriate monitoring to prevent unacceptable impacts to sensitive environmental receptors. Levels may be both physical or chemical and could trigger a variety of responses.

Some trigger levels may be designed to provide a simple and direct response for the maintenance of environmental values, such as the release of additional water from storage into waterways to maintain a minimum flow or to cease or reduce groundwater pumping. Conversely, others may simply be a starting point for further actions, such as a level that triggers an investigation for further work to provide more information.

Trigger levels were developed based on the environmental receptors that were considered at risk through a combination of the outputs of the numerical groundwater model and the DELWP ministerial guidelines (2015). The process for describing risk is described in detail in earlier sections of this document.

The existing trigger levels in the current groundwater licence were reviewed to confirm their relevance for the proposed new licence. New trigger levels were also considered for high value groundwater dependent ecosystems potentially at high risk from operation of the borefield.

Trigger levels were determined by reviewing the existing data to confirm the local hydrogeological conceptual understanding for each receptor. This included confirming the local hydrogeology, groundwater level trends and groundwater surface water interactions. Trigger levels were recommended based on a review of water level trends in existing monitoring bores to confirm the local vertical groundwater flow directions.

It is recommended that the trigger levels be reviewed periodically or adapted when required based on monitoring data.

13.2 Proposed triggers levels for the new licence

Proposed triggers for the new licence will comprise the existing triggers and additional trigger levels for high value groundwater dependent ecosystems potentially at high risk from operation of the borefield. There are existing trigger levels for bores 64229, 64236, 82844 and 109131 and these are recommended for the new licence. More detail on these is provided in the following section.

New trigger levels are also recommended for receptors considered to have potential high value GDEs at high risk from pumping. The intent of these new triggers is shown in Table 13.1 and are discussed more in the following sections.

Table 13.1 : Key receptors and intent of trigger level

Receptor with potential high value GDEs at high risk from groundwater extraction from Barwon Downs borefield	Intent of trigger level
Boundary Creek – Reach 2 between McDonalds Dam and Yeodene Swamp	As per previous licence, 158.5 mAHD and minimum flow required at Yeodene gauge (0.5 ML/day).
Gellibrand River	Assuming that river is gaining in the area identified at high risk, groundwater level in regional aquifer (LTA) remains above the stream bed (e.g. stream bed elevation plus 0.5m).
Ten Mile Creek	Assuming that river is gaining in the area identified at high risk, groundwater level in regional aquifer (LTA) remains above the stream bed (e.g. stream bed elevation plus 0.5m).
Barwon River East Branch	Assuming that river is gaining in the area identified at high risk, groundwater level in regional aquifer (LTA) remains above the stream bed (e.g. stream bed elevation plus 0.5m).
Vegetation	Minimum groundwater level trigger identified for vegetation sites that are dependent on the regional groundwater system (aquifer and aquitard).
Potential acid sulfate soils (PASS)	Minimum groundwater level trigger defined for PASS monitoring sites that overlie the regional aquifer (LTA).
Subsidence	Ongoing monitoring in accordance with pre-existing trigger levels, intended to identify and alert to excessive subsidence or rates that are in excess of expected.

13.2.1 Groundwater level trigger levels (existing triggers)

The historical observed waterlevels, together with the waterlevels from the calibration and the predicted model for the bores with trigger levels in the current groundwater extraction licence are shown in Figure 13.1 to Figure 13.4. These figures show how the drawdown has changed over time historically and is also predicted to vary under the different model scenarios. They demonstrate that borefield has been operated historically within the required trigger levels (as per the licence) and that the predicted water levels for both the constant and intermittent pumping are also generally within the existing trigger levels at all sites. The exception to this is bore 109131, however the model over-predicts drawdown at this location.

For bore 109131 (Figure 13.4) the waterlevel for the intermittent pumping scenario is predicted to drop slightly below the trigger level for a short period of time. The calibration model also predicted that the waterlevels would drop below the trigger level in 2010, however observed waterlevels were over 10 m higher than the model predicted. To date, the observed waterlevels are well above the existing trigger level.

The groundwater model predicts that the waterlevels in bore 109131 could drop below the trigger levels to 140.8 mAHD for a short period of time (less than a year). Taking into consideration that the predicted drawdown in the future is less than the drawdown modelled historically and that the observed waterlevels are significantly higher at this location, the trigger level is not expected to be exceeded with future operation of the borefield.

The model is a representation of the real world and model predictions are not a replacement for ongoing monitoring of groundwater levels. It is recommended that monitoring continues in all currently monitored bores, including Bore 109131 and that the triggers levels in the current licence are applied to the future licence.

Figure 13.1: Hydrograph for bore 64229 (predicted pumping scenarios assume moderate climate change)

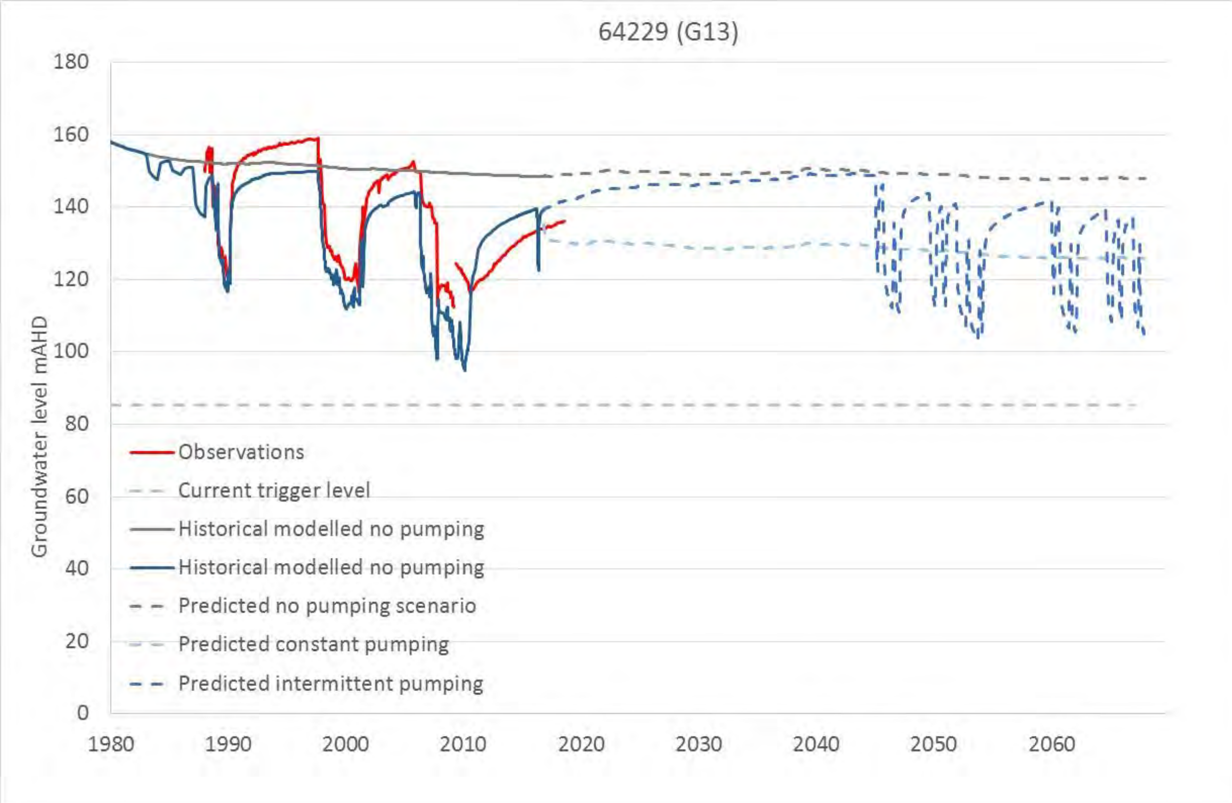


Figure 13.2: Hydrograph for bore 64236 (predicted pumping scenarios assume moderate climate change)

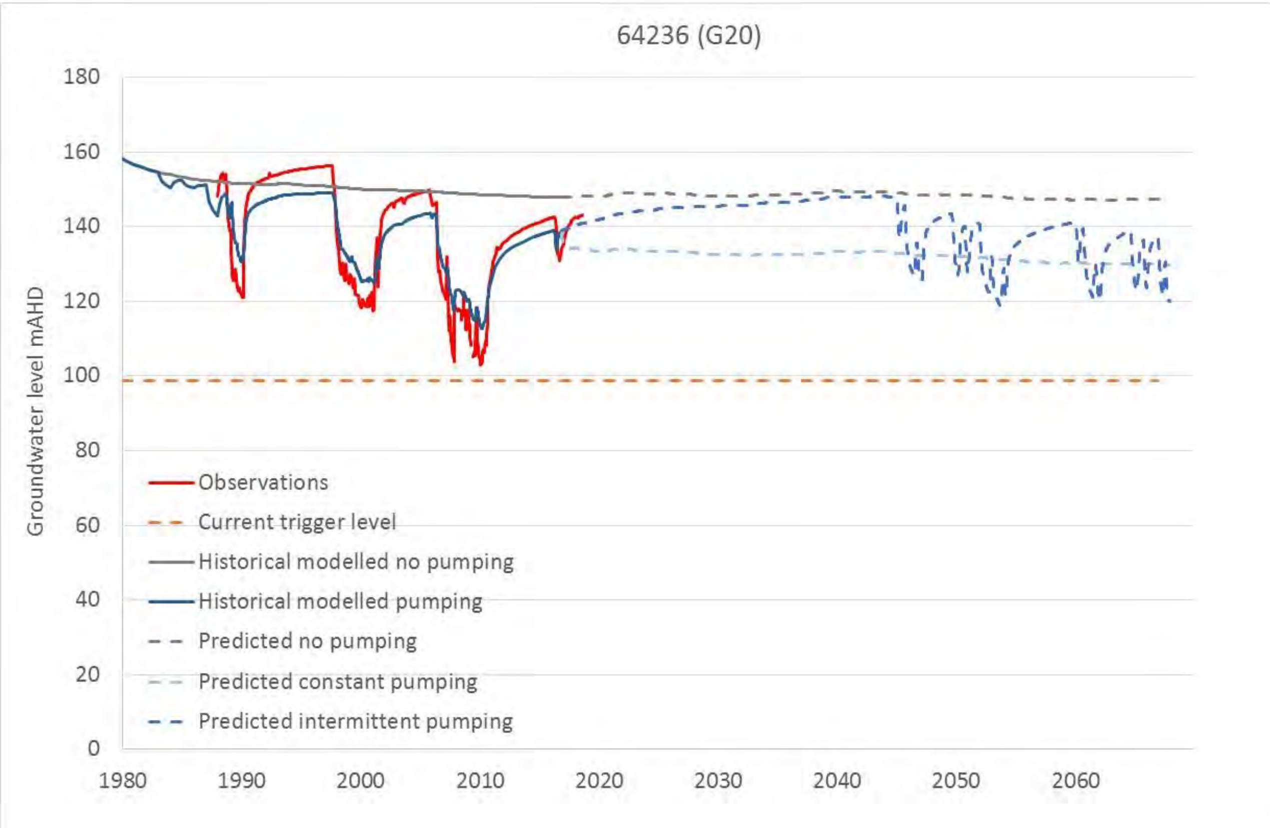


Figure 13.3: Hydrograph for Bore 82844 (predicted pumping scenarios assume moderate climate change)

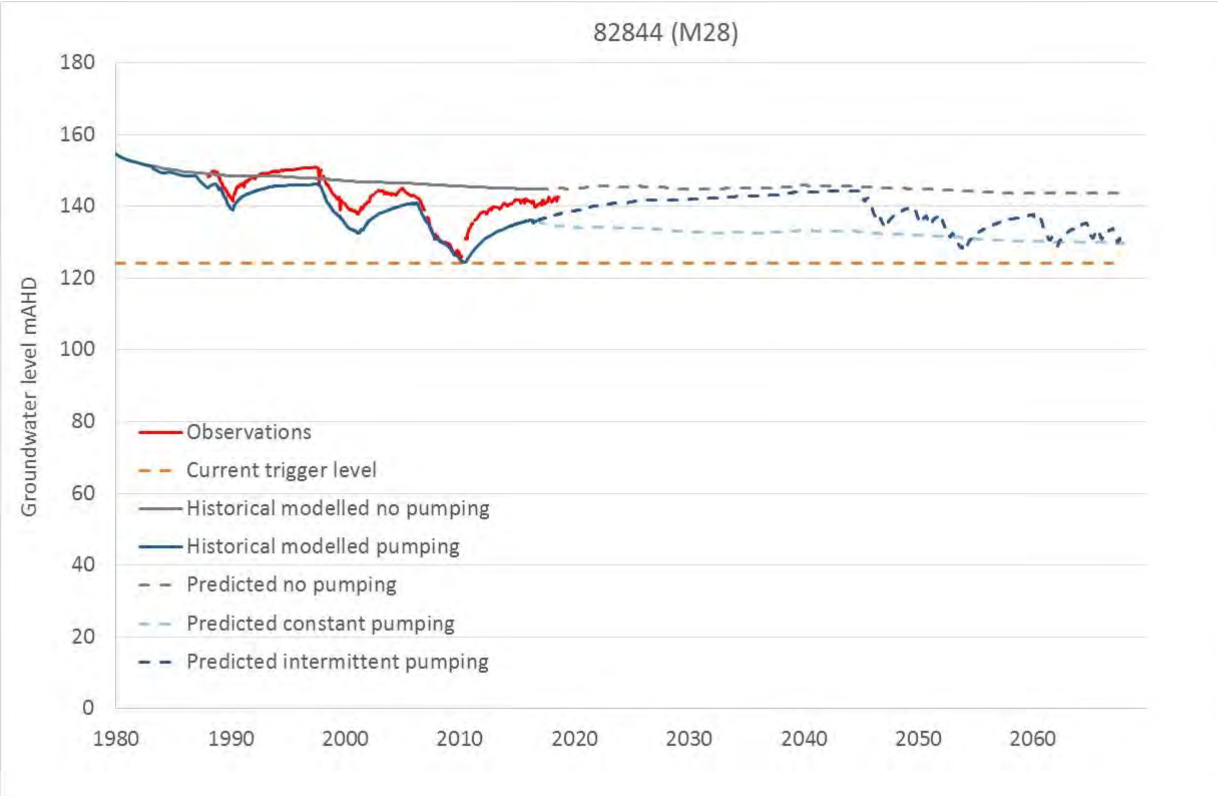
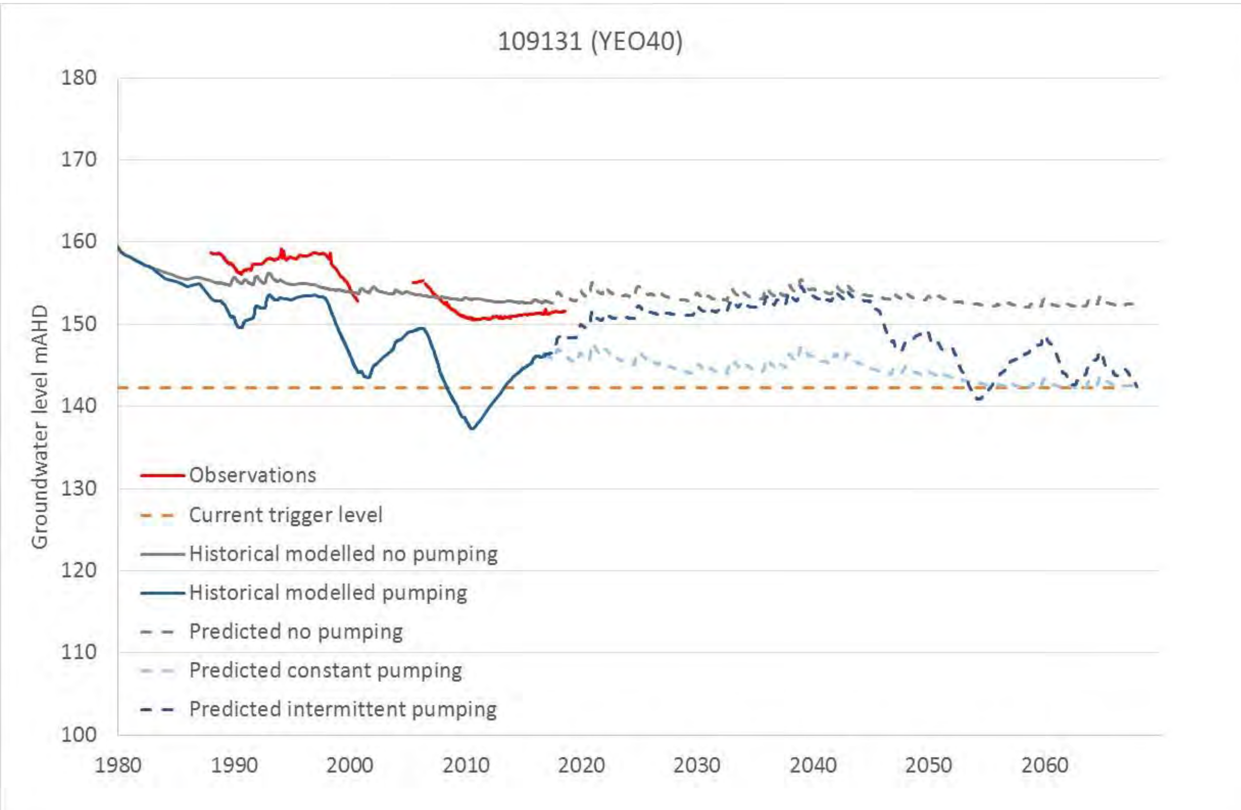


Figure 13.4: Hydrograph for Bore 109131 (predicted pumping scenarios assume moderate climate change). Refer discussion in the text regarding the predicted low point.



13.2.2 Boundary Creek

The existing trigger for Boundary Creek is in Bore 109131. The trigger level is aimed at ensuring a minimum flow in Boundary Creek. When groundwater levels fall below the trigger level, Barwon Water is required to release a 2 ML/day supplementary flow to Boundary Creek. Under the current groundwater extraction licence, the trigger is set at 158.5 mAHD, which was the groundwater level prior to 1997 (Jacobs, 2016b). Until groundwater levels return to above the 1997 groundwater level, Barwon Water will continue to release water to Boundary Creek.

It is recommended that this bore continues to be the point for a trigger level for minimum flow in Boundary Creek. The bore is located in the middle of the high risk zone for Boundary Creek (see Figure 13.6) and water levels from the Water Management Information System (WMIS) for this bore are shown Figure 13.5.

To be consistent with triggers for other surface water receptors, it is recommended that the streambed elevation is surveyed and compared to the existing trigger levels. Depending on the outcomes of the survey, the trigger point could be revised to ensure it is consistent with the intent of the trigger and also with other recommended triggers.

Table 13-2 Potential monitoring bores for environmental maintenance in Boundary Creek

ID	Depth (m)	Formation	Screened interval (m)	Waterlevel range (m)	Trigger level (mAHD)
109131 (Yeo40)	24	LTA	12 – 21	152.7 – 161.2	158.5

Figure 13.5: Observed and modelled waterlevels for Bore 109131 with the trigger level to provide supplementary flow

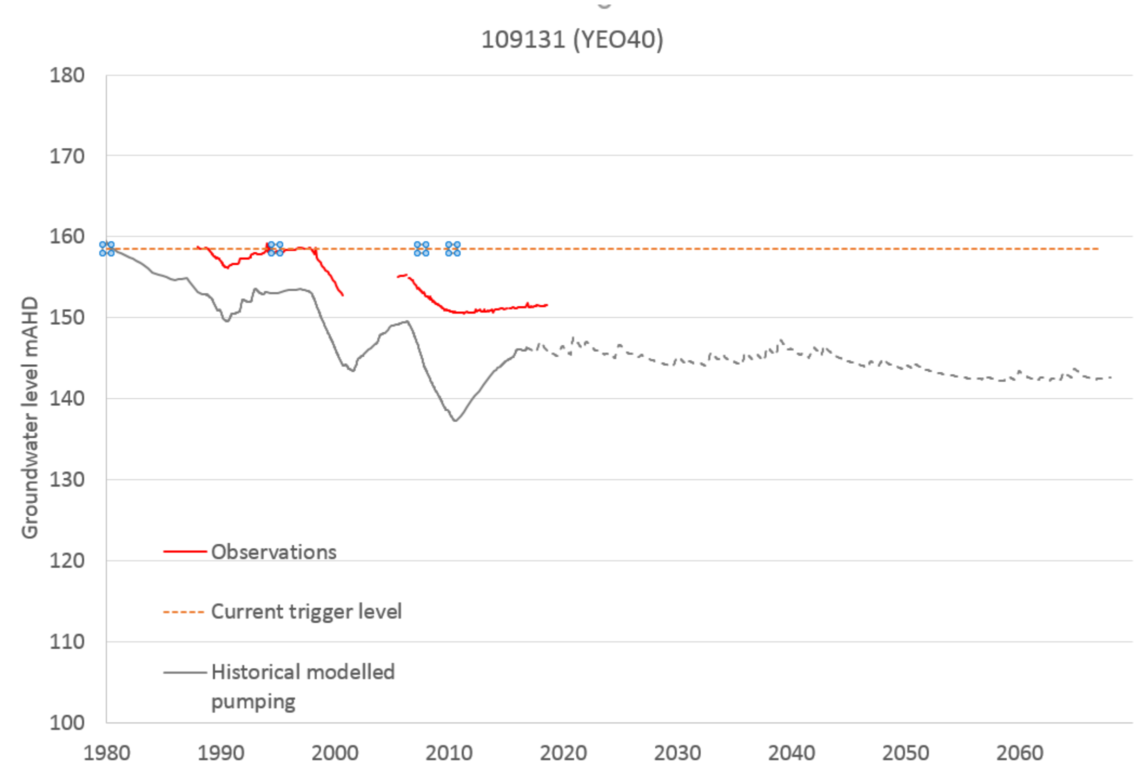
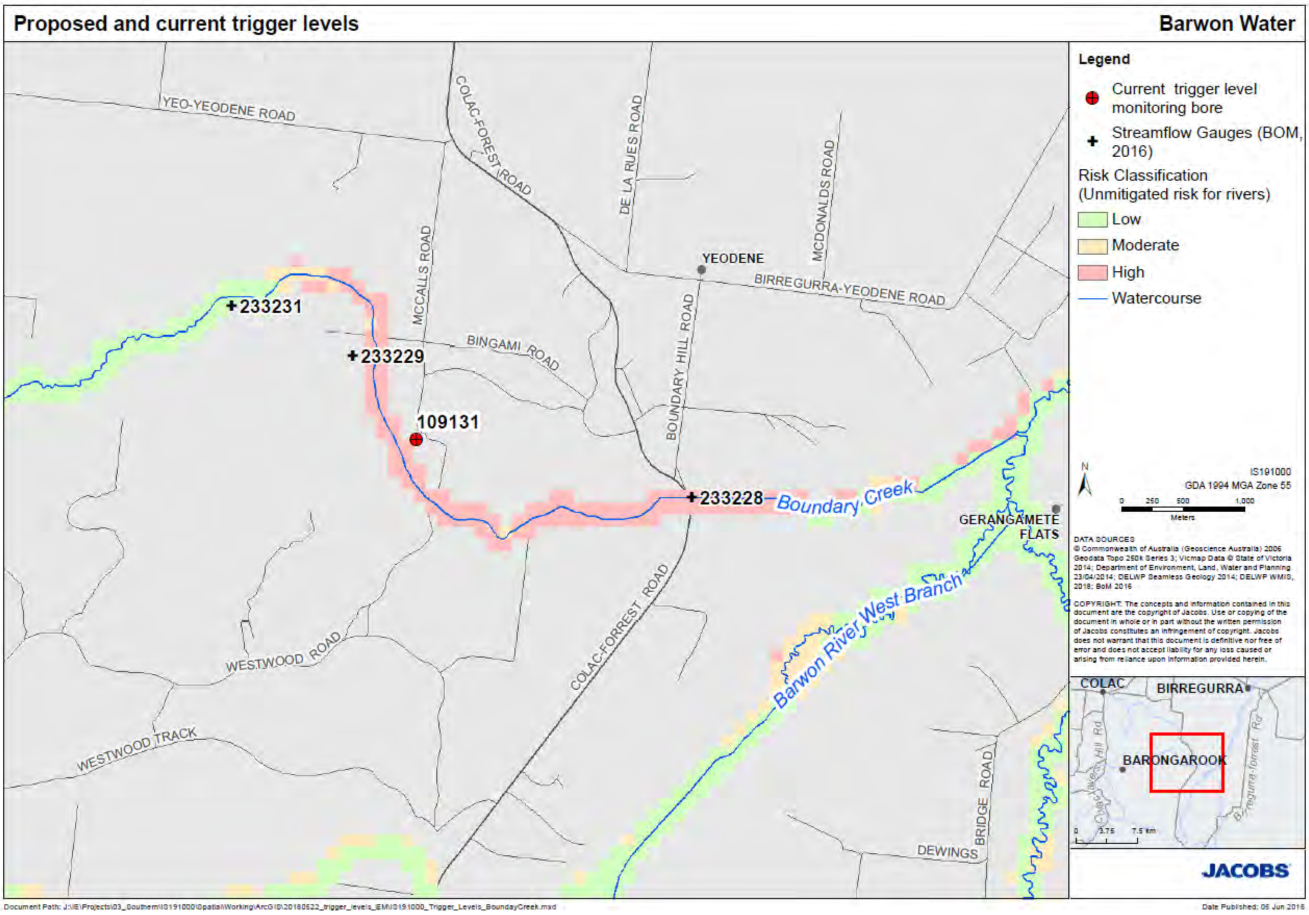


Figure 13.6: Location of existing trigger bore for Boundary Creek



13.2.3 Gellibrand River

There are no existing trigger levels around the Gellibrand River. The objective of the proposed trigger level is to maintain groundwater contributions to the river during summer low flow conditions to minimise any impact to the low flow periods in the Gellibrand River. This trigger level can only be implemented once it is confirmed that the groundwater levels are above the stream bed or have been above stream bed in the past.

The majority of the existing groundwater monitoring bores are located south of the Gellibrand River where the effects of the borefield are diminished. 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 have been listed in Table 13-3 and described below. The locations of these bores is shown in Figure 13.8.

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

The groundwater hydrograph for bore 108898 and bore 108917 is illustrated in Figure 13-7. The figure illustrates that an upward hydraulic gradient has been maintained between the LTA and shallow groundwater system in the area.

The purpose of this trigger is to ensure that the potential for groundwater baseflow to be supported by the regional aquifer is maintained to the Gellibrand River. The proposed action to be triggered is to reduce or cease pumping until the groundwater level is above the trigger level.

Given the lack of monitoring bores in the area, it is recommended that two new monitoring bores are installed closer to the area of potential high risk. One bore would monitor the Lower Tertiary Aquifer and the other would monitor the alluvial aquifer. The trigger level on both bores is recommended to be 0.5 m above the elevation of the streambed. These bores could be installed on the track of Ridge Road, although access along the track has not been confirmed.

Until these new bores are installed, the existing bores 108917 and 108898 could be used as interim trigger levels. The trigger level for both bores would be 0.5 m above the elevation of the streambed, to ensure that the potential for groundwater to provide baseflow to the river is maintained.

It is noted that these bores may not be currently monitored (last reading on WMIS is in 2014) and as such, their current condition should be confirmed prior to acceptance for long term monitoring. Further, it is noted that the below hydrographs are based on the estimated elevation of the bores. These should be surveyed to confirm the groundwater elevations in Figure 13-7. Finally, in order to facilitate future assessment of groundwater inflows and the flow condition in this part of the Gellibrand River, it is recommended that the elevation of the bottom of the streambed (thalweg) near these bores be surveyed.

Table 13-3 Potential monitoring bores to assess impacts on the Gellibrand River

ID	Total Depth (mbgl)	Formation	Screen top (mbgl)	Max water level (mAHD)	Proposed interim trigger level (mAHD)
108898	272.0	LTA	46 – 52	77.4 - 79.1	0.5 m above nearby average stream bed elevation
108899	34.0	LTA	26 – 32	81.3 - 83.1	No
108916	14.9	UNKN	13.9 – 14.9	76.8 - 78.8	No
108917	15.0	UNKN	14.0 – 15.0	76.8 - 78.5	0.5 m above nearby average stream bed elevation
108918	15.3	UNKN	14.3 – 15.3	77.3 – 78.8	No
108919	16.6	UNKN	15.6 – 16.6	76.8 - 78.5	No
108920	18.0	UNKN	17.0 – 18.0	77.3 – 78.4	No
108958	n/a	UNKN	n/a	n/a	No
108959	n/a	UNKN	n/a	n/a	No
108960	n/a	UNKN	n/a	n/a	No
108961	n/a	UNKN	n/a	n/a	No

Figure 13-7 Observed groundwater levels in bore 108898 and 108917

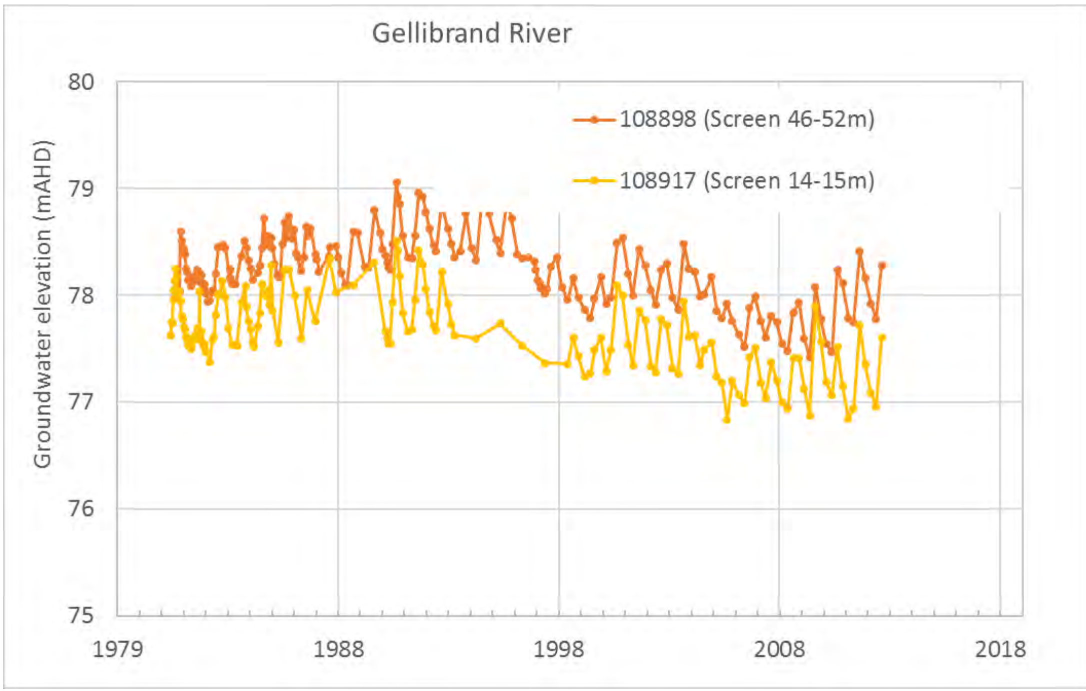
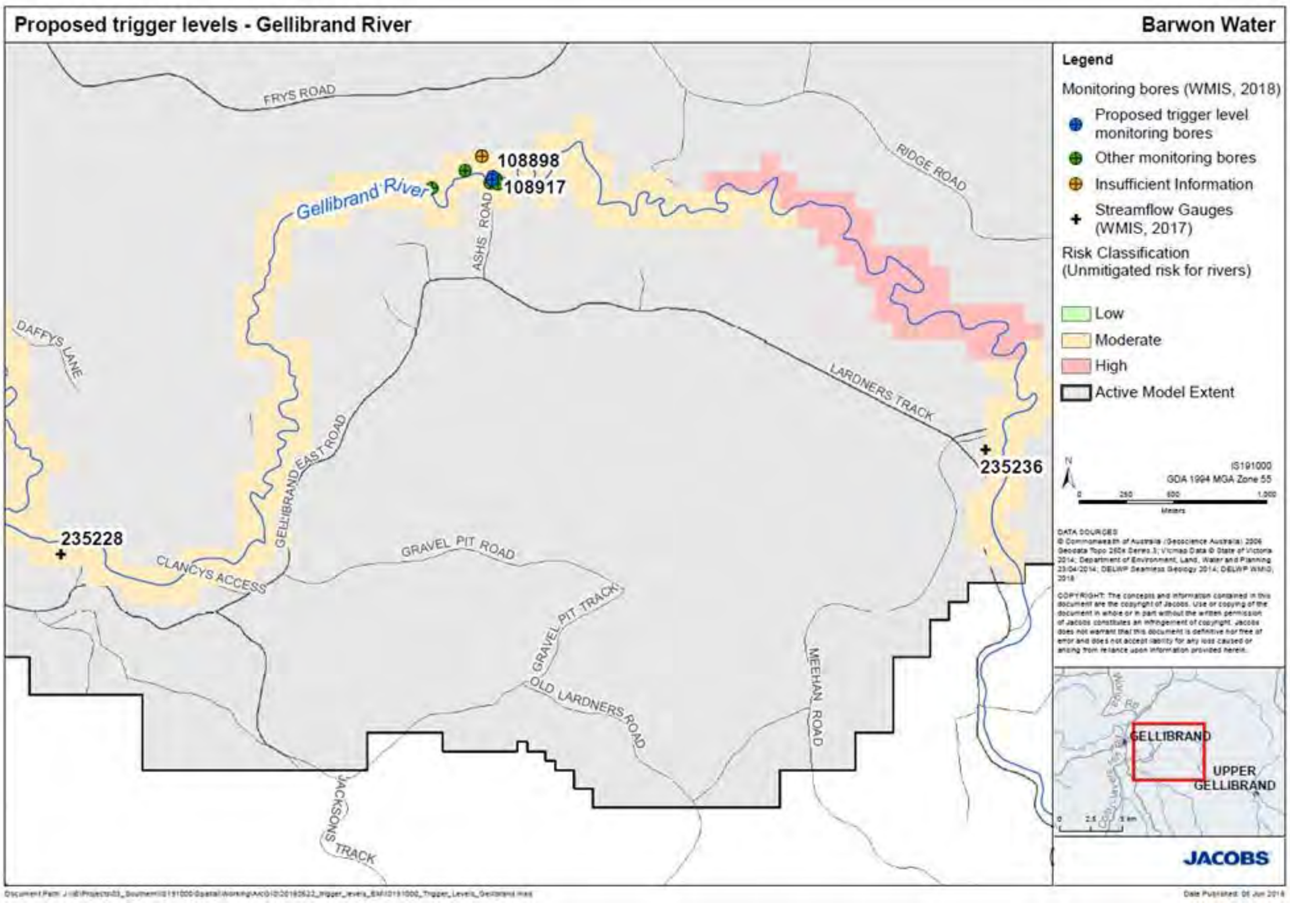


Figure 13.8: Location of proposed trigger bore for Gellibrand River



13.2.4 Barwon River East

There are no triggers near the Barwon River East Branch in the current licence. The Barwon River East Branch is a thought to be gaining river where it flows over the LTA to the south east of the borefield. Predictive scenario modelling indicates that the greatest risk of impact to the Barwon East Branch will occur to the south of the intersection between the river and Birregurra Forest Road. Assuming the river is gaining in this location, the objective of a trigger level in this area would be to ensure that the river continues to receive groundwater contributions during the summer low flow season.

There are two currently existing bores in this area:

- Bore 48249 which is screened between 61 and 68 meters below ground level in the upper portion of the LTA, and

- PASS 2 which is screened between 5 and 9 meters below ground surface in the Quaternary Alluvium.

The groundwater levels in these bores is illustrated in Figure 13-9, which shows there is an upward gradient from the regional aquifer to the shallow alluvial aquifer. The location of these bores is shown Figure 13.10.

An additional monitoring bore is recommended in the Lower Tertiary Aquifer closer to the PASS2 bore. This new monitoring bore and PASS2 are recommended to be trigger levels for the Barwon River East Branch. The trigger level would be set at 0.5 m above the elevation of the nearby stream bed to ensure groundwater contributions to baseflow are maintained. The action triggered would involve reducing or ceasing pumping until groundwater levels are above the trigger level.

It is recommended that ongoing monitoring continue in 48249 as there are limited bores in the area.

Figure 13-9 Observed groundwater levels in bore 48249 and PASS2

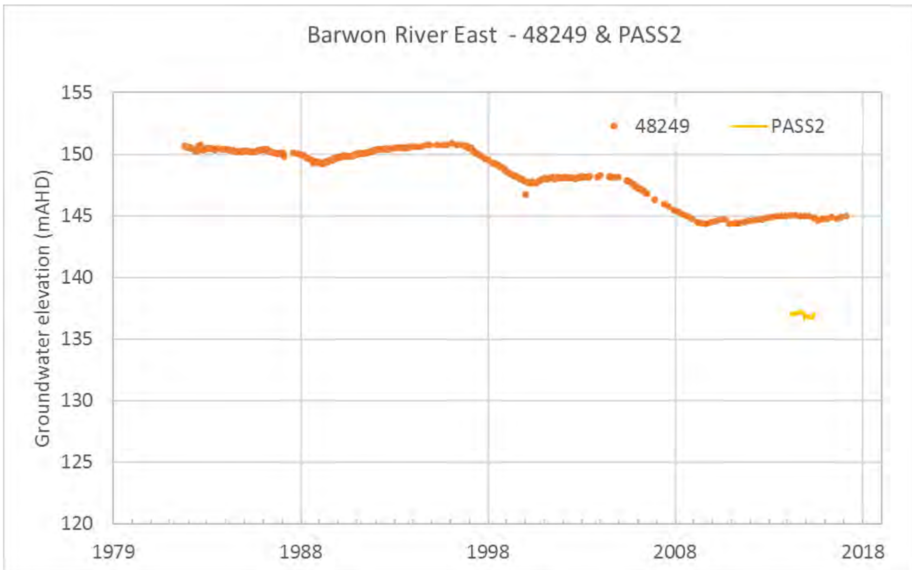
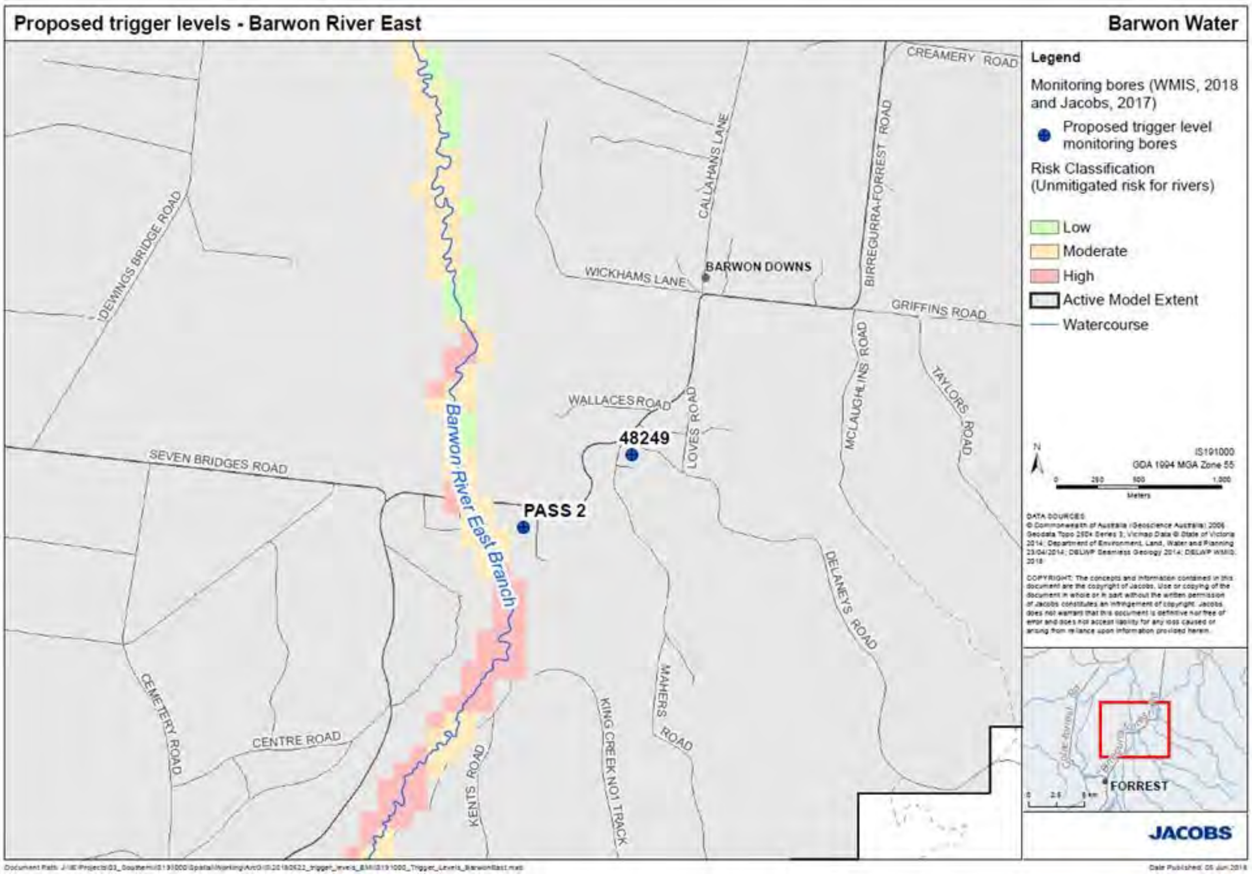


Figure 13.10: Location of proposed trigger bore for Barwon River East Branch



13.2.5 Ten Mile Creek

Ten Mile Creek is a tributary of the Loves Creek and flows over a small outcrop of the Lower Tertiary Aquifer and there are no existing trigger levels near this receptor. The creek is considered to be a gaining creek. Two pairs of nested bores located close to Ten Mile Creek both show there is an upward gradient through the Lower Tertiary Aquifer. It is recommended that a nested pair of bores are monitored to confirm that an upward gradient is maintained towards the river.

Bores 1141168 and 114169 are located just downstream of the where the LTA outcrops and where the aquifer is confined (Figure 13.13). The bores are 139 and 82m deep respectively and typically show an upward gradient in the LTA (see Figure 13.11).

Bores 113705 and 113706 are located further upstream away from the borefield where the LTA is unconfined (Figure 13.13). The bores are 174 and 90m deep respectively and a significant upward gradient exists in the aquifer at this location (see Figure 13.12).

Either of these sites could be used as a trigger, however bores 114168 and 114169 both show a rising trend over the monitoring period, whereas bores 113705 and 113706 show a declining trend which is likely to be the combined result of climate variability and pumping.

It is therefore recommended that latter bores are recommended for monitoring with a trigger level as they appear to be more responsive to pumping. These bores are suitable for a trigger because the area of high risk is very small and these bores are located close to the river. A monitoring trigger 0.5 m above the elevation of the streambed, to ensure that groundwater level in the LTA remains above the streambed.

It is also further recommended that the elevation of the streambed near Bores 11305 and 113706 is surveyed and that the streamflow gauge on Ten Mile Creek is re-instated.

Table 13.4 : Potential monitoring bores to assess impacts on Ten Mile Creek

ID	Total Depth (m)	Formation	Screened interval (m)	Waterlevel range (mAHD)	Proposed trigger level mAHD
114168	139	LTA	130 – 133	138 – 141	N
114169	82	LTA	55.5 – 79.5	138.7 – 141.2	N
113705	174	LTA	137.2 – 140.5	229.7 – 226.3	0.5 m above average stream bed elevation
113706	90	LTA	83.5 – 88.0	221.1 – 219.1	0.5 m above average stream bed elevation

Figure 13.11 : Bores 114168 and 114169 located closer to the borefield where the LTA is confined

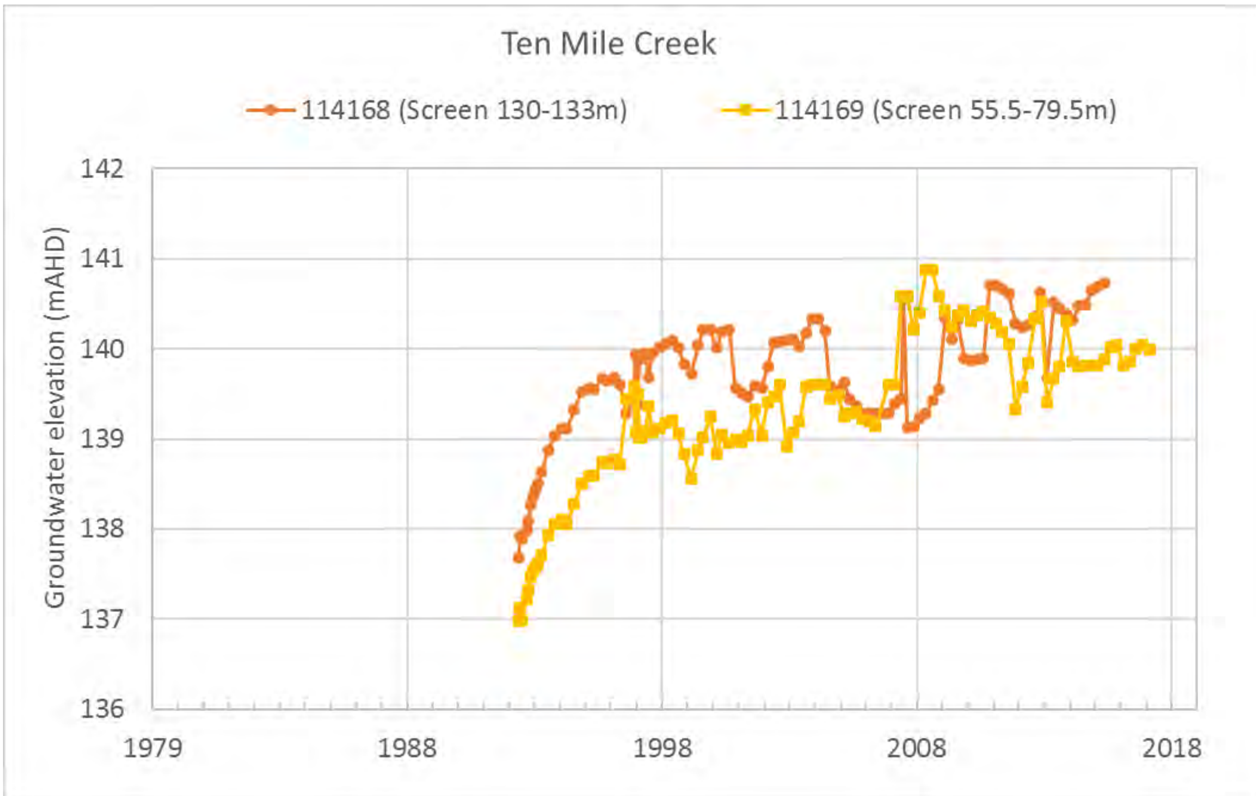


Figure 13.12 : Bores 113705 and 113706 located further from the borefield where the LTA is unconfined

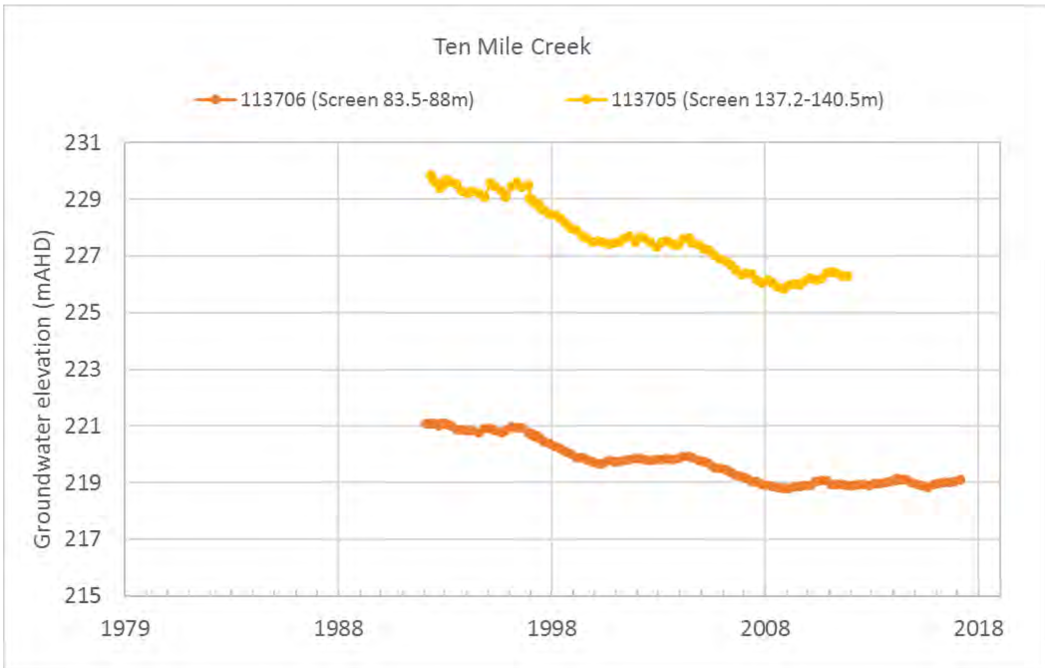
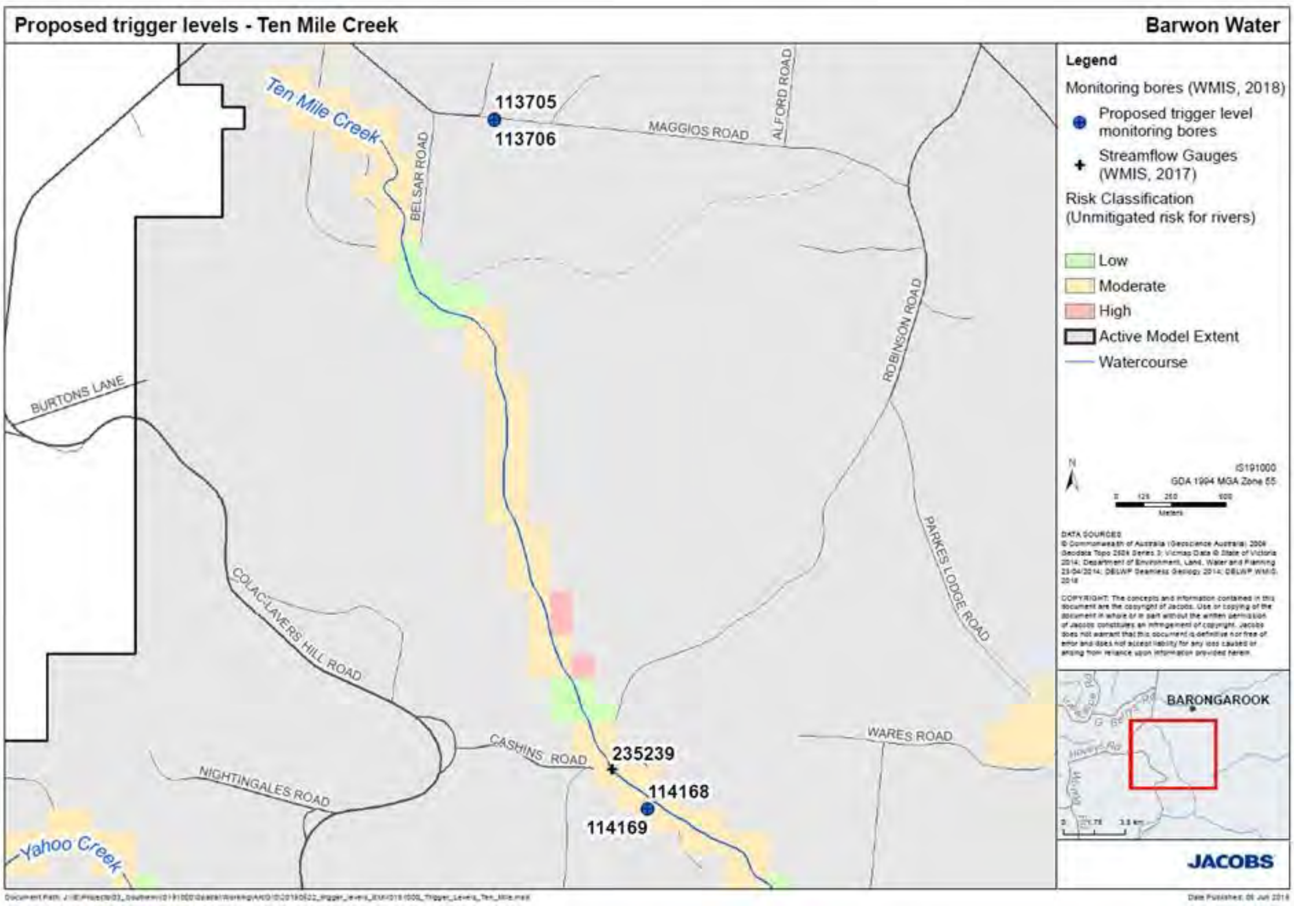


Figure 13.13: Location of proposed trigger bore for Ten Mile Creek



13.2.6 Vegetation and PASS monitoring sites

The majority of groundwater dependent vegetation and PASS are located where alluvial aquifers are present. Monitoring has confirmed that alluvial aquifers are more influenced by climate driven processes compared to groundwater pumping from Barwon Downs. Given the influence of climate on the alluvial aquifer, triggers levels to monitor groundwater level decline in response to pumping are not recommended for vegetation and PASS monitoring sites where alluvial aquifers are present.

Trigger levels are recommended for those sites where there is a direct connection to the regional aquifer, such as vegetation monitoring sites T1 and T2. These sites are located in Reach 2 of Boundary Creek which is at a high risk from groundwater pumping. Boundary Creek was known to be gaining along this reach and groundwater levels have declined significantly so the creek is now losing to the regional groundwater system. The intent of this trigger is to provide an additional source of water to this reach to supplement the groundwater baseflow that would occur without groundwater pumping. The supplementary flow would support aquatic ecology in the creek, groundwater dependent vegetation and PASS along Reach 2.

The trigger is recommended to be the same as the trigger for Boundary Creek where the management response triggered is to provide a supplementary flow. The volume of supplementary flow will be determined as part of future work associated with the remediation of Yeodene Swamp.

13.2.7 Summary

Table 13.5 provides an overview of the recommended trigger levels and more detail is provided in the following sections.

Table 13.5 : Summary of trigger levels

Receptor	Intent of trigger	Trigger	Management action
Regional groundwater levels	• To avoid excessive drawdown in the regional aquifer	• Groundwater observation bore 64229 (G13) to be set at 85.2 mAHD • Groundwater observation bore 64236 (G20) to be set at 98.7 mAHD • Groundwater observation bore 82844 (M28) to be set at 124.1 mAHD • Groundwater observation bore 109131 (Yeo40) to be 142.3 mAHD.	• Reduce pumping rates until the groundwater level has recovered above the trigger value
Boundary Creek	• To indicate when supplementary flows are required to ensure a minimum flow in Boundary Creek	• Groundwater observation bore 109131 (Yeo40) to be 158.5 mAHD which was the groundwater level prior to 1997 (may need to be adjusted pending outcomes of survey of stream bed elevation) AND minimum flow of 0.5 ML/day in Yeodene Swamp	• Provide a supplementary flow to Boundary Creek. The required volume of this flow will be confirmed by future studies focussing on the remediation of the Yeodene Swamp.
Gellibrand River	• To maintain adequate upward gradient to ensure groundwater base flow contribution to the river during summer flow conditions	• If river is gaining in area identified at high risk, groundwater level in the regional and alluvial aquifer remains >0.5m above the streambed elevation bed. • Note that this trigger will require further investigation before it can be fully implemented	• Reduce pumping rates until the groundwater level has recovered above the trigger level

Receptor	Intent of trigger	Trigger	Management action
Ten Mile Creek	• To maintain upward gradient into the creek to ensure adequate groundwater base flow contribution to the river during summer flow conditions	• Trigger level in bore 113705 to be 0.5m above the average stream bed elevation • Trigger level in bore 113706 to be 0.5m above the average stream bed elevation	• Reduce pumping rates until the groundwater level has recovered above the trigger level
Barwon River East Branch	• To enable upward gradient into the river so as to maintain adequate groundwater base flow contribution to the river during summer flow conditions	• If river is gaining in area identified at high risk, groundwater level in the regional aquifer remains >0.5m above the streambed elevation bed. • Note that this trigger will require further investigation before it can be fully implemented	• Reduce pumping rates until the groundwater level has recovered above the trigger level
Vegetation	• To ensure water is available for the groundwater dependent vegetation in Reach 2 of Boundary Creek (T1 and T2)	See trigger for Boundary Creek	
PASS	• No recommended triggers for pumping as PASS monitoring sites are not directly connected to the regional aquifer.		

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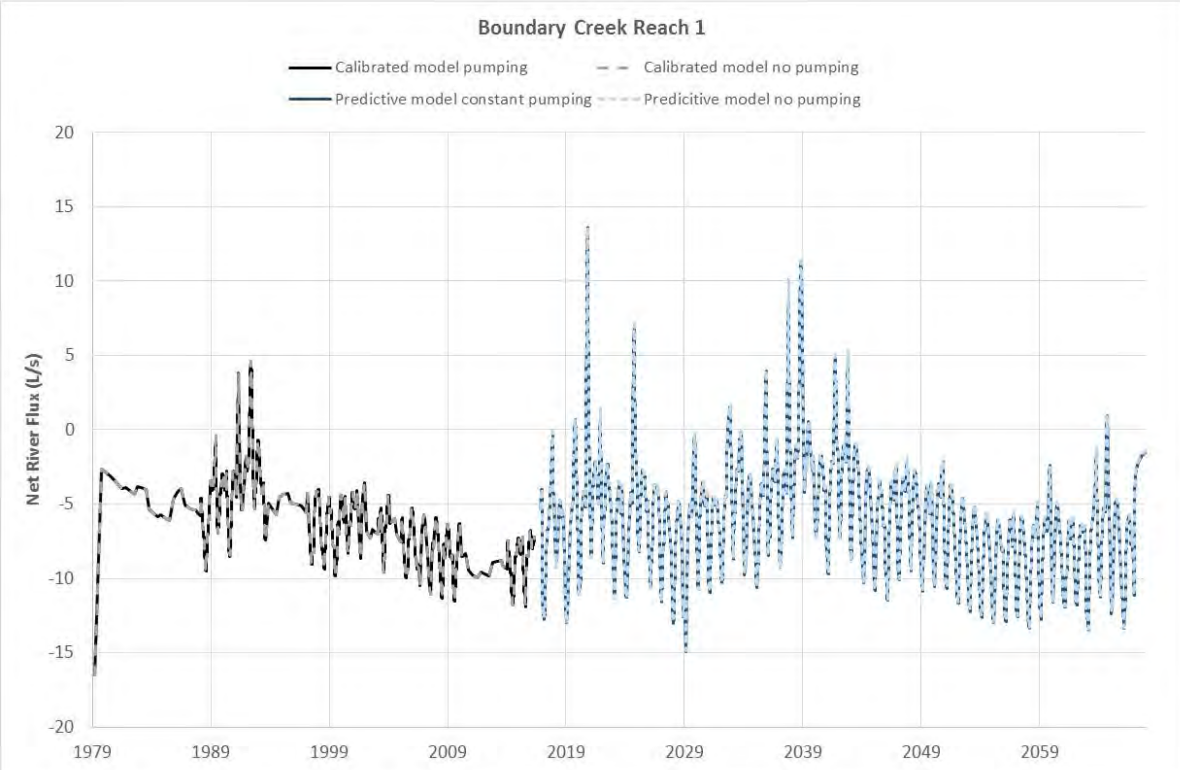
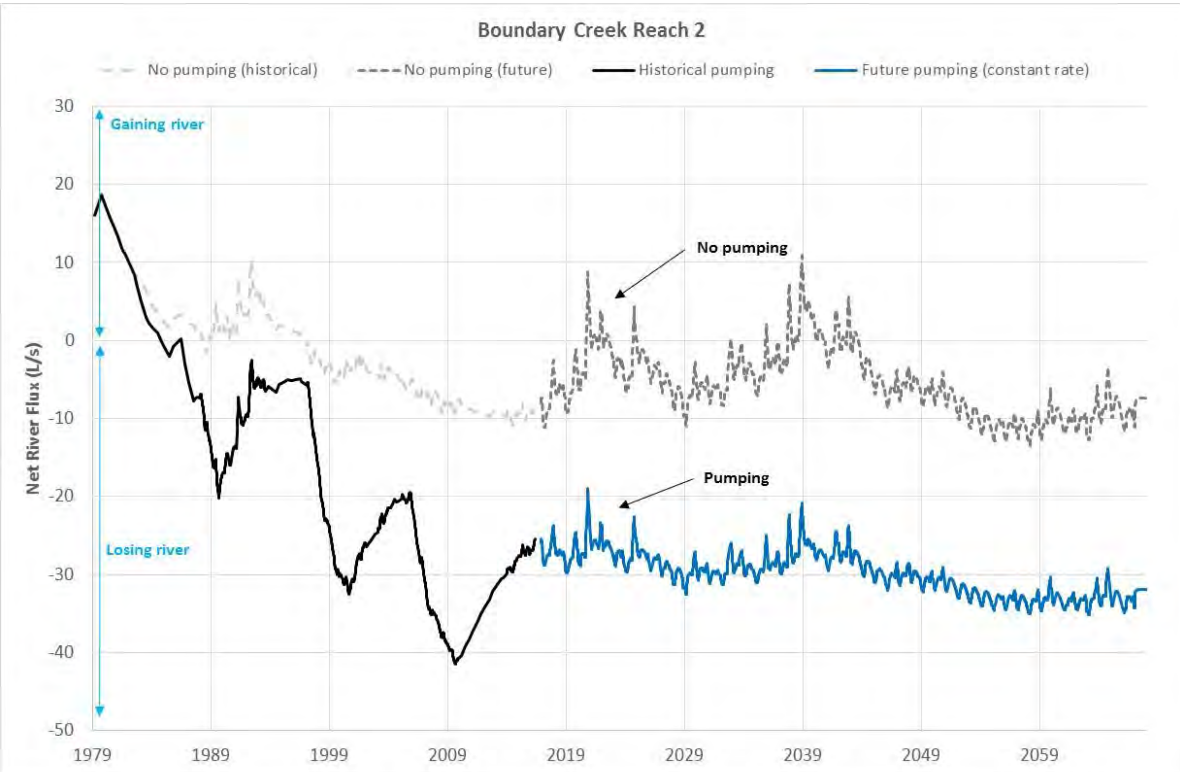
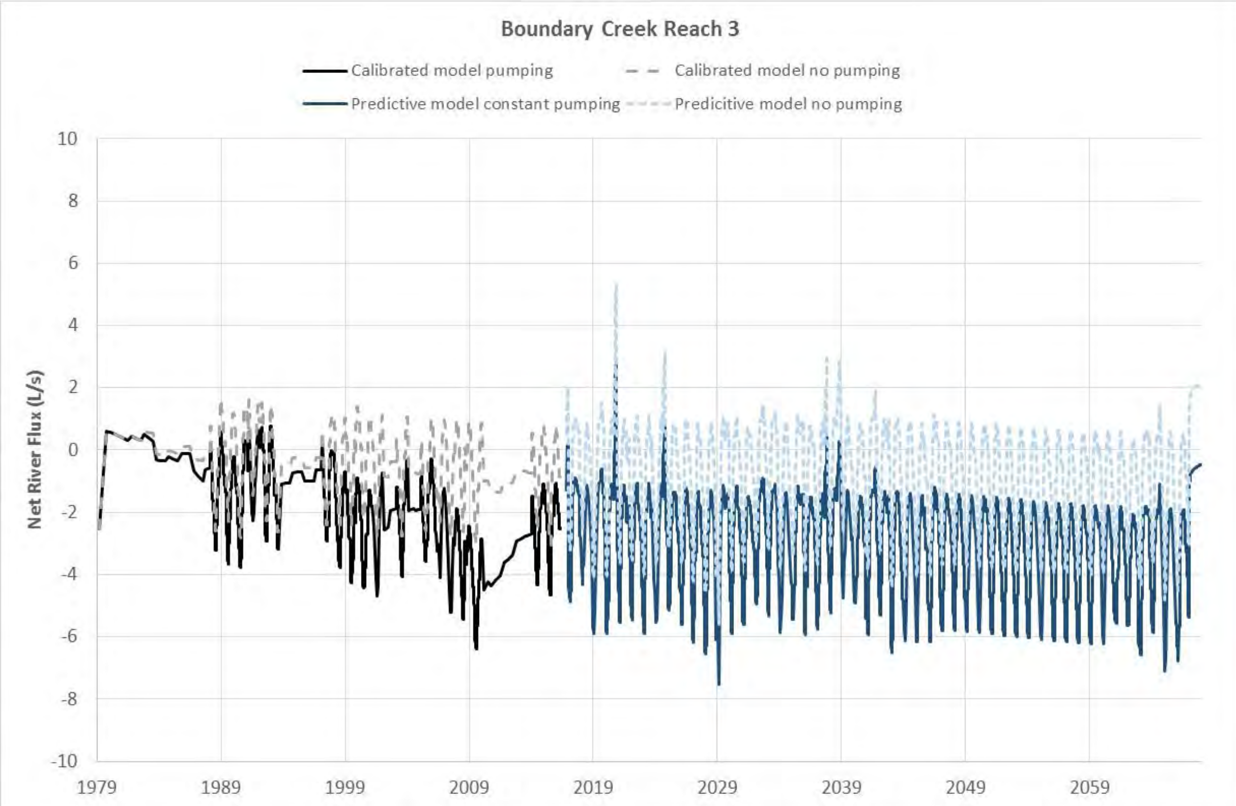
Appendix A. River flux

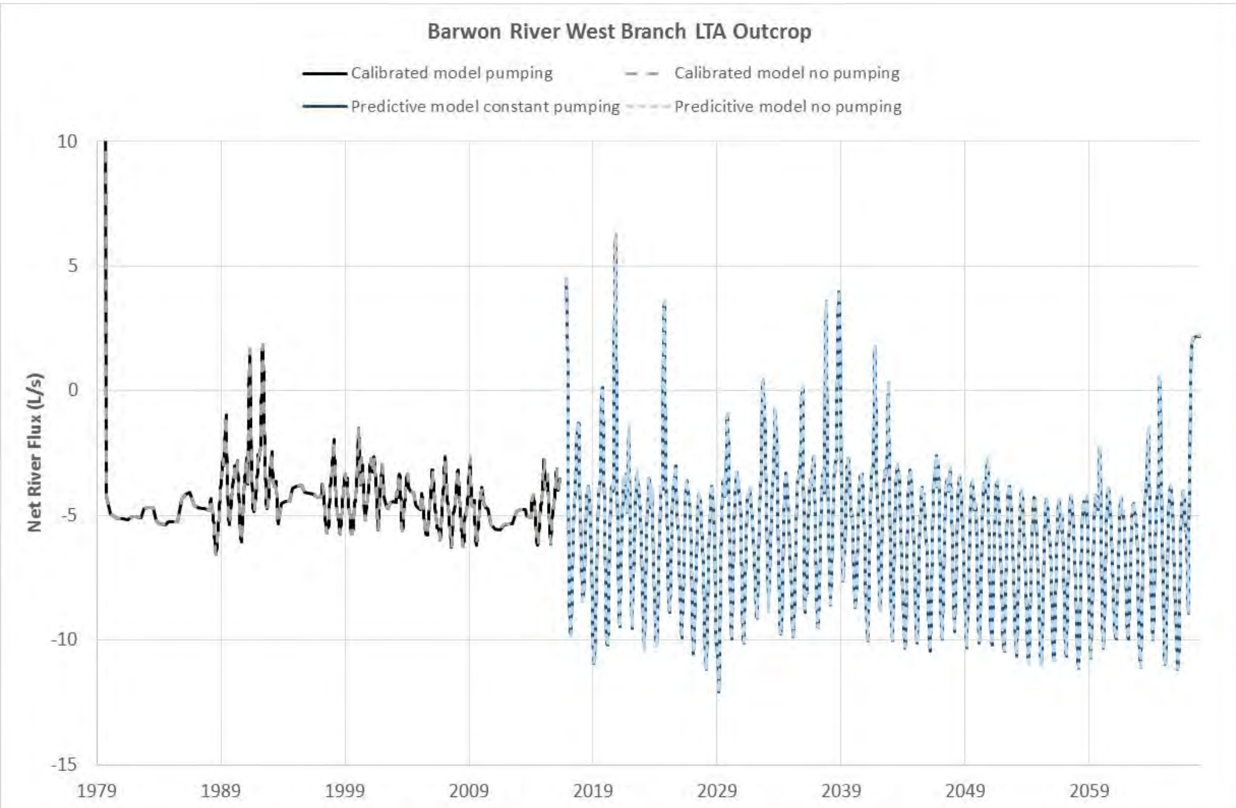
A.1 Boundary Creek

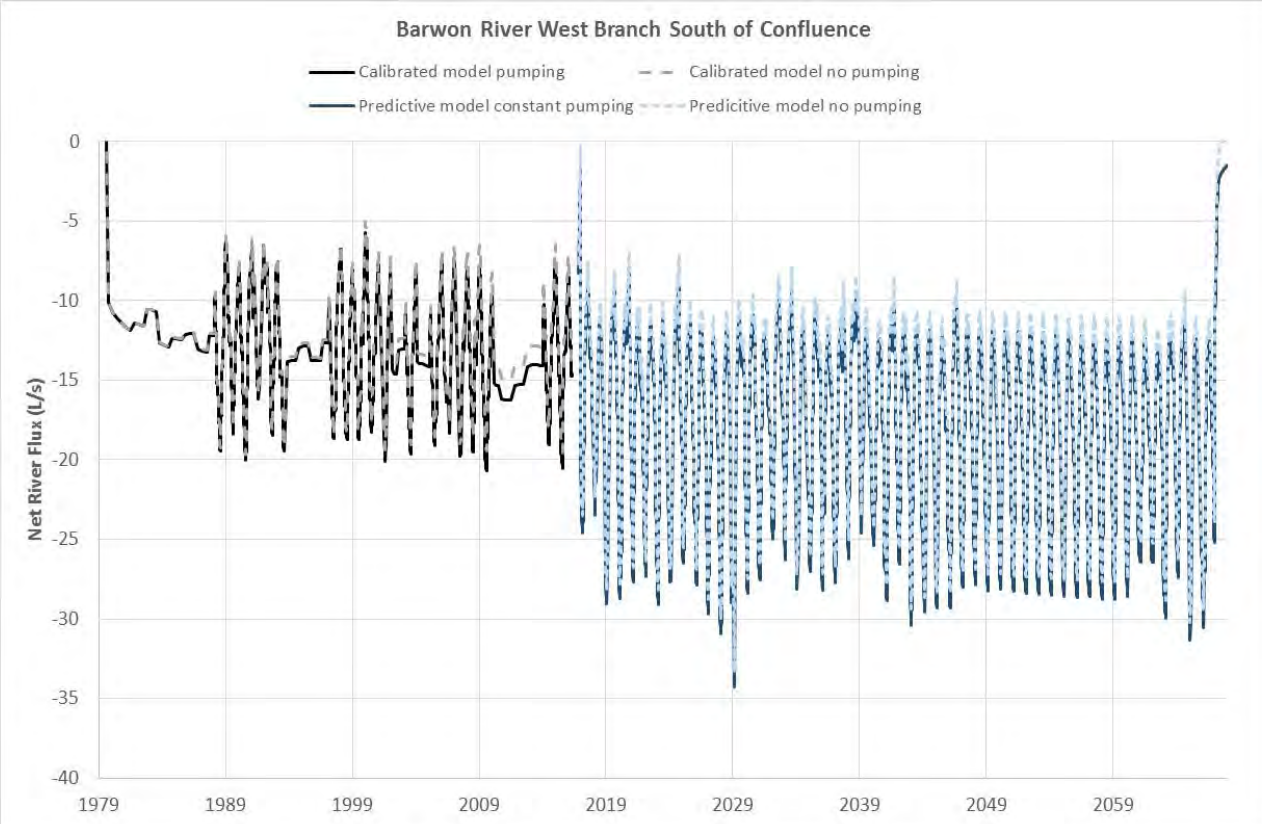


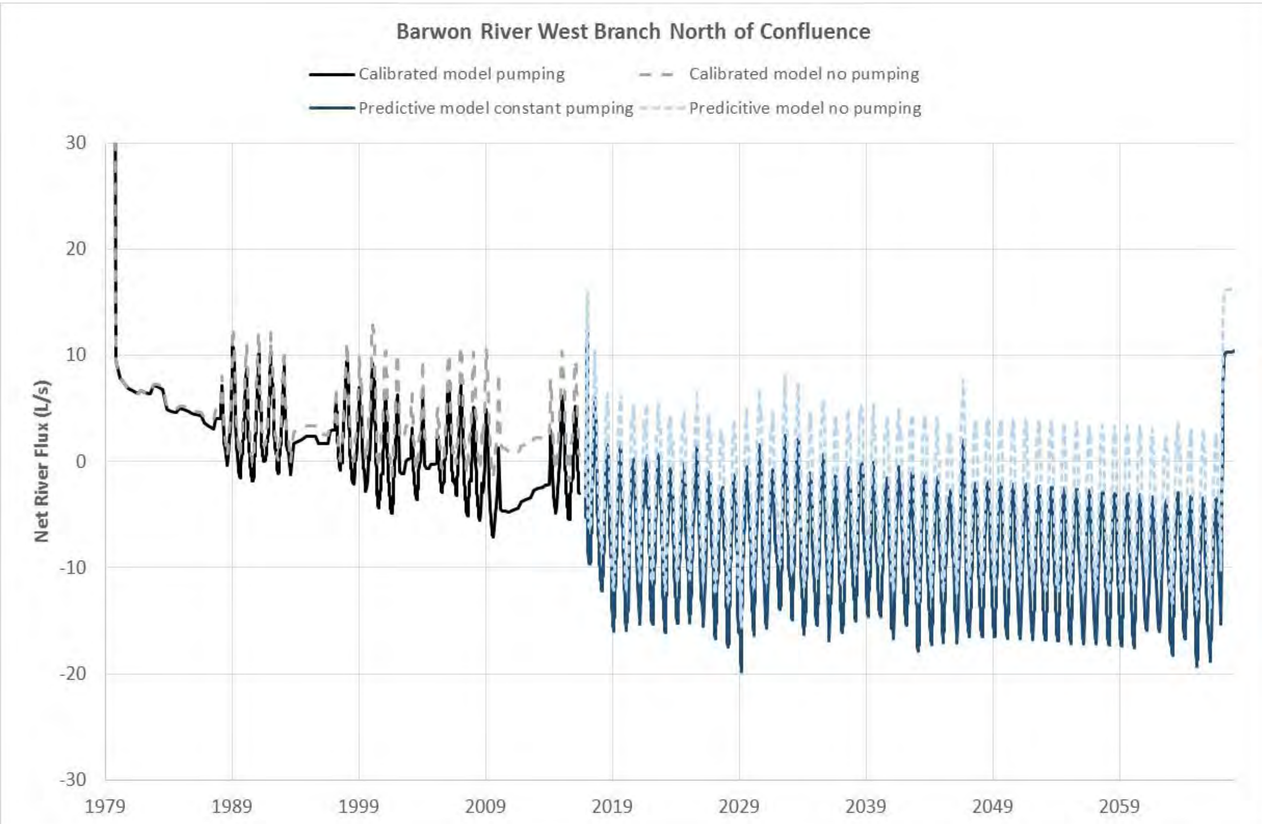


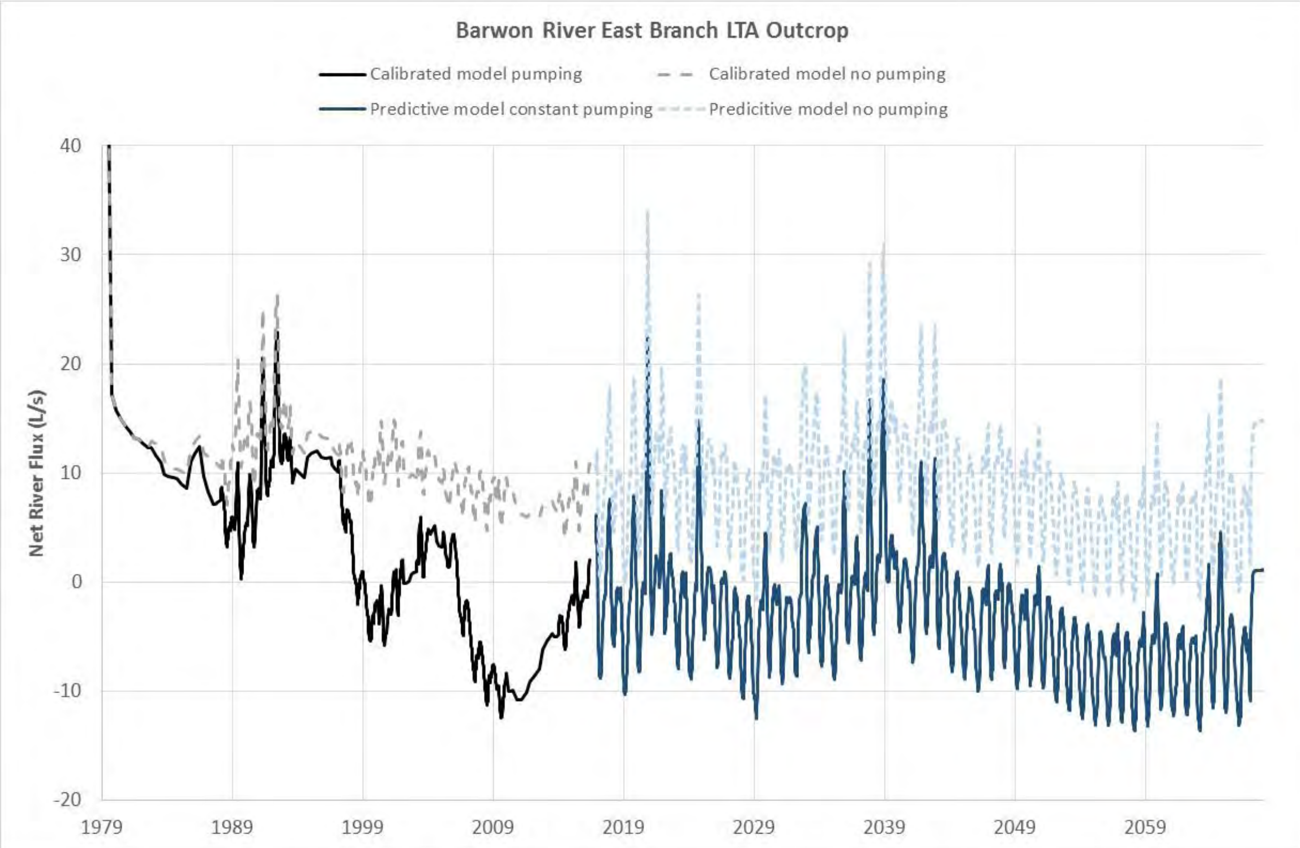


A.2 Barwon River

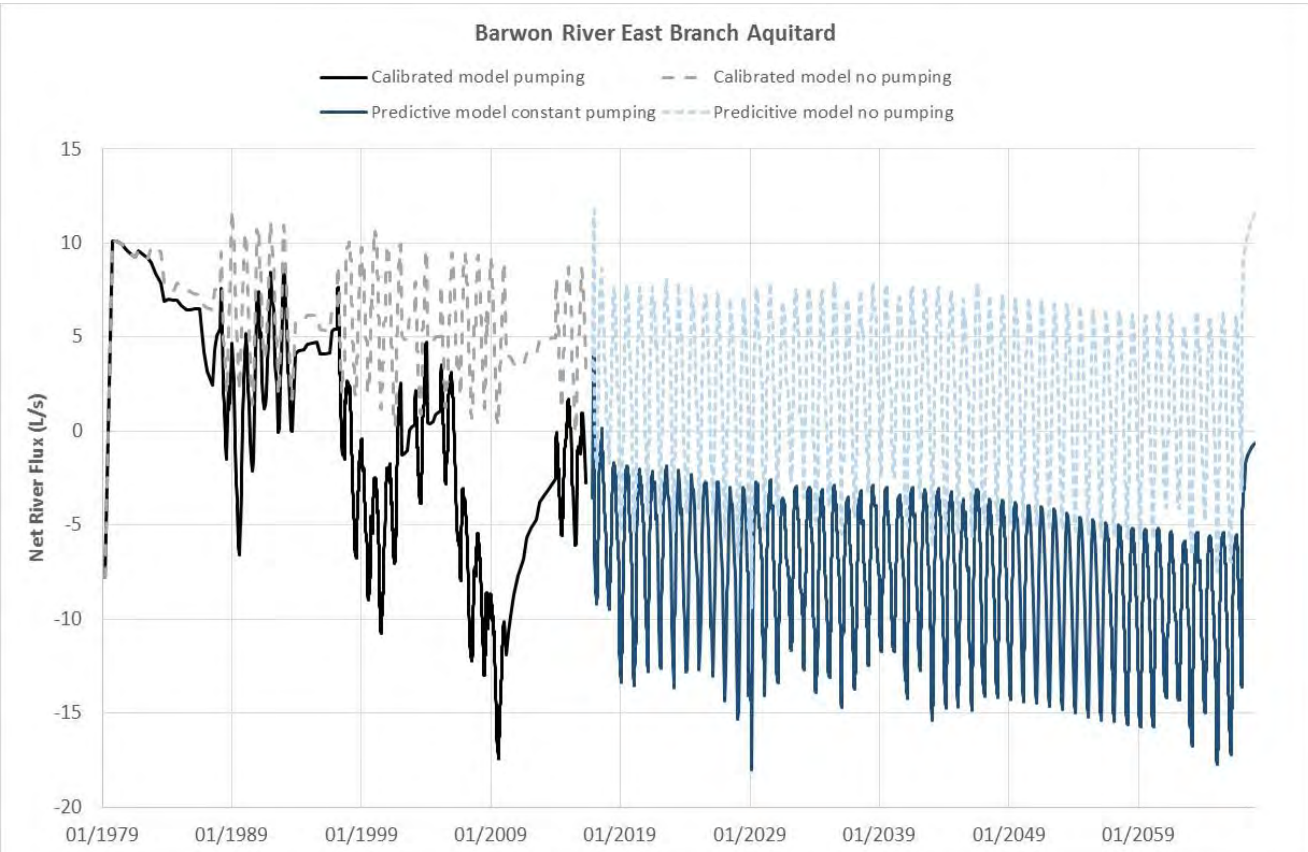



Barwon River West Branch South of Confluence
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
0
-5
-10
-15
-20
-25
-30
-35
-40
1979
1989
1999
2009
2019
2029
2039
2049
2059


Barwon River West Branch North of Confluence
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
30
20
10
0
-10
-20
-30
1979
1989
1999
2009
2019
2029
2039
2049
2059

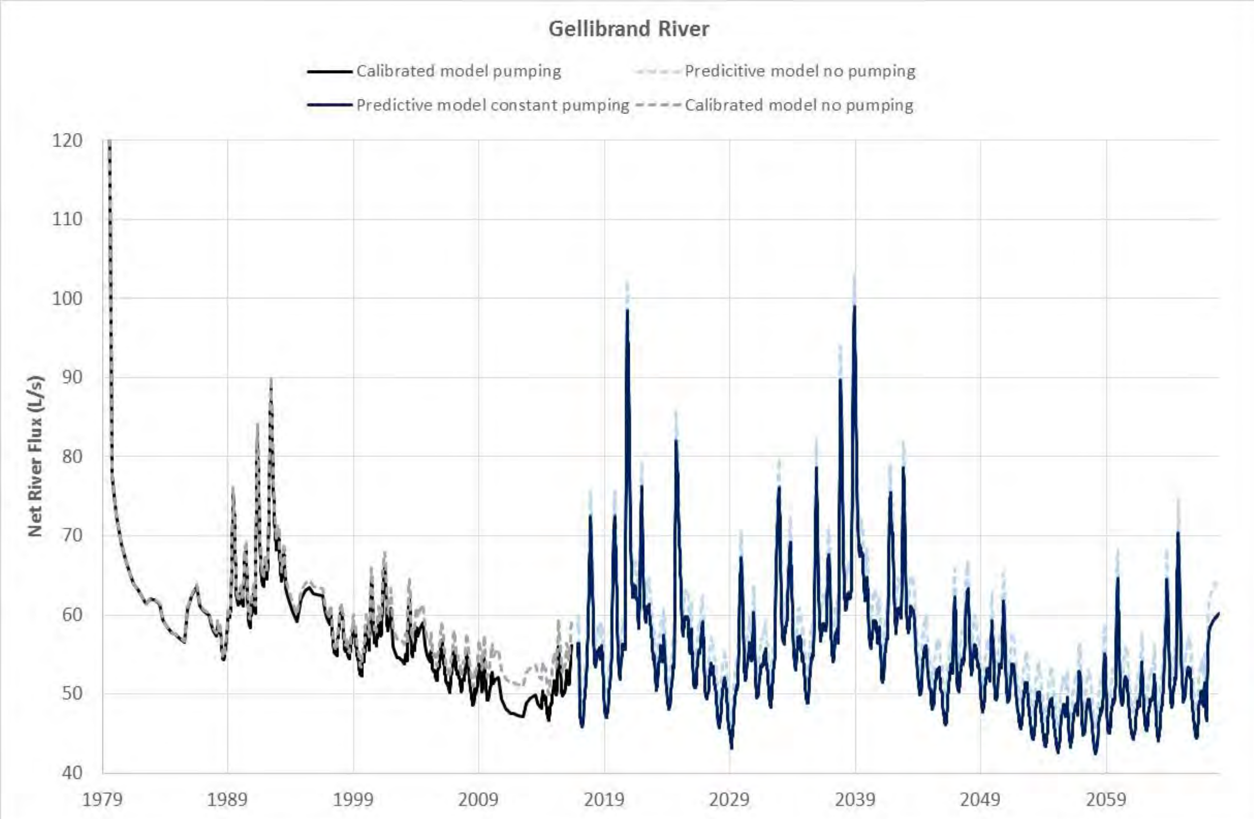


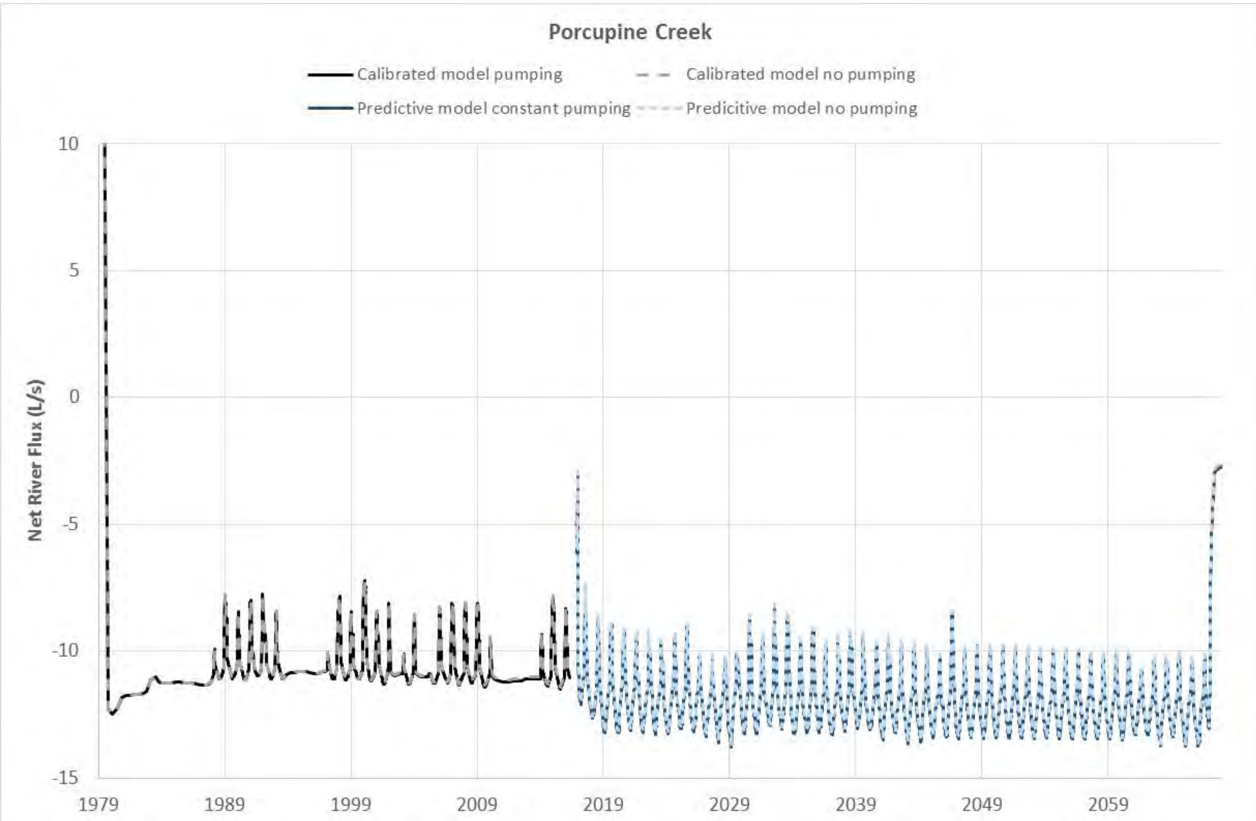
Barwon River East Branch LTA Outcrop
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
40
30
20
10
0
-10
-20
1979
1989
1999
2009
2019
2029
2039
2049
2059

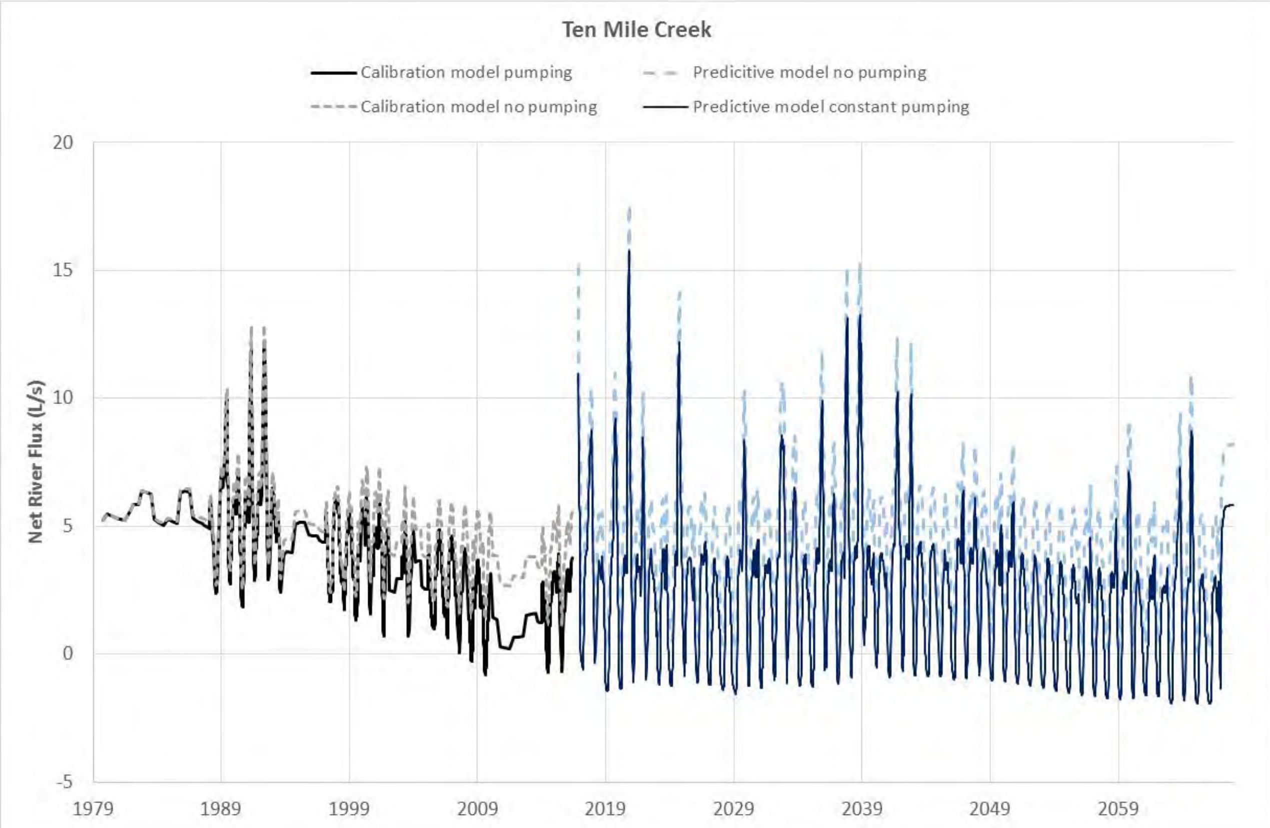


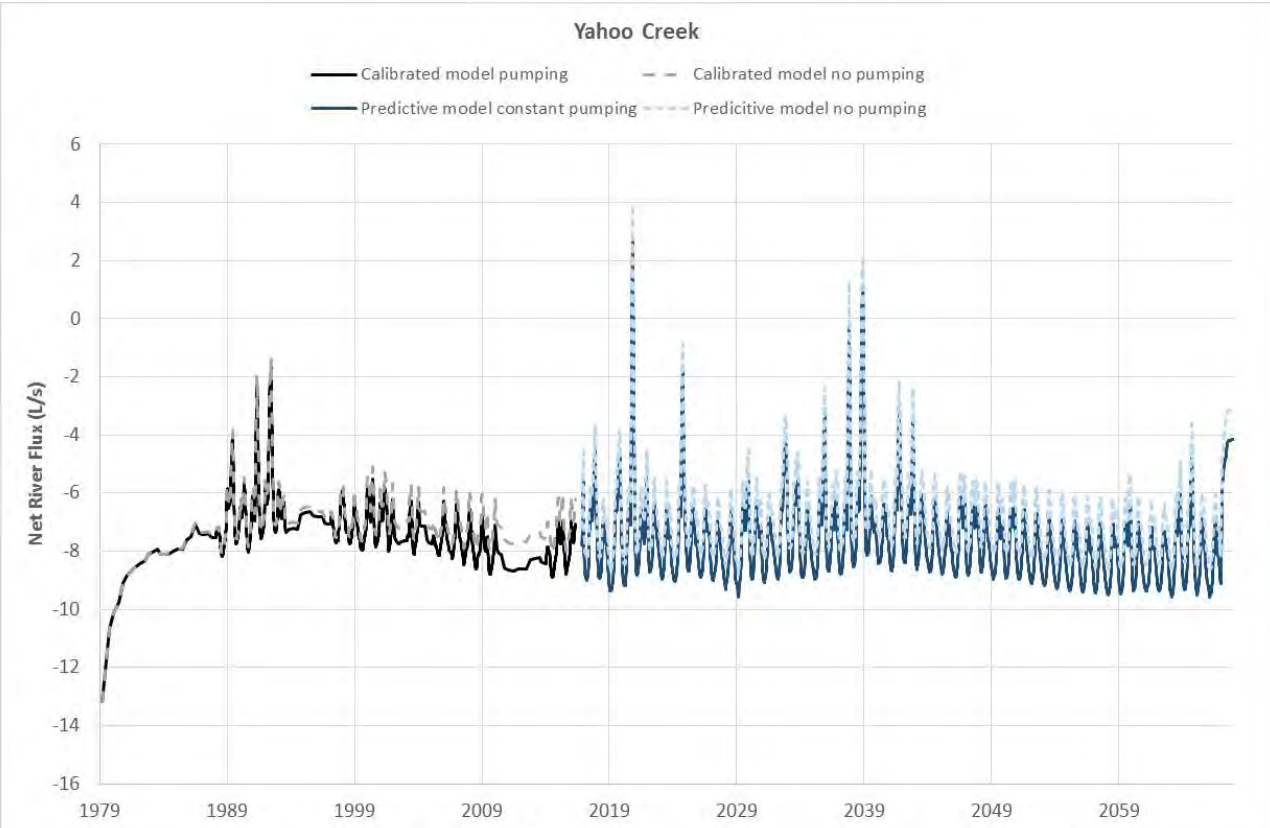
Barwon River East Branch Aquitard
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
15
10
5
0
-5
-10
-15
-20
01/1979
01/1989
01/1999
01/2009
01/2019
01/2029
01/2039
01/2049
01/2059

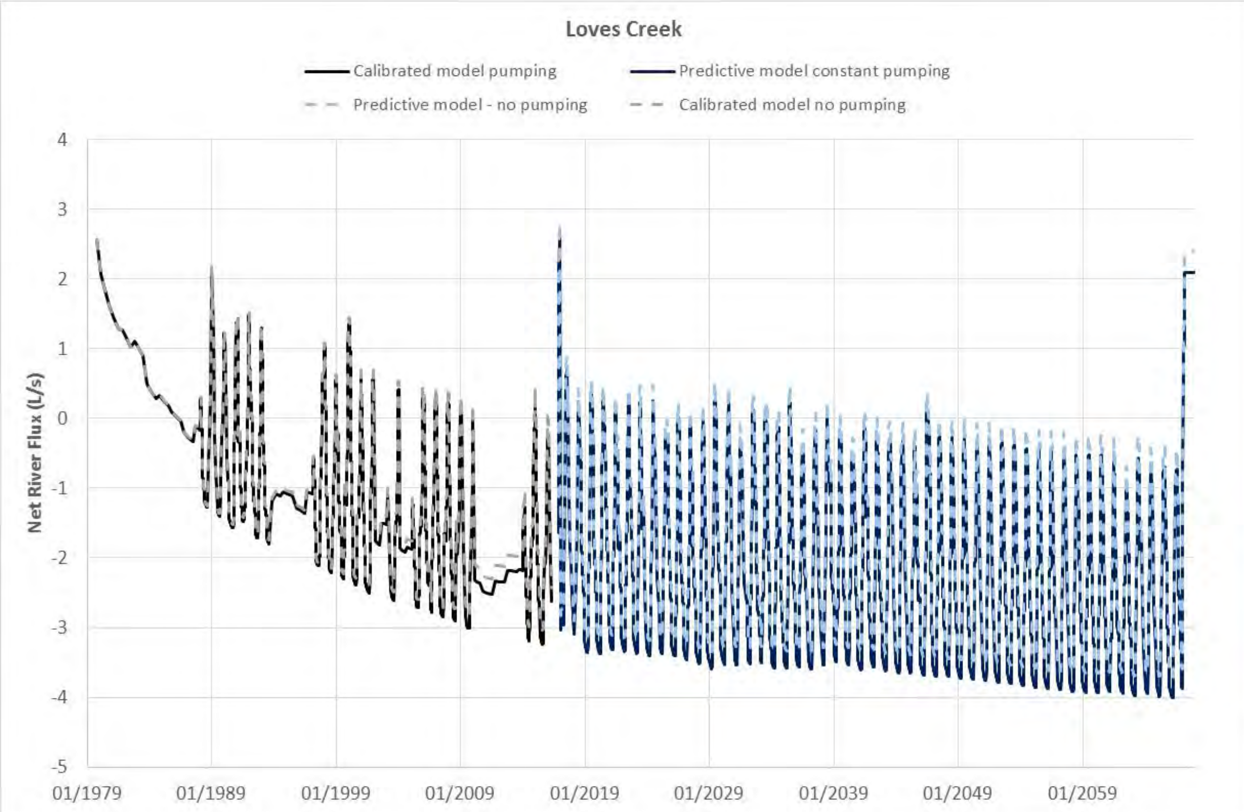
A.3 Gellibrand River and tributaries



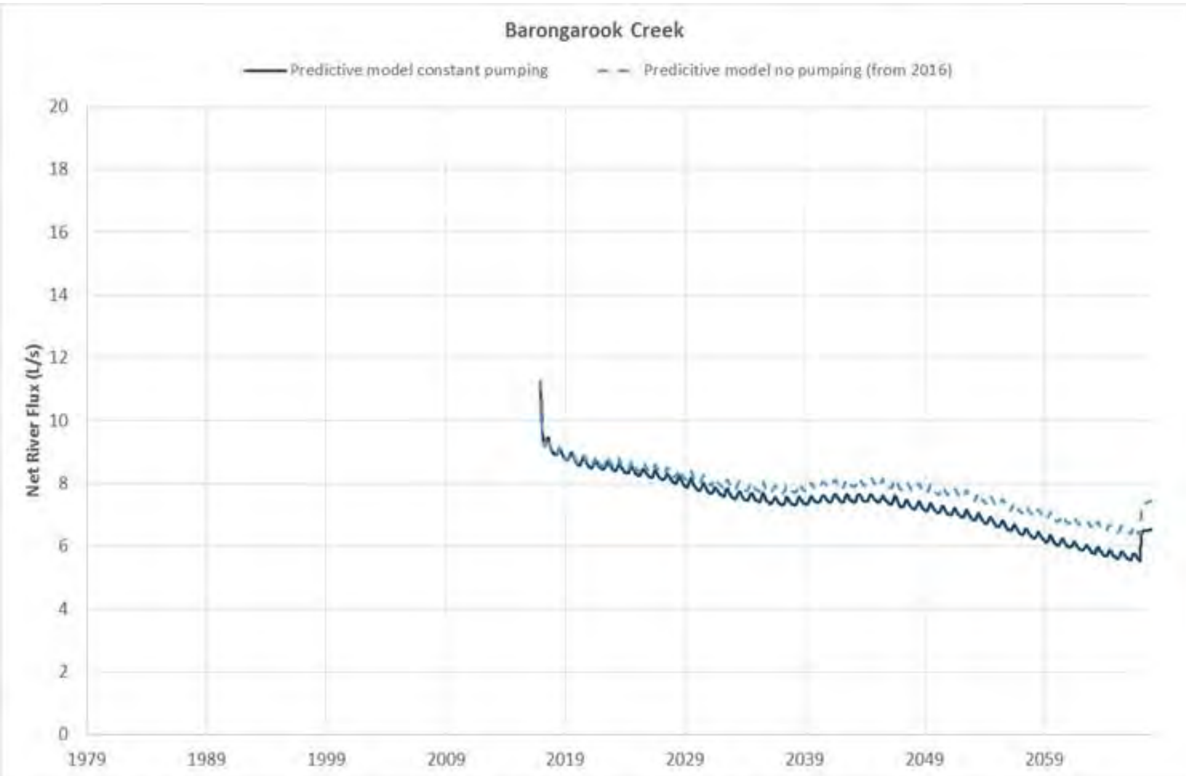



Ten Mile Creek
Calibration model pumping
Calibration model no pumping
Predicitive model no pumping
Predicitive model constant pumping
Net River Flux (L/s)
20
15
10
5
0
-5
1979
1989
1999
2009
2019
2029
2039
2049
2059


Yahoo Creek
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
1979
1989
1999
2009
2019
2029
2039
2049
2059



A.4 Barongarook Creek



Appendix B. Risk classifications for rivers

Table 14-1 Impacts from pumping in the Barwon River Catchment compared to available streamflow data

River Reach	Low Flow (Q90)	Likelihood of connection to regional groundwater	Consequence									Maximum unmitigated risk
			Max impact historic			Max impact constant pumping			Max impact intermittent pumping			
			ML/day	% low flow	Consequence	ML/day	% low flow	Consequ-ence	ML/day	% low flow	Consequence	
Barwon River (total)	**4.9**[1]		**4.1**			**3.2**			**3.4**			
West Branch aquifer		High	<0.01	<1%	Low	<0.01	<1%	Low	<0.01	<1%	Low	Medium
West Branch aquitard		Moderate	0.1	2%	Med	0.2	4%	Med	0.2	4%	Med	Medium
Downstream confluence		Moderate	0.7	14%	High	0.6	12%	High	0.5	12%	High	High
East Branch aquifer		High	1.6	33%	High	1.2	24%	High	1.3	27%	High	High
East Branch aquitard		Moderate	1.7	35%	High	1.1	22%	High	1.3	27%	High	High
Boundary Creek	**1.0**[2]		**3.1**			**2.9**			**2.6**			
Reach 1		Moderate	<0.01	<1%	Low	<0.1	<1%	Low	<0.1	<1%	Low	Low
Reach 2		High	2.9	>100%	High	2.7	>100%	High	2.3	>100%	High	High
Reach 3		Moderate	0.3	30%	High	0.2	20%	High	0.2	20%	High	Medium
Dividing Creek	**NA**	**Low**	**0.4**	**NA**	**NA**	**0.3**	**NA**	**NA**	**0.3**	**NA**	**NA**	**NA**

1.Based on Ricketts March gauge

2.Based on Yeodene gauge

Table 14-2 Impacts from pumping in the Barwon River Catchment compared to predicted drawdown in the unconfined Lower Tertiary Aquifer

River Reach	Likelihood of connection to regional aquifer	Consequence						Overall unmitigated risk
		Max impact historic		Max impact constant pumping		Max impact intermittent pumping		
		Drawdown	Consequence	Drawdown	Consequence	Drawdown	Consequence	
Barwon River (total)								
West Branch aquifer	High	<0.1 m	Low	<0.1 m	Low	<0.1 m	Low	Medium
West Branch aquitard	Moderate	NA		NA		NA		
Downstream confluence	Moderate	NA		NA		NA		
East Branch aquifer	High	>2 m	High	>2 m	High	>2 m	High	High
East Branch aquitard	Moderate	NA		NA		NA		
Boundary Creek								
Reach 1	Moderate	NA		NA		NA		
Reach 2	High	>2m	High	>2m	High	>2m	High	High
Reach 3	Moderate	NA		NA		NA		
Dividing Creek	**Low**	>2m	High	>2m	High	>2m	High	Medium

Table 14-3 Impacts from pumping in the Gellibrand River Catchment

River Reach	Low Flow (Q90) (ML/day)	Likelihood of connection	Consequence									Overall risk
			Max impact historic			Max impact constant pumping			Max impact intermittent pumping			
			ML/day	% low flow	Consequ-ence	ML/day	% low flow	Consequ-ence	ML/day	% low flow	Consequ-ence	
Gellibrand River	12.24	High	0.3	2%	Moderate	0.4	3%	Moderate	0.3	3%	Moderate	High risk
Porcupine Creek	0.35	Moderate	0.008	2%	Moderate	0.02	6%	Moderate	0.02	5%	Moderate	Medium
Ten Mile Creek	1.33	Moderate – High	0.2	15%	High	0.2	15%	High	0.2	13%	High	High risk
Yahoo Creek	1.02	Moderate – High	0.08	8%	Moderate	0.1	10%	Moderate	0.1	11%	Moderate	High risk
Loves Creek	1.67	Moderate	0.02	1%	Moderate	0.03	2%	Moderate	0.02	1%	Moderate	Medium

Table 14-4 Impacts from pumping in the Gellibrand River Catchment compared to predicted drawdown in the unconfined Lower Tertiary Aquifer

River Reach connected to unconfined LTA	Likelihood of connection to regional aquifer	Consequence						Overall risk
		Max impact historic		Max impact constant pumping		Max impact intermittent pumping		
		Drawdown	Consequence	Drawdown	Consequence	Drawdown	Consequence	
Gellibrand River	High	0.1 – 2 m	Moderate	0.1 – 2 m	Moderate	0.1 – 2 m	Moderate	High
Porcupine Creek	Low	<0.1	Low	<0.1	Low	<0.1	Low	Low
Ten Mile Creek	High	0.1 – 2 m	Moderate	0.1 – 2 m	Moderate	<0.1	Moderate	High
Yahoo Creek	High	<0.1	Low	<0.1	Low	<0.1	Low	Medium
Loves Creek	Low	<0.1	Low	<0.1	Low	<0.1	Low	Low

Appendix C. Predicted groundwater levels at vegetation monitoring sites

Table C.1 : Risk to vegetation monitoring locations

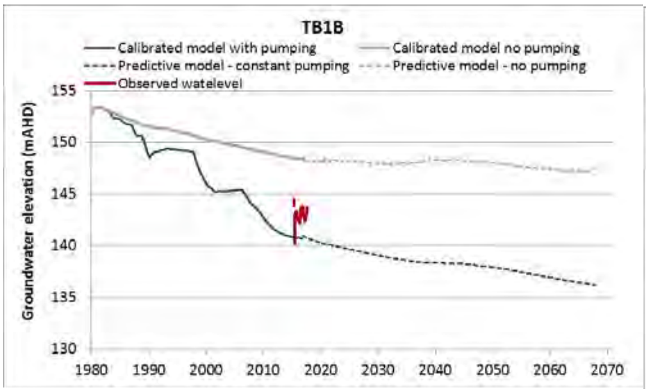
Vegetation monitoring site	Impact/ Reference site	Local Hydrogeology	Vegetation dependent on regional aquifer	Likelihood of connection to regional aquifer	Consequence (drawdown predicted in regional aquitard/aquifer)			Unmitigated Potential Risk	Mitigated potential risk (presence of alluvial aquifer)
					HISTORICAL	PREDICTED CONSTANT PUMPING	PREDICTED INTERMITTENT PUMPING		
T1/TB1c	Impact	Alluvial / aquitard	No	Low	29.3	16.6	21.8	**High**	**Medium**
T2	Impact	Alluvial / aquifer	Yes	High	16.1	10.2	11.6	**High**	**High**
T3	Impact	Perched / aquifer	No	Low	0.6	1.6	0.9	**Low**	**Low**
T4	Impact	Perched / aquifer	No	Low	16.4	12.6	11.8	**Medium**	**Low**
T5	Reference	Alluvial / aquifer	Yes	High	0	0	0	**Medium**	**Low**
T6	Reference	Alluvial / aquifer	Yes	High	0	0.1	0.1	**Medium**	**Low**
T7	Reference	Alluvial / aquifer	Yes	High	0	0.1	0.1	**Medium**	**Low**
T8	Impact	Alluvial / aquitard	No	Low	9.4	8.4	7.4	**Medium**	**Low**
T9	Impact	Alluvial / aquitard	No	Low	0.1	0.7	0.4	**Low**	**Low**
T10	Impact	Alluvial / aquitard	No	Low	15.5	11.4	10.9	**Medium**	**Low**
T11	Reference	Alluvial / aquitard	No	Low	0	0.1	0.1	**Low**	**Low**
T12	Reference	Alluvial / aquitard	No	Low	5.0	6.3	4.5	**Medium**	**Low**
T13	Reference	Alluvial / aquitard	No	Low	0.4	1.0	0.6	**Low**	**Low**
T14	Reference	Alluvial / aquitard	No	Low	0.2	0.6	0.6	**Low**	**Low**

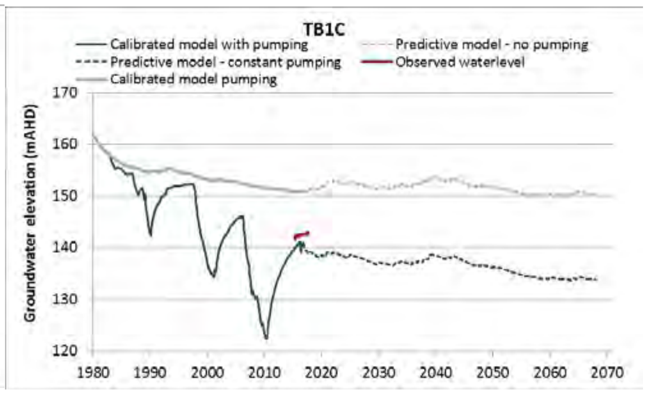
C.1 Impact sites

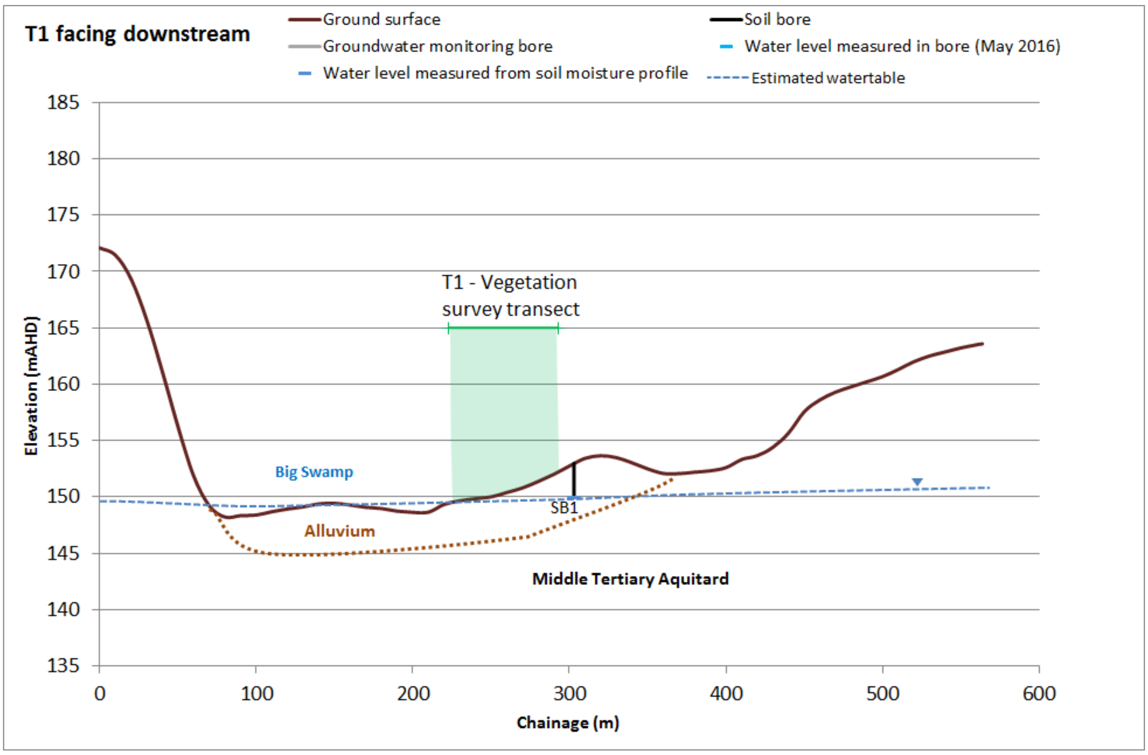
Impact sites

TB1 – Impact site, regional aquifer confined

- A nested group of bores are located just downstream of T1. TB1B monitors shallow aquitard overlying the confined aquifer and TB1C monitors regional confined aquifer.
- Predicted groundwater levels at depth in the aquitard in the calibration model are higher than surface elevation at site (approximately 144 mAHD). This indicates the model is not well calibrated for the shallow aquitard.
- Predicted response shows drawdown in regional aquifer, where groundwater levels are approximately 2 m lower than in the overlying aquifer, highlighting there is potential for downward vertical leakage.
- No evidence that predicted drawdown in regional aquifer has propagated to shallow groundwater.



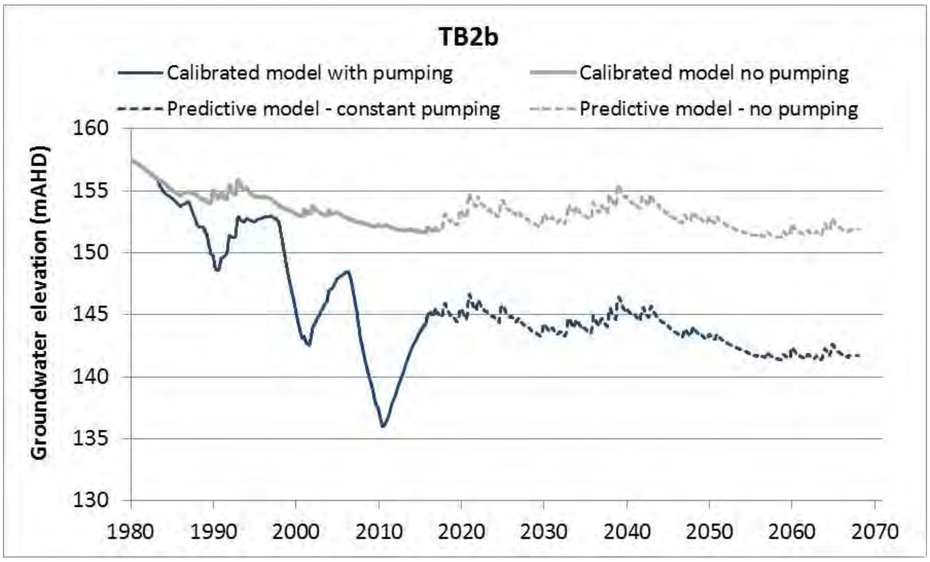


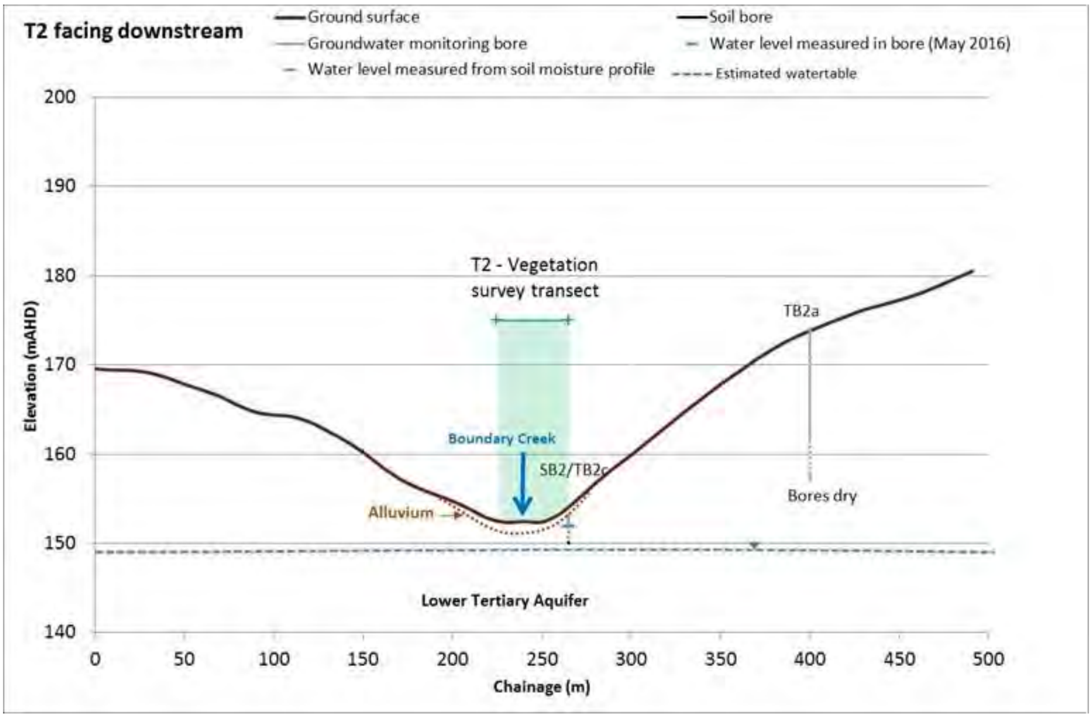


Impact sites

T2 - Impact site, regional aquifer unconfined

- TB2 monitors regional confined aquifer, although bore is currently dry (therefore no observation data)
- Predicted response in regional aquifer shows maximum drawdown in regional aquifer in 2010 was almost 20 m. Waterlevels have recovered since then and drawdown was around 8 m in 2016.
- Predicted drawdown as a result of potential constant pumping is predicted to be 10 m in 2067.
- Site is located near Boundary Creek upstream of Big Swamp, and the supplementary flow is likely to be sustaining the vegetation at this location.

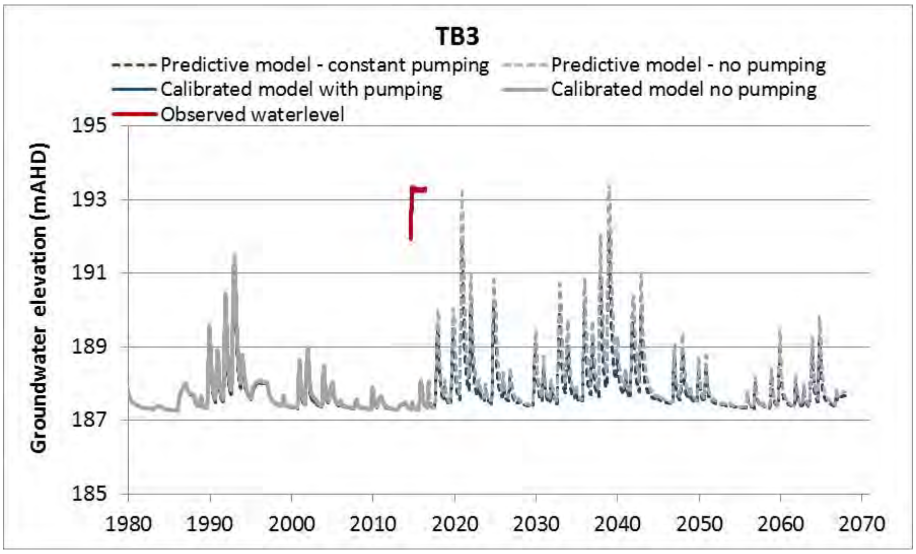


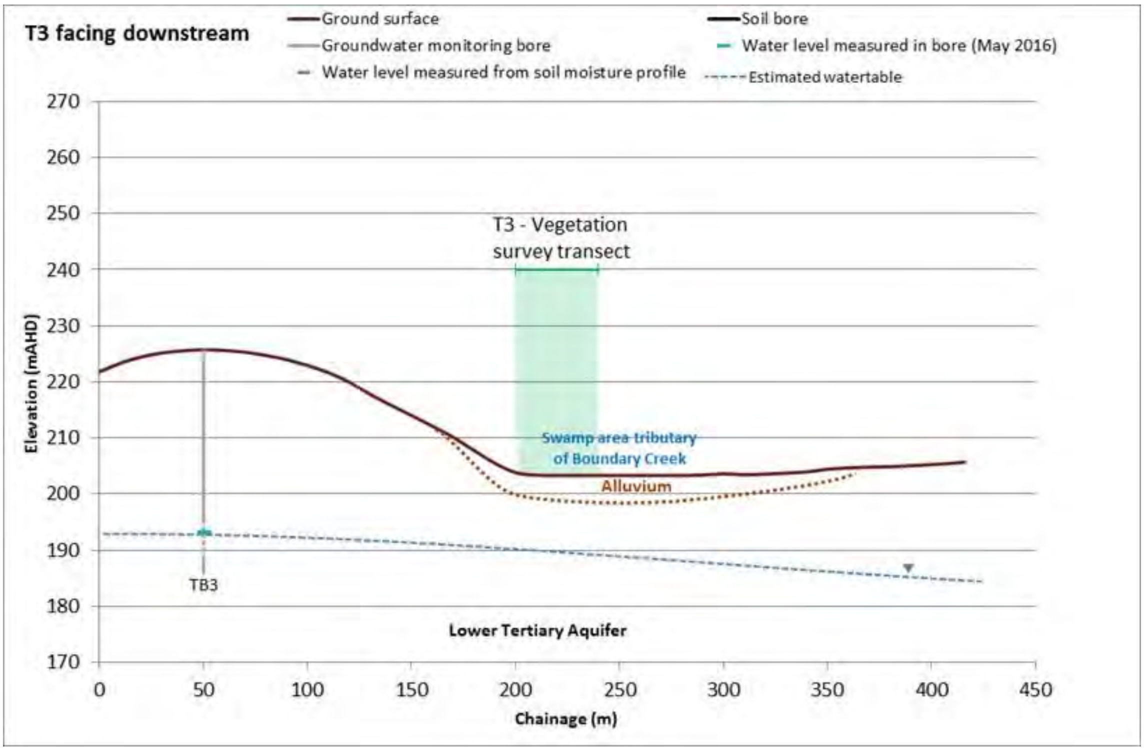


Impact sites

T3 - Impact site, regional aquifer unconfined

- TB3 monitors the regional aquifer. A shallow perched aquifer in the alluvial aquifer overlies the regional aquifer
- Predicted waterlevels are 15 m lower than observed and show more seasonal fluctuations than observed in the bore. Predicted waterlevels are representative of waterlevels at depth in the aquifer.
- Although the model is not well calibrated for the upper part of the aquifer, no significant drawdown predicted at this location.

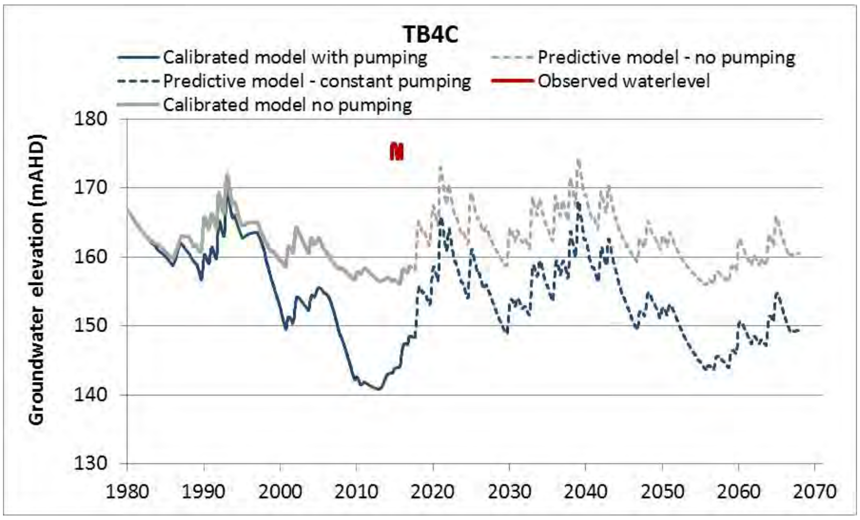


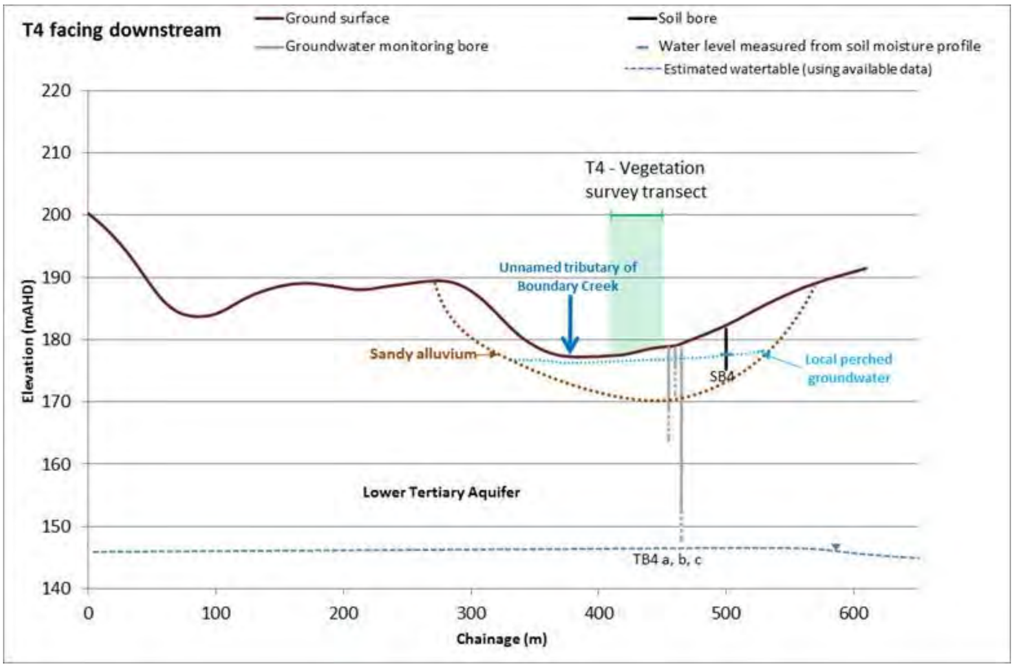


Impact sites

T4 - Impact site, regional aquifer unconfined

- T4 site is an example of a perched alluvial aquifer above the regional aquifer.
  - TB4b monitors the shallow sandy alluvial perched aquifer
  - TB4a and TB4c monitors the Lower Tertiary Aquifer at different depths, which are both dry.
- The waterlevel in the regional aquifer is 30 m below the perched shallow alluvial layer.
- Vegetation is dependent on perched alluvial aquifer.
- Predicted impact in regional aquifer from is 20-25m from historical pumping and 10-15 from potential future pumping. Historical drawdown has not impacted perched alluvial aquifer and consequently future drawdown is not predicted impact alluvial aquifer.

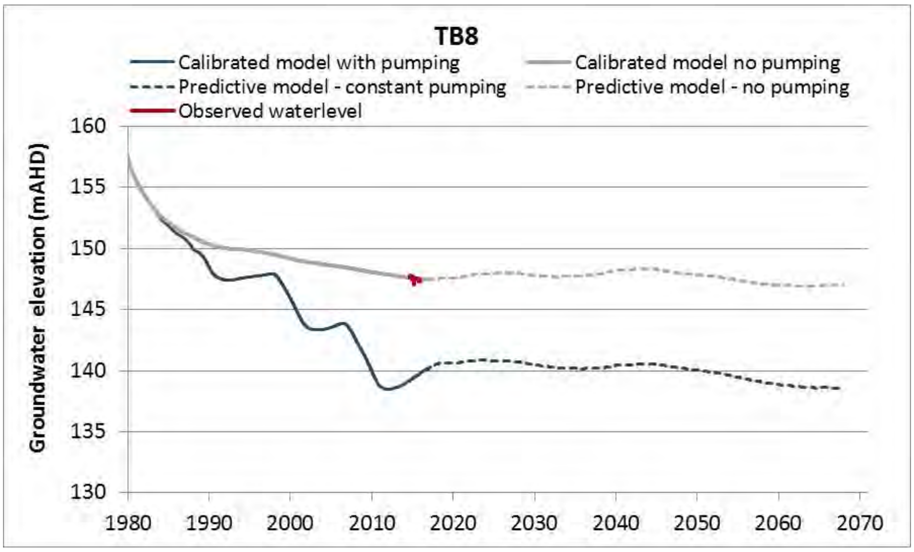


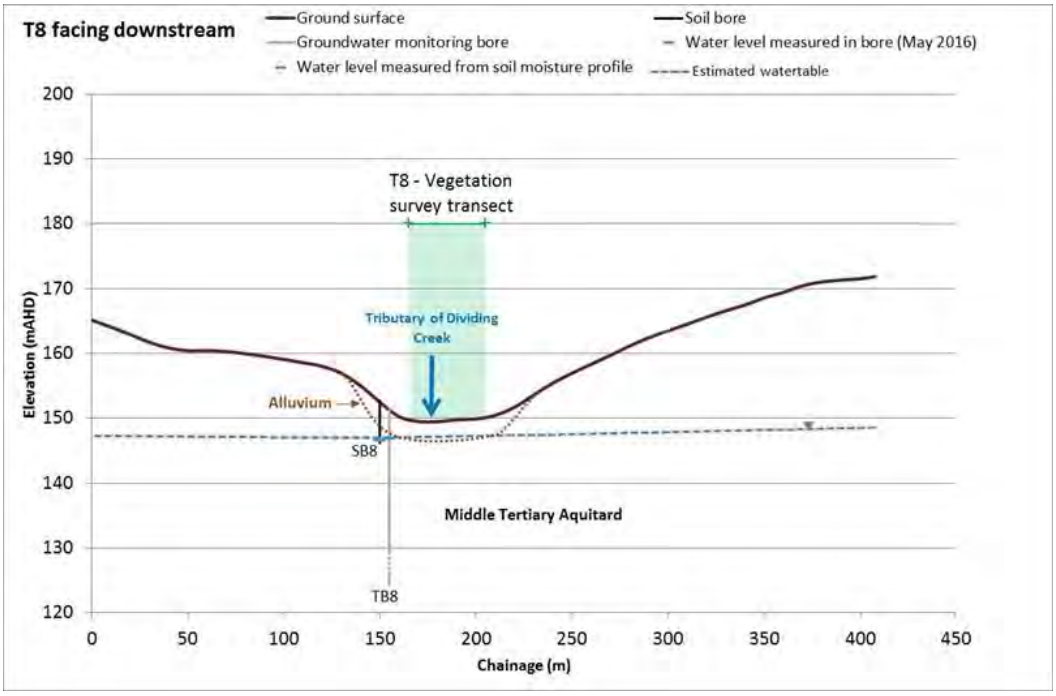


Impact sites

T8 - Impact site, regional aquifer confined

- TB8 monitors the top 20 m of the aquitard.
- Predicted waterlevel at depth in the aquitard is 10 m lower than observed.
- Drawdown is predicted to have occurred at depth in the aquitard as a result of historical operation of the borefield, however no drawdown has been observed in the top of the aquitard. Predicted waterlevel in 1980 is also approximately 5 m above the surface elevation, which the model was over-predicting the waterlevel in this location and if drawdown has occurred, it has not propagated to the top of the aquitard.

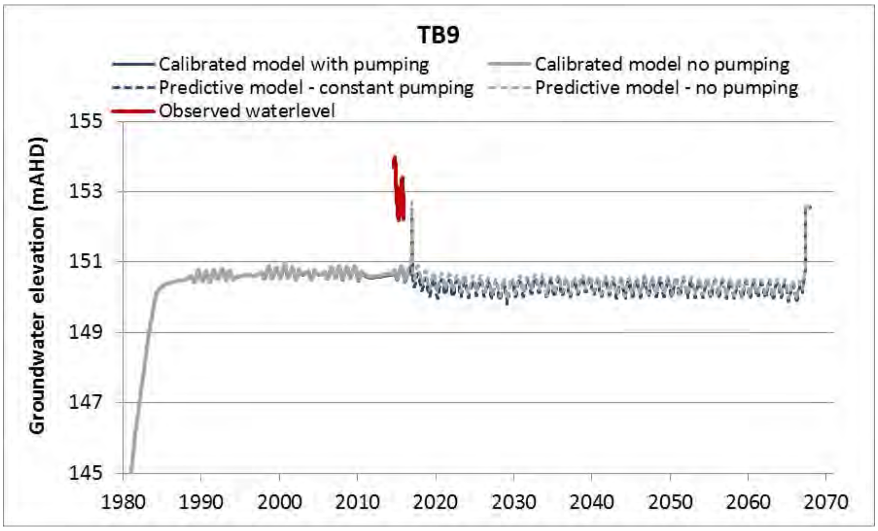


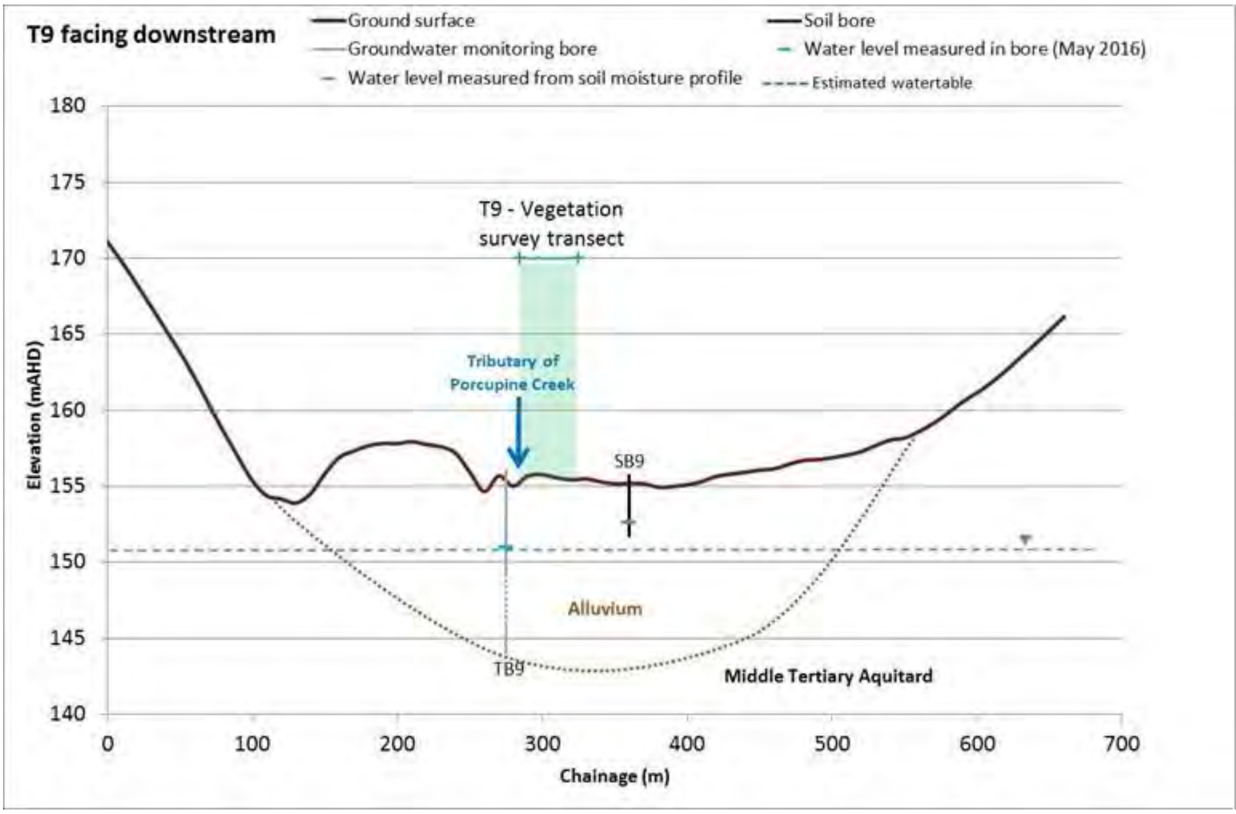


Impact sites

T9 impact site – regional aquifer confined

- TB9 monitors the alluvium overlying the aquitard.
- Predicted groundwater levels are slightly lower than observed and seasonal fluctuation not replicated in the model.
- Minor drawdown predicted in the aquitard as a result of borefield operation.

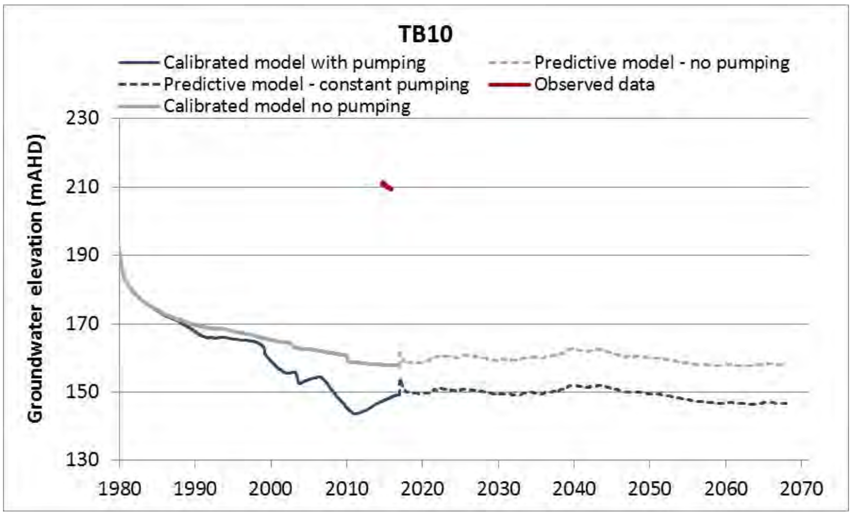


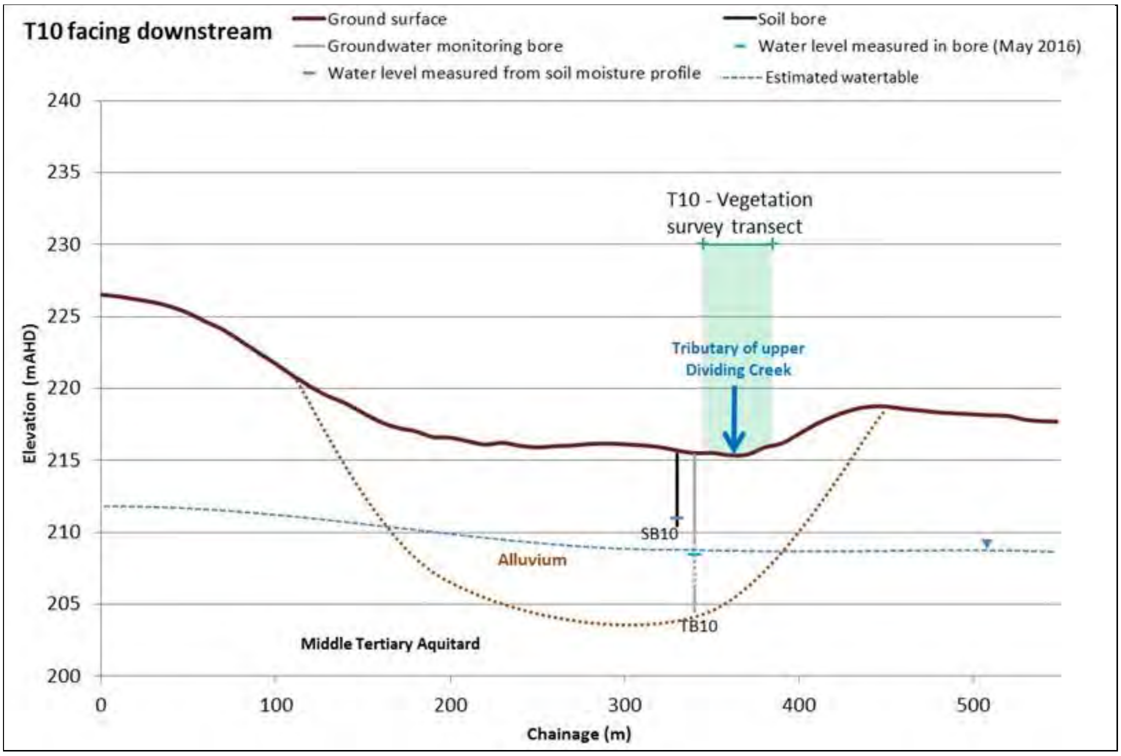


Impact sites

T10 - Impact site regional aquifer confined

- TB10 monitors the alluvial aquifer overlying the aquitard.
- Predicted groundwater levels at depth in the aquitard are 60 m lower than the observed waterlevels, which could indicate a downward vertical gradient to the aquitard.
- Drawdown predicted in the aquitard, although observed waterlevels indicate drawdown has not propagated to the alluvial aquifer.



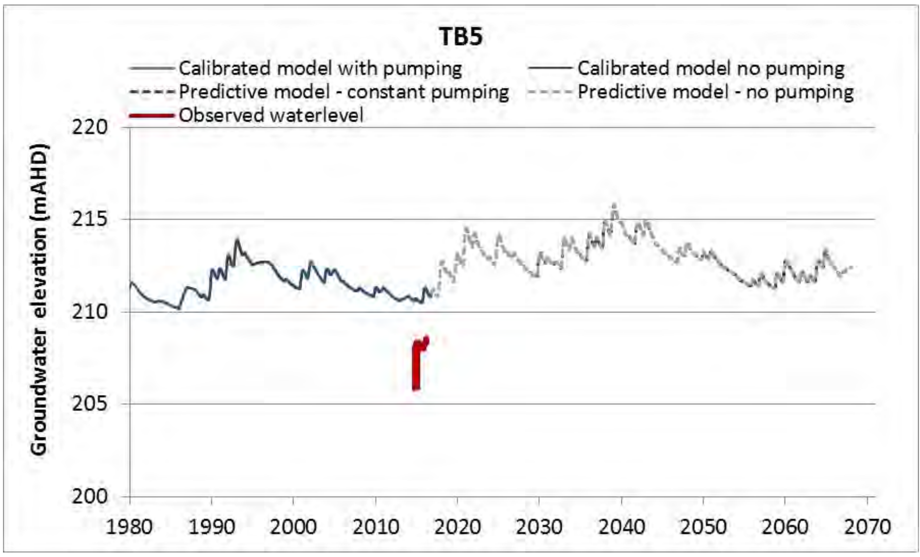


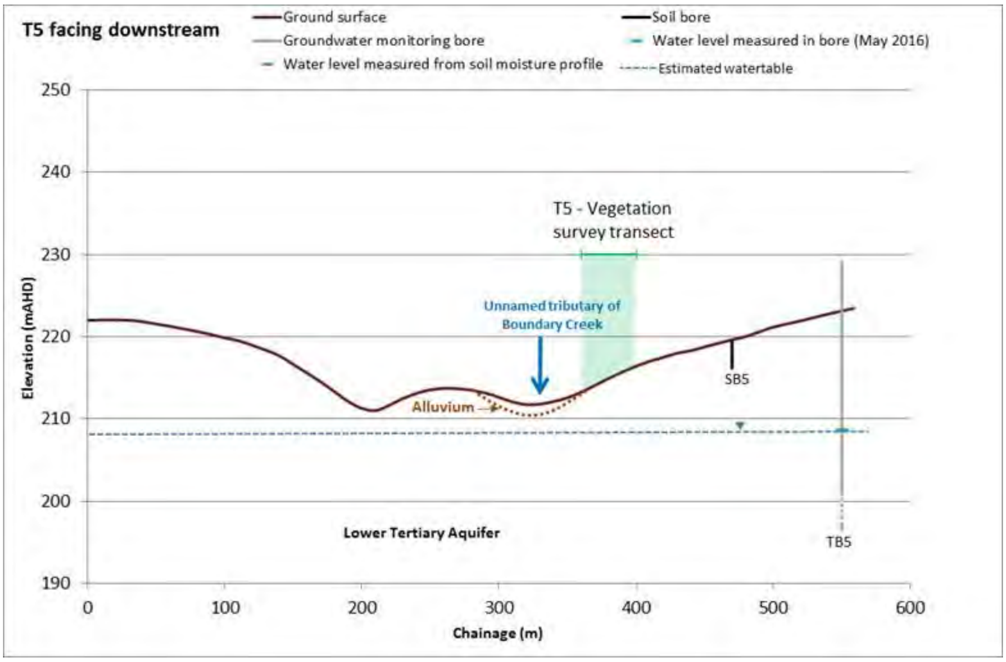
C.2 Reference vegetation monitoring sites

Reference sites

T5 Reference site

- TB5 monitors the regional aquifer outside the zone of influence from the borefield.
- Predicted GW levels are slightly higher than observed (2 m).
- No predicted impact from pumping.

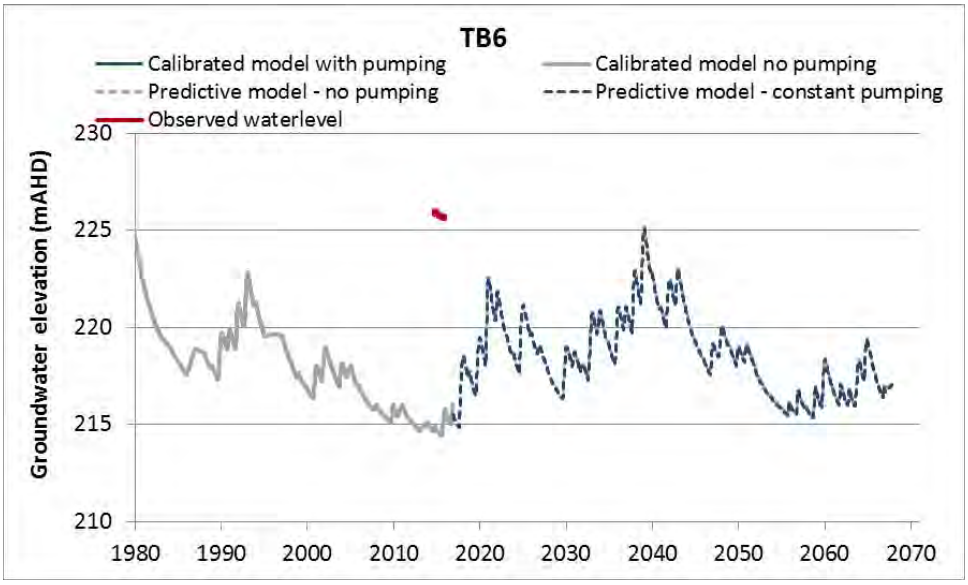


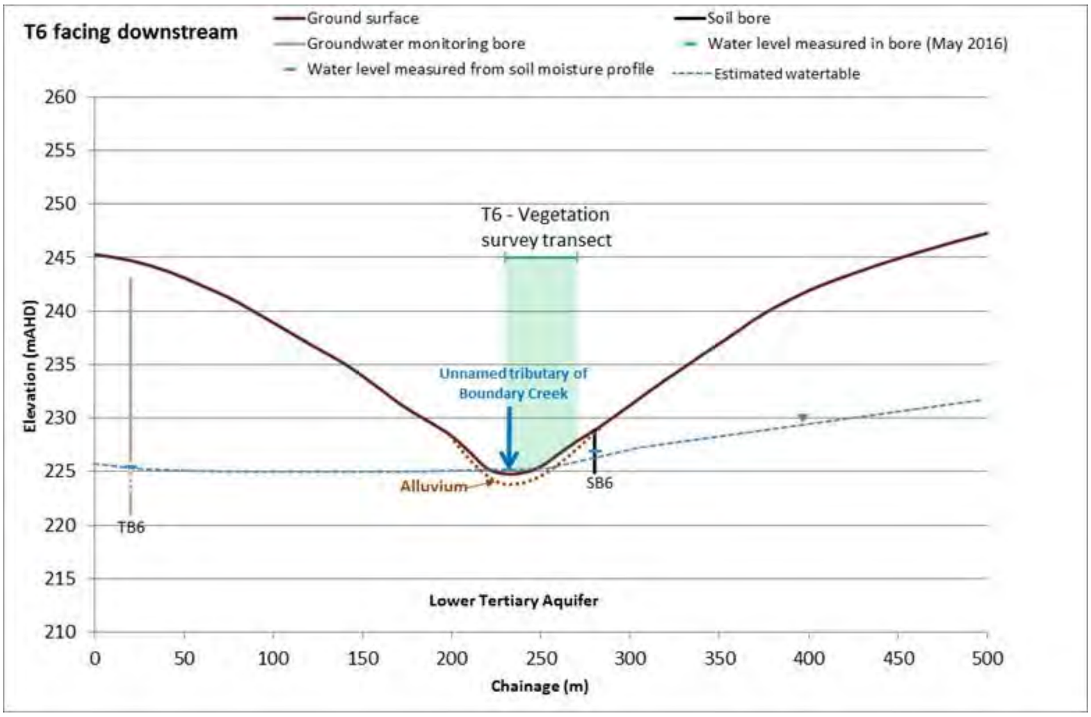


Reference sites

T6 - Reference site

- TB6 monitors the regional aquifer, that is hydraulically connected to the alluvial aquifer located on an unnamed tributary of Boundary Creek, outside the zone of influence of the borefield
- Predicted regional groundwater levels is 10 m lower than observed water level in the local alluvial aquifer.
- No predicted impact from pumping.

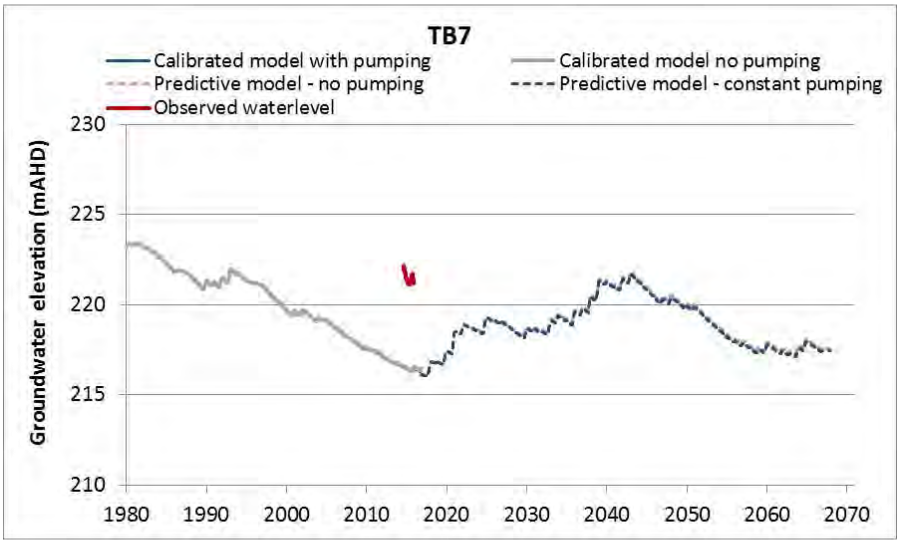


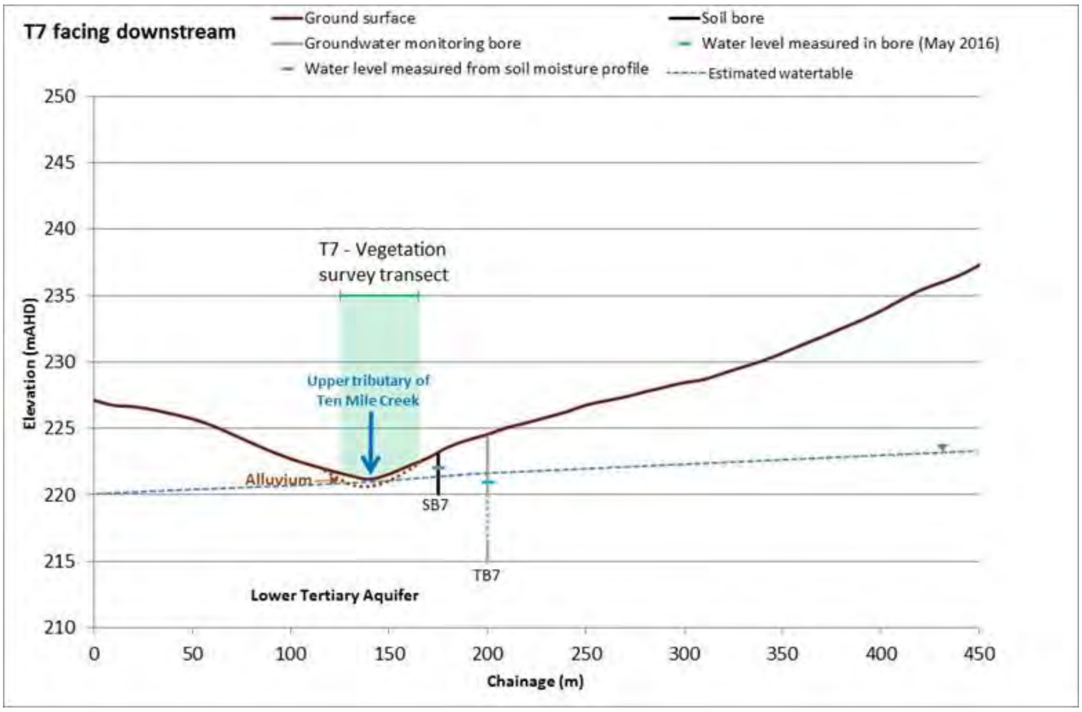


Reference sites

T7 – Reference site regional aquifer unconfined

- TB7 monitors the regional aquifer, that is hydraulically connected to the alluvial aquifer located on an unnamed tributary of Boundary Creek outside the zone of influence of the borefield.
- Predicted groundwater levels is 5 m lower than observed.
- No predicted impact from operation of the borefield.

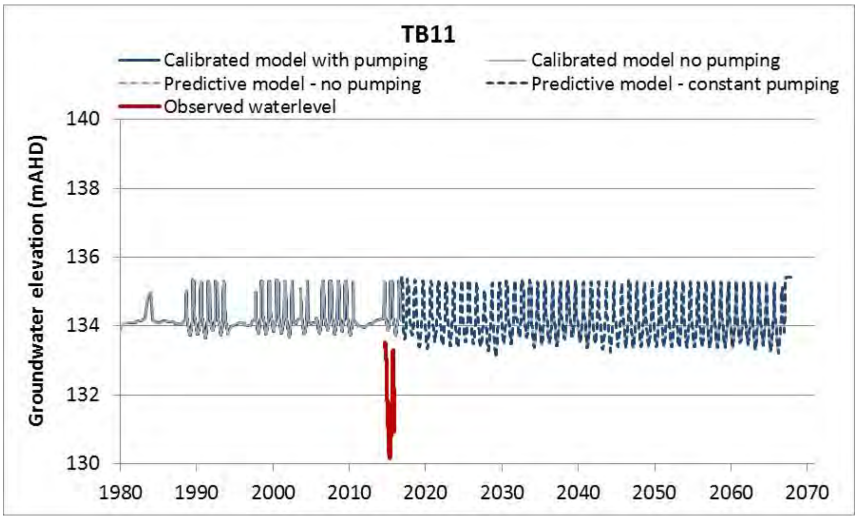


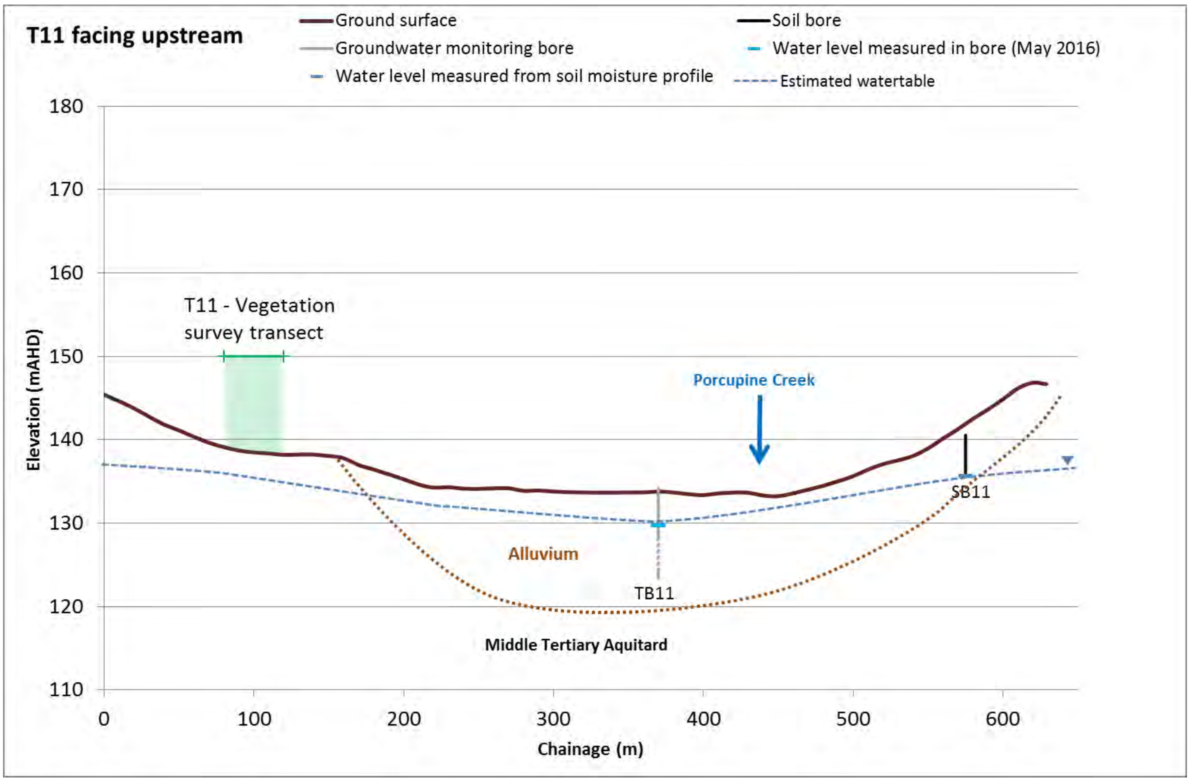


Reference sites

T11 – Reference site regional aquifer confined

- TB11 monitors the alluvial aquifer overlying the aquitard.
- Predicted groundwater levels are slightly higher than observed, but a similar seasonal response to rainfall recharge is observed, albeit more subdued.
- No drawdown is predicted in the aquitard.

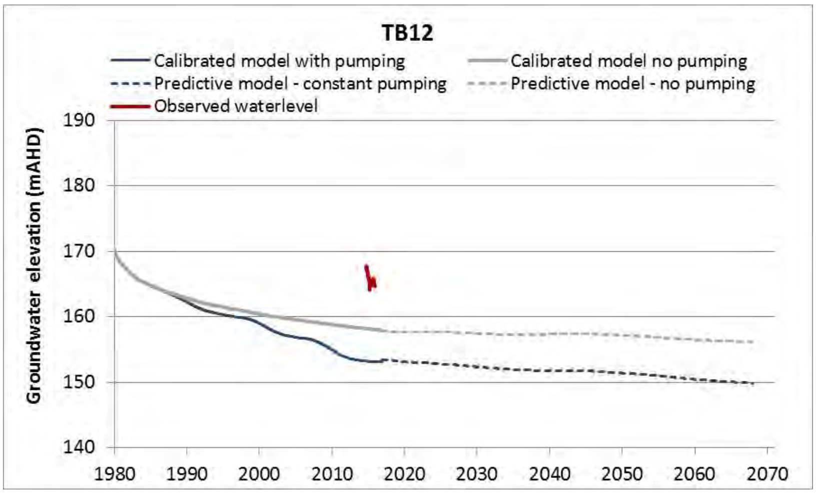


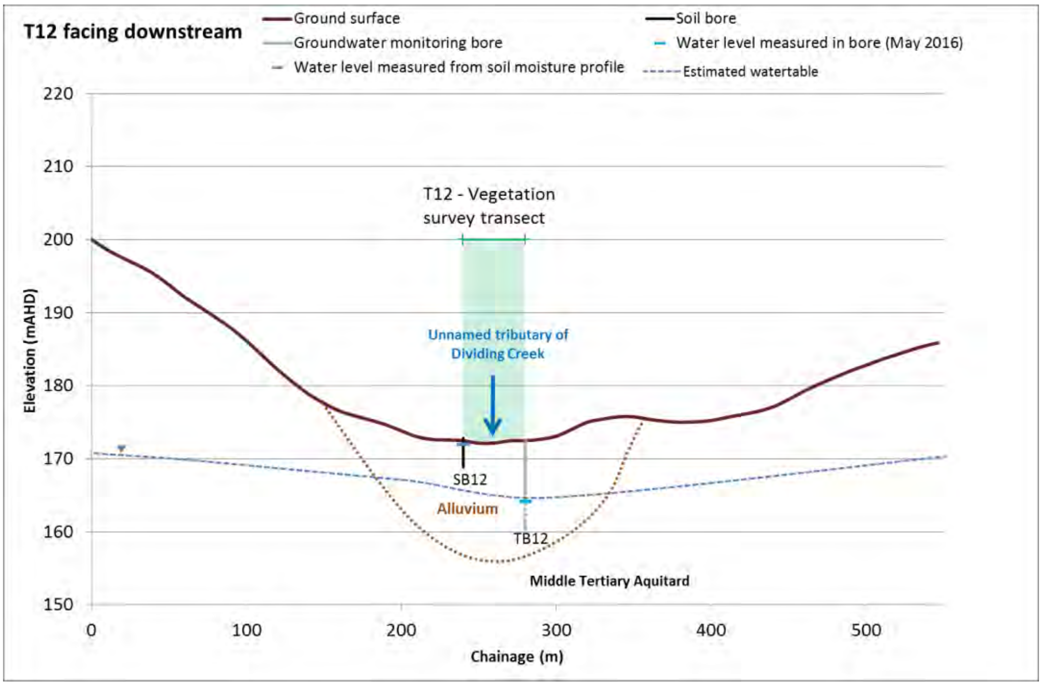


Reference sites

T12 – Reference site regional aquifer confined

- TB12 monitors the alluvial aquifer overlying the aquitard.
- Predicted groundwater levels in the aquitard are 10 m lower than observed, which could indicate a downward vertical gradient.
- Historical drawdown was predicted to occurred as a result of borefield operation and observed groundwater levels indicate that this has not propagated to the upper aquitard or the alluvial aquifer.
- Drawdown is predicted as a result of future operation of the borefield, however monitoring demonstrates this will not impact the shallow aquifer.

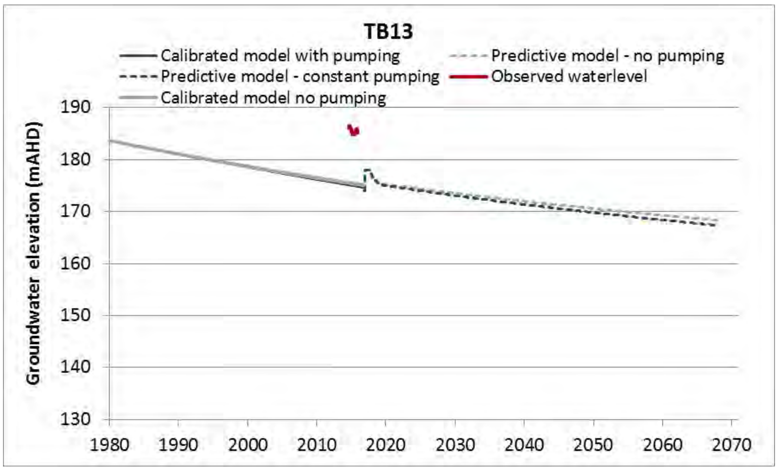


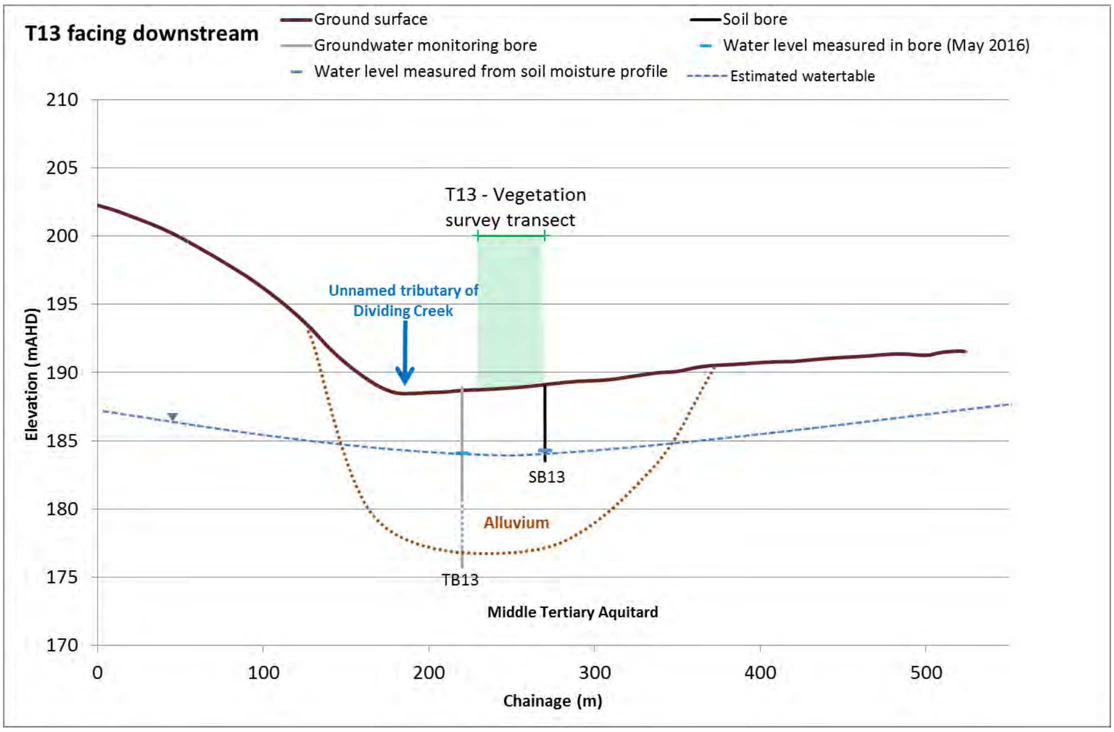


Reference sites

T13 – Reference site regional aquifer confined

- TB13 monitors the alluvial aquifer overlying the aquitard.
- Predicted groundwater levels in the aquitard are 10 m lower than observed, which could indicate a downward vertical gradient.
- Minimal drawdown was predicted at depth in the aquitard, however the model response is not well calibrated.

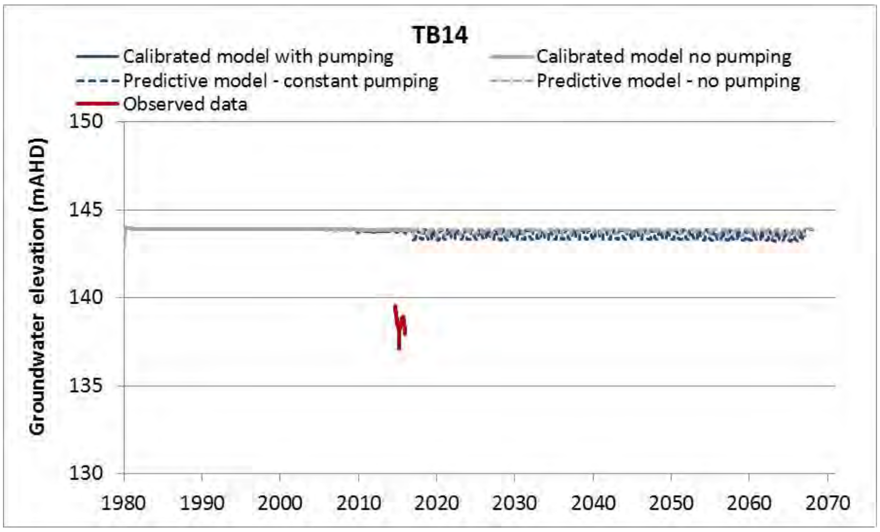


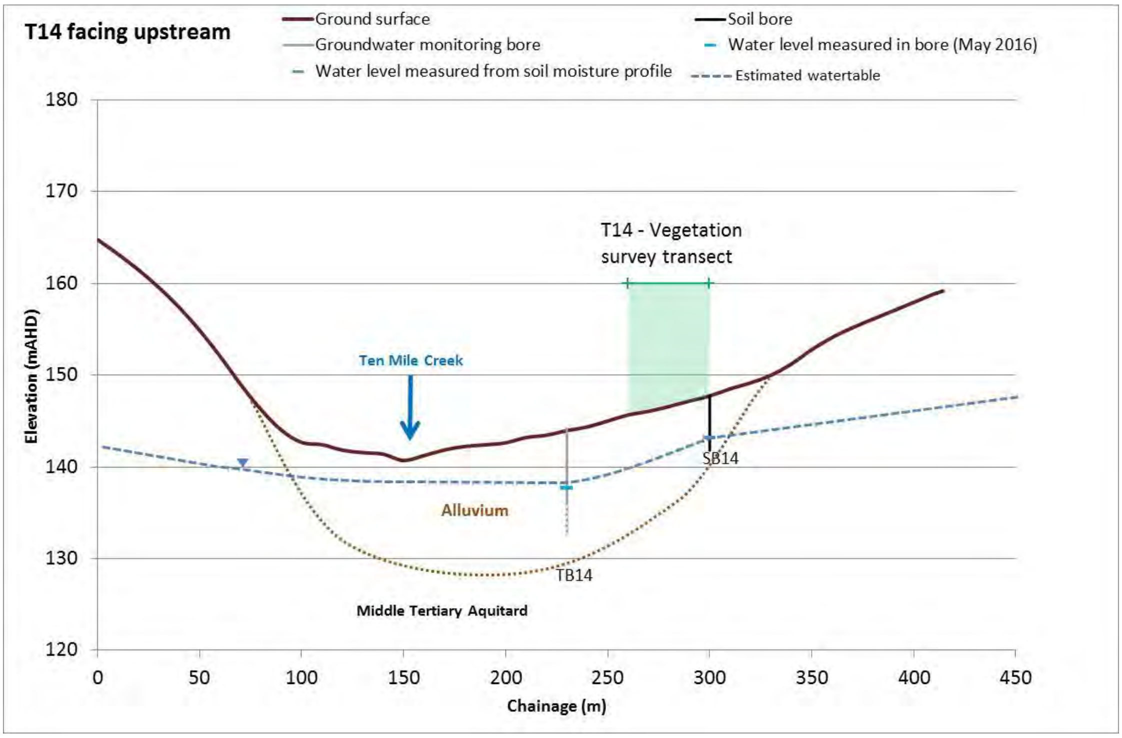


Reference sites

T14 – Reference site regional aquifer confined

- TB14 monitors the alluvial aquifer overlying the aquitard.
- Predicted groundwater levels are 6 m above the observed groundwater level which could indicate there is an upward vertical gradient at this site.
- No historical or future drawdown is predicted in the aquitard at this location as a result of borefield operations.





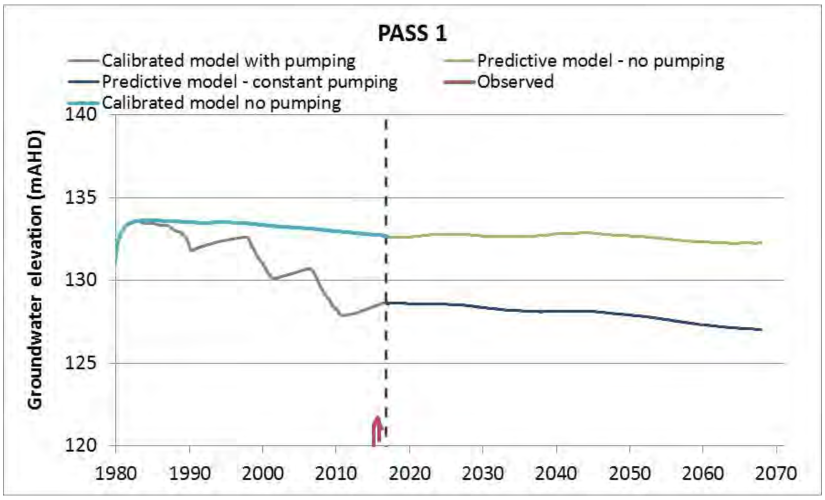
Appendix D. PASS monitoring sites

Vegetation monitoring site	Local Hydrogeology	Vegetation dependent on regional aquifer	Likelihood of connection to regional aquifer	Consequence (drawdown predicted in regional aquitard/aquifer)						Unmitigated Potential Risk	Mitigate potential risk (presence of alluvial aquifer)
				HISTORICAL		PREDICTED CONSTANT PUMPING		PREDICTED INTERMITTENT PUMPING			
PASS1	Alluvial / aquitard	No	Low	5.0	High	5.2	High	4.4	High	**Medium**	**Low**
PASS2	Alluvial / aquifer	No	Low	5.9	High	3.4	High	3.8	High	**Medium**	**Low**
PASS3	Alluvial / aquitard	No	Low	0.4	Moderate	1.9	Moderate	1.2	Moderate	**Low**	**Low**
PASS4	Alluvial / aquitard	No	Low	2.5	High	4.9	High	2.9	High	**Medium**	**Low**

PASS monitoring sites

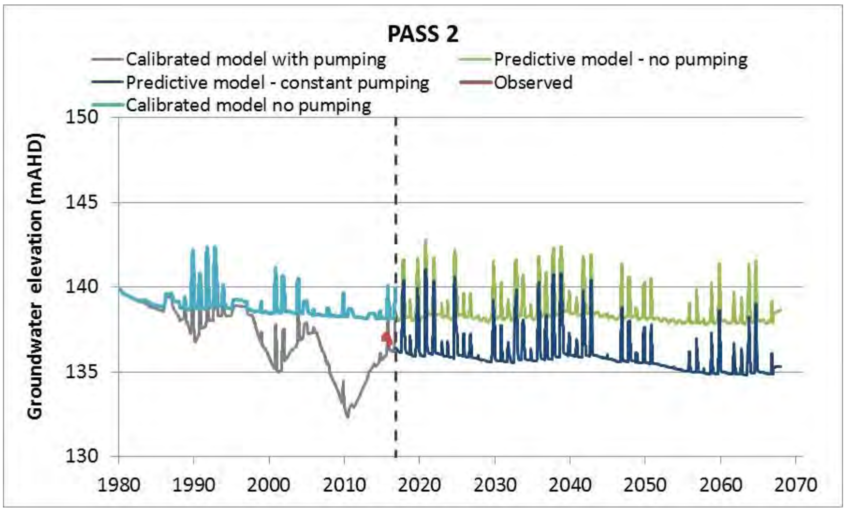
PASS 1

- Located on the northern floodplain of Boundary Creek, approximately 1 km upstream of its confluence with the Barwon River
- Groundwater levels at the site are shallow and range between 1 and 1.5 m below the surface in the alluvial aquifer (Jacobs 2017d).



PASS 2

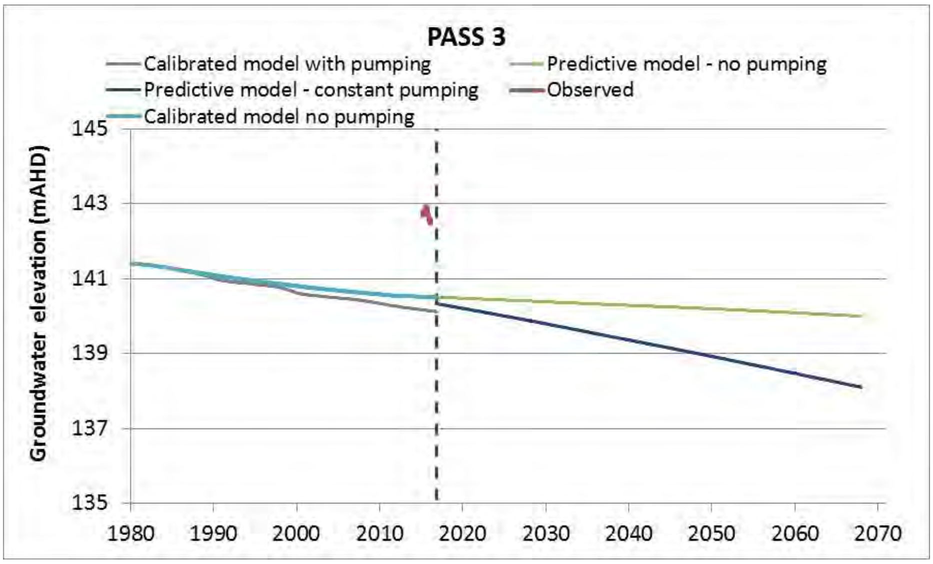
- Located to the east of the Barwon River East Branch approximately 7 km upstream of its confluence with the Barwon River West Branch
- Groundwater levels are weakly artesian (above ground level) for much of the year and decline below the ground level during the summer months. The surface water is supported by the shallow groundwater aquifer (Jacobs 2017d).



PASS monitoring sites

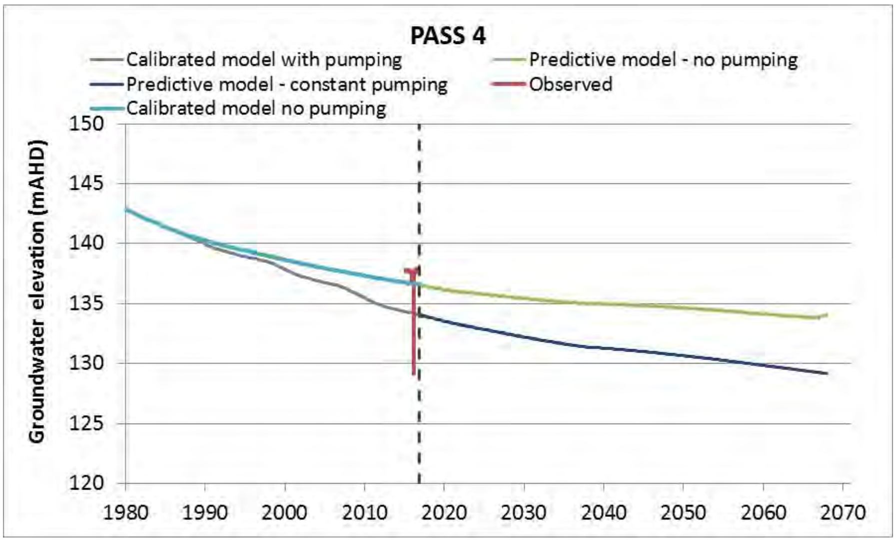
PASS 3

- Located along a tributary to Boundary Creek, approximately 1 km to the north west of the confluence between Boundary Creek and the Barwon River.
- Groundwater levels at the site fluctuated by around 0.5 m seasonally, ranging between around 1 m below ground level during higher rainfall periods and 1.5 m below ground level in response to reduced rainfall in the catchment (Jacobs 2017d).



PASS 4

- Located on the eastern floodplain of Yan Yan Gurt Creek, approximately 4 km north of the Deans Marsh town centre.
- Groundwater levels at the site are weakly artesian (<0.5 m above ground level) and exhibit only minor (~0.2 m) seasonal fluctuations (Jacobs, 2017d)



Appendix E. Monitoring bores

Table E.1: Bores recommended for ongoing monitoring

Bore ID	Layer	Model layer	Bore depth	Monitoring start date	Data collection method	Monitored by
TB1a	Quaternary alluvium	*	13	Aug 2014	Data logger	Barwon Water
TB9	Quaternary alluvium	*	12	Aug 2014	Data logger	Barwon Water
TB10	Quaternary alluvium	*	11	Aug 2014	Data logger	Barwon Water
TB11	Quaternary alluvium	*	11	Aug 2014	Data logger	Barwon Water
TB13	Quaternary alluvium	*	13	Aug 2014	Data logger	Barwon Water
A1	Gellibrand Marl	1	42	Sept 2014	Data logger	Barwon Water
A5a	Gellibrand Marl	1	98	Sept 2014	Data logger	Barwon Water
A5b	Gellibrand Marl	1	19	Sept 2014	Data logger	Barwon Water
A6a	Gellibrand Marl	1	98	Sept 2014	Data logger	Barwon Water
A6b	Gellibrand Marl	1	18	Aug 2014	Data logger	Barwon Water
64234	Clifton Formation	2	255	Feb 1983	Manual quarterly	DELWP (SOBN)
64235	Clifton Formation	2	192.5	Sept 1983	Manual quarterly	DELWP (SOBN)
82838	Clifton Formation	2	285.1	Jan 1974	Manual quarterly	DELWP (SOBN)
A2	Narrawaturk Marl	3	41	Mar 2015	Data logger	Barwon Water
A3	Narrawaturk Marl	3	14	Sept 2014	Data logger	Barwon Water
A4	Narrawaturk Marl	3	41	Sept 2014	Data logger	Barwon Water
PASS1	Narrawaturk Marl	3	10	Mar 2015	Data logger	Barwon Water
PASS2	Narrawaturk Marl	3	10	Mar 2015	Data logger	Barwon Water
PASS3	Narrawaturk Marl	3	10	Mar 2015	Data logger	Barwon Water
PASS4	Narrawaturk Marl	3	8	Mar 2015	Data logger	Barwon Water
TB1b	Narrawaturk Marl	3	19	May 2015	Data logger	Barwon Water
TB8	Narrawaturk Marl	3	27	Sept 2014	Data logger	Barwon Water
TB12	Narrawaturk Marl	3	12	Sept 2014	Data logger	Barwon Water
TB14	Narrawaturk Marl	3	12	Sept 2014	Data logger	Barwon Water
47771	Mepunga/Dilwyn	4	345	Nov 1985	Manual quarterly	DELWP (SOBN)
47773	Mepunga/Dilwyn	4	297.5	Sept 1986	Manual quarterly	DELWP (SOBN)
47774	Mepunga/Dilwyn	4	222.5	Dec 1987	Manual quarterly	DELWP (SOBN)
47775	Mepunga/Dilwyn	4	381.2	Dec 1988	Manual quarterly	DELWP (SOBN)
47986	Mepunga/Dilwyn	4	296	Nov 1982	Manual quarterly	DELWP (SOBN)
47996	Mepunga/Dilwyn	4	94	Jul 1985	Manual quarterly	DELWP (SOBN)
48249	Mepunga/Dilwyn	4	135.3	Oct 1982	Manual quarterly	DELWP (SOBN)

Bore ID	Layer	Model layer	Bore depth	Monitoring start date	Data collection method	Monitored by
64233	Mepunga/Dilwyn	4	249	Jan 1981	Manual quarterly	DELWP (SOBN)
64236	**Mepunga/Dilwyn**	**4**	**470**	**Aug 1983**	**Manual monthly**	**Barwon Water**
64237	Mepunga/Dilwyn	4	422	Sept 1985	Manual quarterly	DELWP (SOBN)
64240	Mepunga/Dilwyn	4	311	Sept 1986	Manual quarterly	DELWP (SOBN)
64244	Mepunga/Dilwyn	4	326	Sept 1987	Manual quarterly	DELWP (SOBN)
82841	Mepunga/Dilwyn	4	485	Jun 1974	Manual quarterly	DELWP (SOBN)
82843	Mepunga/Dilwyn	4	462	Apr 1986	Manual quarterly	DELWP (SOBN)
82844	**Mepunga/Dilwyn**	**4**	**233**	**Mar 1985**	**Manual monthly**	**Barwon Water**
82845	Mepunga/Dilwyn	4	226	Jan 1986	Manual quarterly	DELWP (SOBN)
82846	Mepunga/Dilwyn	4	131	Apr 1986	Manual quarterly	DELWP (SOBN)
82847	Mepunga/Dilwyn	4	117	May 1986	Manual quarterly	DELWP (SOBN)
102868	Mepunga/Dilwyn	4	577	May 1984	Manual quarterly	DELWP (SOBN)
102869	Mepunga/Dilwyn	4	431	Jan 1986	Manual quarterly	DELWP (SOBN)
107720	Mepunga/Dilwyn	4	259	Dec 1988	Manual quarterly	DELWP (SOBN)
108897	Mepunga/Dilwyn	4	86	May 1981	Manual quarterly	DELWP (SOBN)
108907	Mepunga/Dilwyn	4	362.5	Nov 1982	Manual quarterly	DELWP (SOBN)
108910	Mepunga/Dilwyn	4	271	Jan 1983	Manual quarterly	DELWP (SOBN)
108913	Mepunga/Dilwyn	4	152	Nov 1984	Manual quarterly	DELWP (SOBN)
108915	Mepunga/Dilwyn	4	208.5	Jul 1987	Manual quarterly	DELWP (SOBN)
109112	Mepunga/Dilwyn	4	292	Jan 1984	Manual quarterly	DELWP (SOBN)
109128	Mepunga/Dilwyn	4	30	Jun 1986	Manual quarterly	DELWP (SOBN)
109130	Mepunga/Dilwyn	4	17.5	May 1986	Data logger	Barwon Water
109131	**Mepunga/Dilwyn**	**4**	**86.5**	**Jun 1986**	**Manual monthly**	**Barwon Water**
109133	Mepunga/Dilwyn	4	211.5	Jul 1986	Manual quarterly	DELWP (SOBN)
109135	Mepunga/Dilwyn	4	237	Aug 1986	Manual quarterly	DELWP (SOBN)
114169	Mepunga/Dilwyn	4	82	May 1993	Manual quarterly	DELWP (SOBN)
TB1c	Mepunga/Dilwyn	4	37	May 2015	Data logger	Barwon Water
TB6	Mepunga/Dilwyn	4	22	Aug 2014	Data logger	Barwon Water
TB5	Mepunga/Dilwyn	4	32.5	Aug 2014	Data logger	Barwon Water
TB7	Mepunga/Dilwyn	4	9	Aug 2014	Data logger	Barwon Water
UDvCk	Mepunga/Dilwyn	4	61	Sept 2014	Data logger	Barwon Water
48001	Pebble Point	6	43	Nov 1986	Manual quarterly	DELWP (SOBN)
62578	Pebble Point	6	85	Sept 1986	Manual quarterly	DELWP (SOBN)
64229	**Pebble Point**	**6**	**560.8**	**Dec 1973**	**Manual monthly**	**Barwon Water**

Bore ID	Layer	Model layer	Bore depth	Monitoring start date	Data collection method	Monitored by
64241	Pebble Point	6	280	Oct 1986	Manual quarterly	DELWP (SOBN)
82840	Pebble Point	6	611	Dec 1973	Manual quarterly	DELWP (SOBN)
109110	Pebble Point	6	99	Jan 1981	Manual quarterly	DELWP (SOBN)
109113	Pebble Point	6	270.6	Jun 1984	Manual quarterly	DELWP (SOBN)
109114	Pebble Point	6	308.5	Dec 1984	Manual quarterly	DELWP (SOBN)
109132	Pebble Point	6	123	Jun 1986	Manual quarterly	DELWP (SOBN)
113706	Pebble Point	6	90	Feb 1993	Manual quarterly	DELWP (SOBN)
TB3	Pebble Point	6	40	Sep 2014	Data logger	Barwon Water
TB4c	Pebble Point	6	7.7	Sep 2014	Data logger	Barwon Water
113705	Basement	7	174	Feb 1993	Manual quarterly	DELWP (SOBN)
RB1	Basement	7	92	Sept 2014	Data logger	Barwon Water
UBCk1	Basement	7	21	Sept 2014	Data logger	Barwon Water
UBCk2	Basement	7	19	Sept 2014	Data logger	Barwon Water