Barwon Downs Technical Works Program

Barwon Water

Potential impacts and risks from future operation of the Barwon Downs Borefield

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Executive Summary

The Barwon Downs borefield is operated under licence from Southern Rural Water. This licence was granted in 2004 and is due for renewal by June 2019.

This study details the outcomes of the groundwater modelling and risk assessment to identify environmental receptors at risk from future pumping under both constant and intermittent pumping scenarios. Barwon Water would prefer to operate the borefield based on the following pumping regime:

- Maximum daily rate of 45 ML/day
- Maximum annual rate of 12,000 ML/year, and
- Maximum 15-year total take of 60,000 ML.

Trigger levels are recommended in some groundwater monitoring bores along with appropriate management actions when the triggers levels are reached. The trigger levels are recommended to prevent unacceptable impacts to environmental receptors in the catchment.

Objectives

The objectives of this study are to:

- Inform Barwon Water's upcoming licence application by using the groundwater model to predict potential impacts of future pumping to environmental indicators in the Gerangamete region.
- Assess the level of risk associated with the predicted potential impacts of future pumping using the Ministerial Guidelines for Groundwater Licensing and Protection of Groundwater Dependent Ecosystems (DELWP, 2015)
  - Provide recommendations for appropriate triggers / off set measures where environmental receptors are at risk from the effects of future pumping, and

    Provide commentary on the sustainability of the proposed pumping regimes for the duration of the next licence.

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 Lower Tertiary Aquifer (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 1.

Table 1: 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

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 2. 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 2: 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 forecast to impact on the aquifer matrix through subsidence.

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 3. 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 3: 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

Proposed 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 4 provides an overview of the recommended trigger levels and more detail is provided in Section 12.7.

Table 4: 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	
		• Groundwater observation bore 109131 (Yeo40) to be 142.3 mAHD.	
Boundary Creek	• To indicate when supplementary flows are	• Groundwater observation bore 109131 (Yeo40) to be 158.5 mAHD	• Provide a supplementary flow to Reach 2 of

Receptor	Intent of trigger	Trigger	Management action
	required to ensure a minimum flow in Boundary Creek	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	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.		

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, with the rate and final level being dependent on the eventual climate (particularly rainfall).

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.

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.

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1. Introduction

1.1 Barwon Downs region

The Barwon Downs bore field is located approximately 70 km south west of Geelong and 30 km south east of Colac (refer to Figure 1-1). The surrounding land is a mixture of agriculture and state forest. A substantial proportion of the study area has been farmed for over a century which has resulted in some parts of the landscape being highly modified compared to the surrounding natural environment.

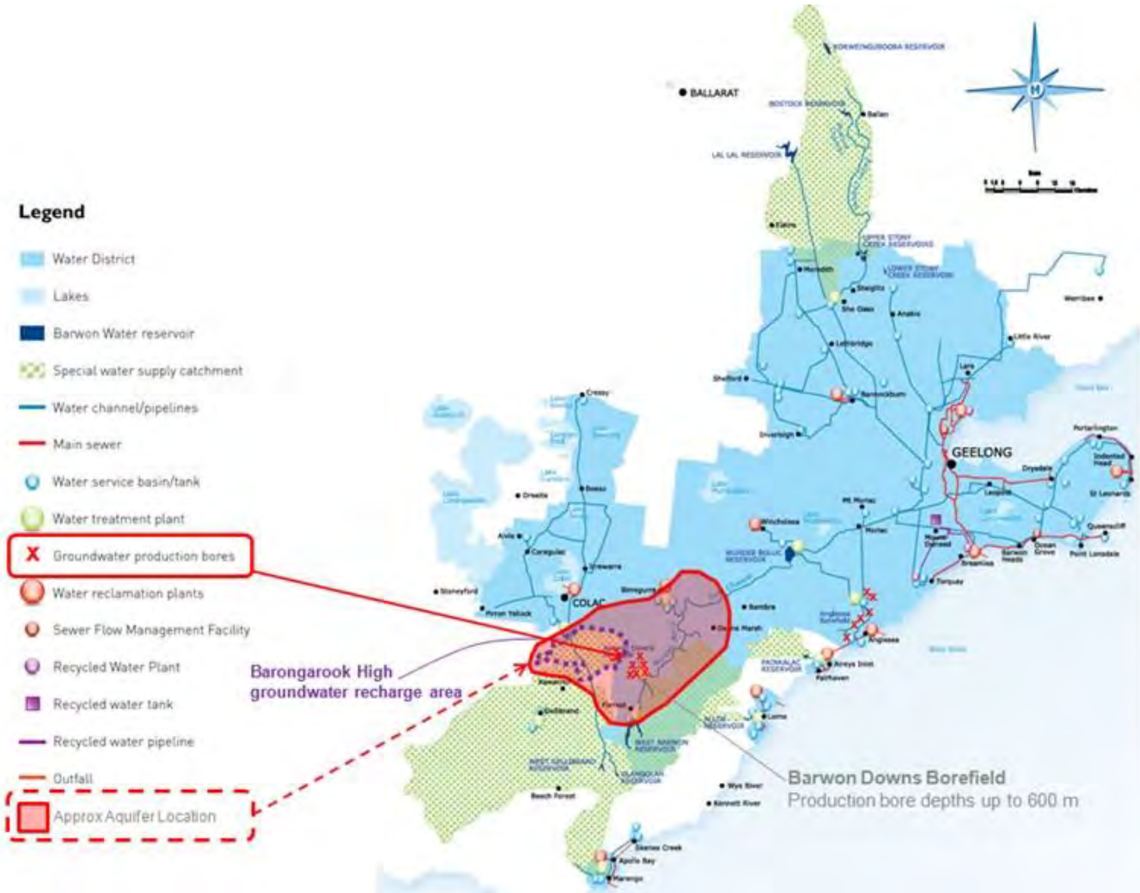


Figure 1-1 Map of the Barwon Downs region including the aquifer extent and the primary groundwater recharge area.

The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment.

The Barwon River and its tributaries rise in the Otway Ranges and flow north through Forrest and Birregurra. The Barwon River West Branch and East Branch drain the southern half of the catchment and come together just upstream of the confluence with Boundary Creek. Boundary Creek flows east across the Barongarook High and joins the Barwon River around Yeodene.

The Otways Coast catchment is a large catchment with many rivers that flow towards the coast. The Gellibrand River is in the Otways Coast catchment and rises near Upper Gellibrand and flows in a westerly direction towards Gellibrand. The Gellibrand River discharges to the ocean at Princetown.

The borefield taps into an underground source of water, known as the Lower Tertiary Aquifer (LTA), with depths of up to 600 metres at the borefield (see Figure 1-2). The aquifer covers an area of approximately 500 km^2 below the surface and is connected to the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment near Gellibrand. Barongarook High is the main recharge area of the aquifer because of its unconfined nature.

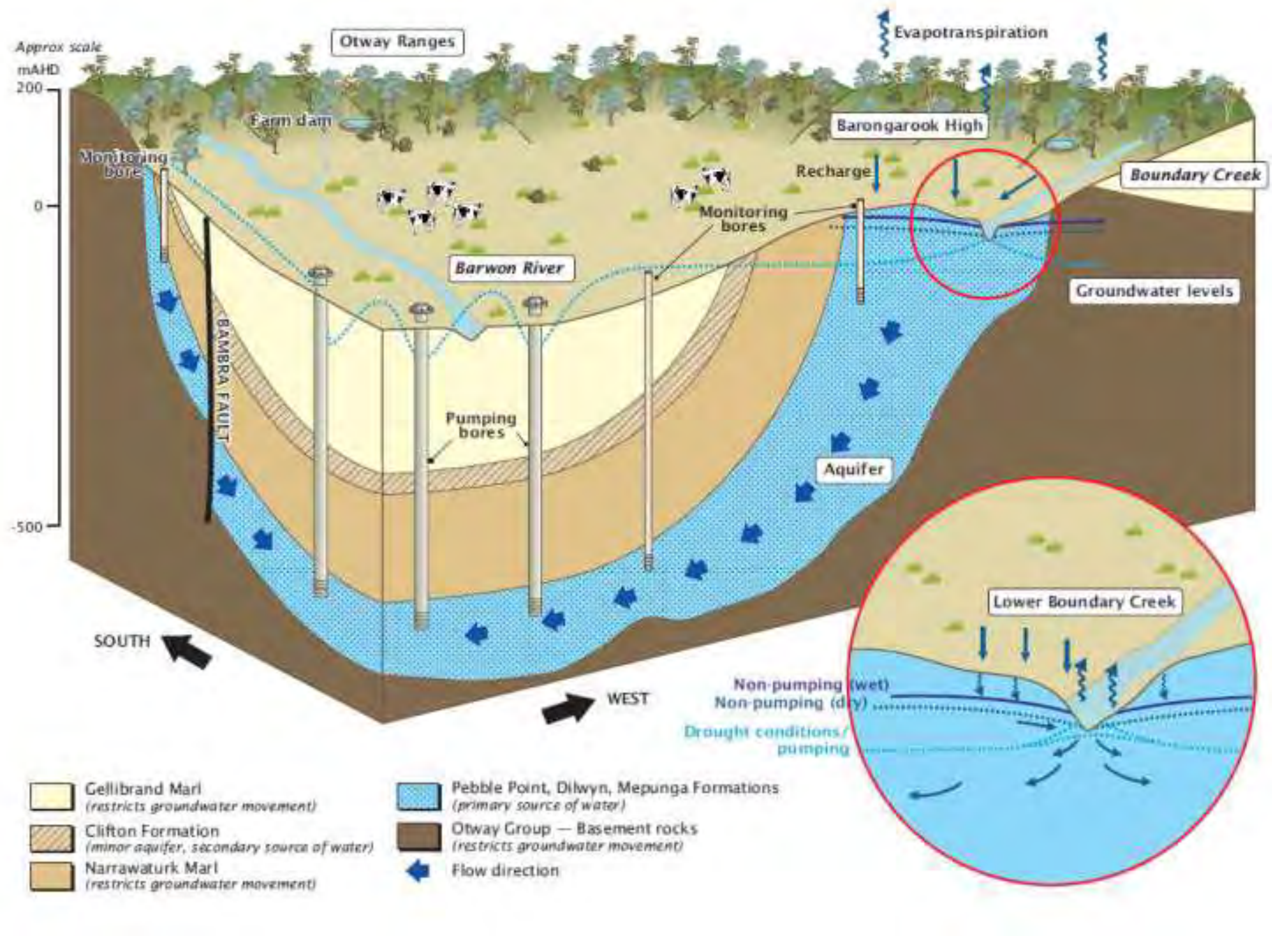


Figure 1-2 Schematic of the Lower Tertiary Aquifer and where it outcrops at the surface.

1.2 History of the Barwon Downs borefield

1.2.1 Borefield history

In response to the 1967-68 drought, when water supplies reached critical levels, the Geelong Waterworks and Sewerage Trust (now Barwon Water) began investigating groundwater resources as a means of supplementing surface water supplies used for the Geelong region. Investigations conducted in the Barwon Downs region revealed a significant groundwater resource with potential to meet this need.

In 1969 a trial production bore was built and tested close to the Wurdee Boluc inlet channel at Barwon Downs. With knowledge gained from these results another bore was built at nearby Gerangamete in 1977. A long term pump testing programme from 1987-1990 confirmed that the borefield should be centred on Gerangamete.

There are now six production bores in the borefield each between 500 and 600 metres deep. Pumps in each bore are capable of providing daily flows of up to 12 megalitres (ML) per day per bore. The pumped water is treated by an iron removal plant prior to transfer to Wurdee Buloc Reservoir. Total borefield production capacity is 55 ML per day.

1.2.2 Groundwater extraction

Barwon Water operates the borefield in times of extended dry periods. This has occurred only five times in the last 30 years. The borefield is a critical back up source for Barwon Water because it is buffered from climate variability due to the depth and large storage capacity of the aquifer, whereas surface water catchments are susceptible to seasonal fill patterns mostly driven by rainfall.

Although extraction occurs infrequently, large amounts of groundwater are drawn when needed to supplement surface water storages during drought. This is completed in compliance with the groundwater licence (refer to Section 1.3). This operational philosophy of intermittent pumping has been an effective way to provide customers with security of supply, especially in times of prolonged dry conditions.

To date, Barwon Water has extracted the following volumes from the aquifer:

- 3,652 ML from February to April in 1983 due to drought,
- 19,074 ML during a long term pump test in the late 1980s,
- 36,817 ML during the 1997 - 2001 drought,
- 52,684 ML during the 2006 – 2010 millennium drought, and
- 3,449 ML in 2016 to boost storages after a record dry summer.

Groundwater extraction has supplemented surface water supply by a total of 115,676 ML equating to approximately 30 per cent of the maximum volume of water that may be taken in any period of 100 years according to the current licence conditions (400,000ML).

1.2.3 Licence history

The first licence was issued in 1975 but did not come into effect until 1982, as the bores were not brought into operation until the 1982-83 drought. This was the first time the borefield was used to supply water to Geelong. The licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water) was to allow Barwon Water to operate four production bores based on the following conditions:

- Extraction for the purpose of urban water supply;
- Maximum daily extraction rate of 42.5 ML;
- Maximum annual extraction rate of 12,600 ML;
- Maximum ten-year extraction of 80,000 ML; and
- Periods of licence renewal of 15 years (1975 – 1990).

The licence was subsequently renewed for two periods of five years up to 2000. From 2000, the licence was temporarily extended three times for a total of four years to allow the licence renewal to take place through to 31 August 2004.

In 2002[1], Barwon Region Water Authority (now Barwon Water) applied to renew the Barwon Downs borefield licence for extraction of groundwater to meet urban water supply needs. The application proposed the following:

- Maximum daily extraction rate of 55 ML;
- Maximum annual extraction rate of 20,000 ML;
- Maximum ten-year extraction rate of 80,000 ML;

[1] *Note: Bulk Entitlement was considered in 2002 so that the Upper Barwon System could be managed conjunctively. This was put aside as the view at the time was that the rights to groundwater should continue to be contained in a licence and subject to regular review.*

- Long term (100-year period) average extraction rate of 4,000 ML/year; and
- Licence renewal period of 15 years.

From 2004 to 2006, the licence was temporarily extended to allow for the licence renewal to take place. Licence conditions were drafted by the panel taking into consideration the findings of the technical groups and the submissions received. This licence is valid to 30 June 2019.

A timeline of events relating to the Barwon Downs borefield is shown in Figure 1-3.

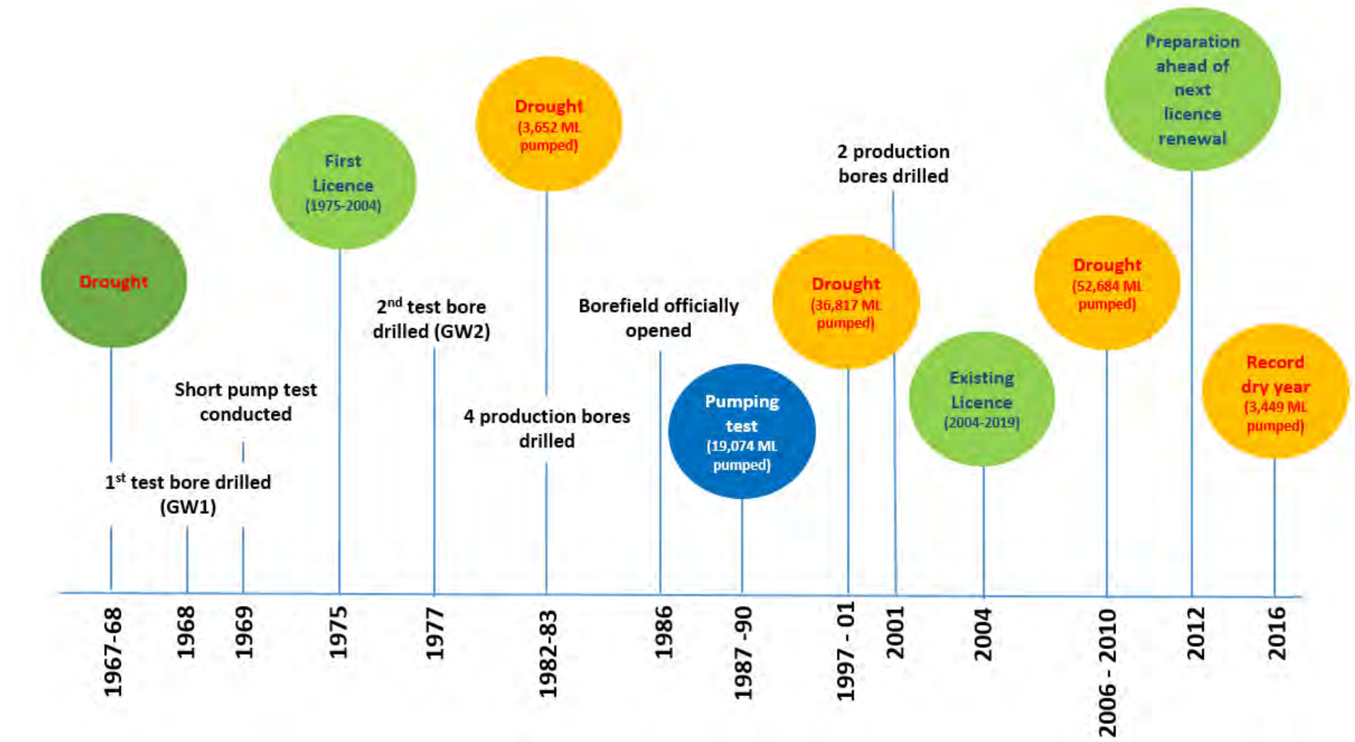


Figure 1-3 Timeline of events that surround the development and use of the Borefield.

1.3 Current groundwater licence

The Barwon Downs borefield is operated under licence from Southern Rural Water. This licence was granted in 2004 and is due for renewal by June 2019.

This licence makes provision for extraction limits on a volumetric basis over a range of time scales. As part of the licence conditions, Barwon Water monitor groundwater levels and quality, subsidence, flow in Boundary Creek and Barwon River, as well as the protection of riparian vegetation, protection of stock and domestic use and the protection of flows in the Barwon River tributaries.

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

1.4 Strategic drivers for the Barwon Downs technical works monitoring program

Ahead of the upcoming 2019 licence renewal process, Barwon Water instigated a technical works monitoring program to improve the comprehensiveness of the current monitoring program to ensure the submission of a technically sound licence application.

Driving the need for this monitoring program is the reliance on the borefield to provide water security for Barwon Water customers, to address outstanding community issues particularly where the relationship between cause and effect is not yet fully understood, and to close out any known technical knowledge gaps.

1.4.1 Water security

The Barwon Downs borefield provides water for the regional communities of Geelong, the Surf Coast, the Bellarine Peninsula and part of the Golden Plains Shire.

A prolonged period of unprecedented drought (known as the Millennium drought) saw a sustained dry climate average from 1997 to 2011. In 1997, many of the region’s water storages were close to capacity, however by January 1998, after high consumption and low catchment inflows, water restrictions were necessary to balance supply and demand in the Geelong area. This clearly highlighted that even by having large storages the region was susceptible to rapid changes.

In 2001, strong catchment inflows from healthy rainfall refilled storages, ending water restrictions in Geelong. Five years later, after a very dry year, strict water restrictions were again required with climate extremes exceeding the historical record. At the height of the Millennium drought, Geelong’s water storages dropped to 14 per cent when catchment inflows were severely reduced. To meet demand during this time 52,684 ML was extracted from the borefield providing up to 70 per cent of Geelong's drinking water.

In 2010, improved rainfall restored storages and restrictions were again slowly lifted in the Geelong area. This allowed the Barwon Downs borefield to be switched off and to begin recharging. Without the use of the borefield during this time, residents and industry in Geelong, Bellarine Peninsula, Surf Coast and southern parts of the Golden Plains Shire would have run out of water.

The township of Colac will soon be connected to the Geelong system through construction of a pipeline between Colac and Geelong. This interconnection will also allow the borefield to supply Colac residents and will provide additional water security for the water supply system which is currently susceptible to seasonal fill patterns.

1.4.2 Community issues

Although Barwon Water is compliant with the monitoring program associated with the 2004 licence, it is accepted that this program is not comprehensive enough to address community interest about specific issues centred on potential environmental impacts in the local catchment.

Areas of community interest recently have included the:

- extent of stream flow reduction and any ecological impacts at various points along Boundary Creek, which flows across the key recharge area for Lower Tertiary Aquifer and has the potential to be impacted by drawdown in the aquifer
- potential to increase existing acid sulfate soil risks in the Yeodene peat swamp, and impacts on Boundary Creek and the Barwon River downstream of the swamp from decreased pH,
- potential to increase the existing fire risk at the Yeodene peat swamp if the swamp dries, and
- extraction limits and the current operational regime of the borefield, and whether they are sustainable under climate change projections.

A Community Reference Group was established in 2013 to provide community feedback and input into the technical works monitoring program.

1.4.3 Informing the licence renewal

To address community interest adequately and inform the licence renewal in 2019, Barwon Water commissioned a review of the existing monitoring program associated with the 2004 licence. This technical review recommended that a revised technical works monitoring program be developed with the following objectives:

- Better understand the environmental impacts throughout the study area of groundwater extraction;
- Estimate, and quantify where possible, the causes and relative contributions of groundwater variability (for example, groundwater extraction and drought) in contributing to environmental impacts; and
- Provide additional monitoring data and subsequent analysis required to support the licence renewal process.

1.5 Overview of the technical works monitoring program

1.5.1 Monitoring program development

The development of the technical works monitoring program is shown in Figure 1-4 and can be broken down into the following stages.

Stage 1: Review of the existing monitoring program

In 2012, Barwon Water initiated a review of the Barwon Downs monitoring program. The technical works monitoring program was developed in response to the:

- desire to address key community issues (see section 1.4.2), and
- 2008-09 flora study which recommended a long term vegetation and hydrogeological monitoring program be designed and implemented to better understand a range of factors such as groundwater extraction, drought and land use changes that were contributing to the drying of the catchment.

This review took into account both the social and technical issues that needed to be addressed to inform the licence renewal process in 2019 and was initiated early to allow sufficient time to establish a comprehensive monitoring program. A risk based approach was used to rank these issues, and control measures were developed to downgrade the residual risk ranking, which included activities such as additional monitoring and technical studies.

Stage 2: Technical works monitoring program scope refinement

In 2013, the scope of the technical works monitoring program was developed based on the recommendations of Stage 1. The Technical Works Monitoring Program was designed to improve the capacity of the monitoring to differentiate between groundwater extraction and climate effects on the groundwater system, predict water table and stream flow changes, and increase understanding of potential ecological impacts. Key improvement areas include:

- differentiating between groundwater extraction and climate effects on the regional groundwater system,
- understanding the potential risks of acid sulfate soils and whether that could change future extraction practices,
- assessing whether vegetation in areas dependent on groundwater will be at risk from water table decline, which could change future extraction practices,
- assessing flow requirements in Boundary Creek to determine if the current supplementary flow is effective,
- characterising groundwater dynamics in the aquitard to improve hydrogeological understanding of groundwater flow and quantity, and
- better understanding of groundwater and surface water interaction, particularly along Boundary Creek where groundwater contributes to base flow.

In the same year, the Barwon Downs Groundwater Community Reference Group was also formed by Barwon Water to ensure where possible, the monitoring program was adjusted and the scope refined, to take into consideration community issues and views. This was a critical contribution towards the broader licence renewal strategy as it raised confidence that the right monitoring data would be captured to specifically target key areas of community concern.

Stage 3: Construction of additional monitoring assets

During 2014-15, the following construction works were completed:

- 33 new groundwater monitoring bores drilled, including the replacement of one existing bore,
- 3 existing bores refurbished,
- 4 new potential acid sulfate soils monitoring bores were installed,
- 32 data loggers and two barometric loggers installed in new and existing bores,
- 1 new stream flow gauges installed, and
- 2 existing stream flow gauges replaced refurbished and reinstated.

Stage 4: Ongoing monitoring

The technical works monitoring program is now in a phase of data collection and preliminary analysis. The intention of this stage is to update the conceptual understanding of the hydrogeology in the Barwon Downs region. This will be based on data collected from additional and existing monitoring assets and the outcomes of a range of investigative technical studies, all of which will be used to update and calibrate the groundwater model.

Preparation will also begin at this stage to form a comprehensive licence application.

Stage 5: Preparation for licence renewal submission

Prior to 2019, Barwon Water will need to formally submit a licence renewal application to Southern Rural Water. This will initiate a groundwater resource assessment process as set out under the Water Act.

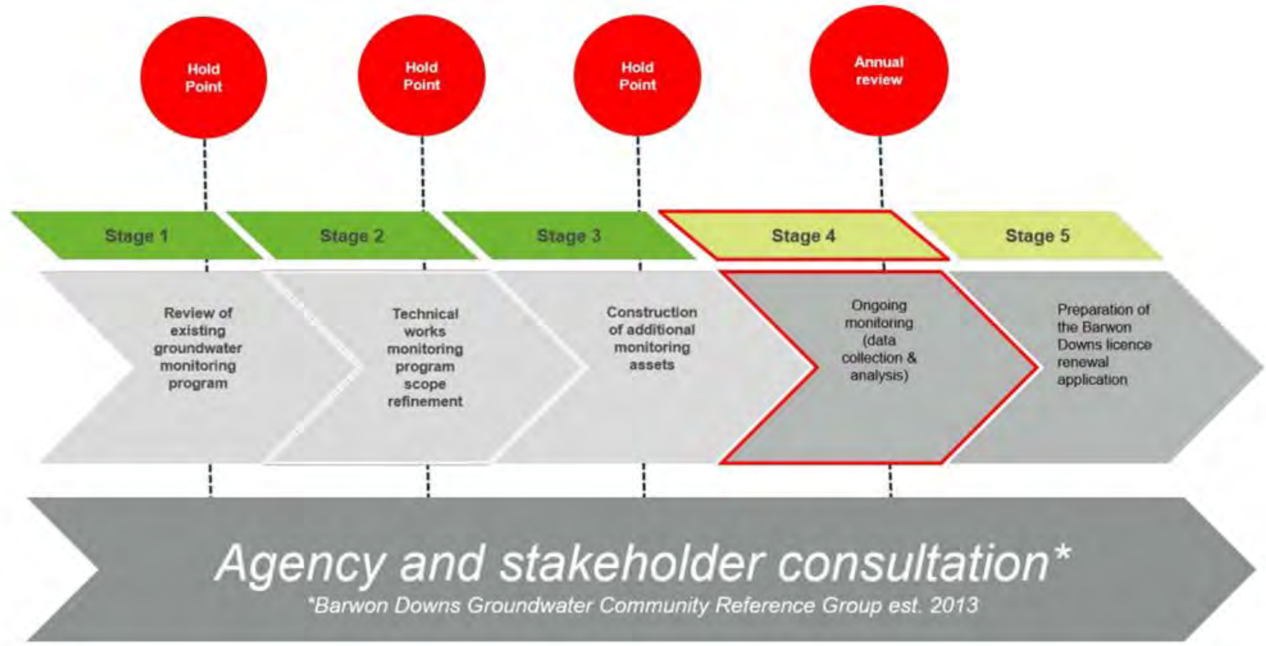


Figure 1-4 Development of the technical works monitoring program.

1.5.2 The inter-relationships of the technical works monitoring program

The technical works monitoring program is a complex, multi-disciplinary project due to the overlapping nature of the various components of the program as shown in Figure 1-5.

Changes in climate, land use practices and groundwater pumping will alter water availability throughout the catchment, including stream flow and groundwater levels. Many receptors are sensitive to changes in groundwater levels and stream flows, particularly those that are dependent on groundwater. Ultimately this can lead to the loss of ecological values (refer to Figure 1-5).

For example, a decline in groundwater level beneath a stream can cause a reduction in stream flow, which in turn can impact the habitat of aquatic ecology in the stream. Declining groundwater levels or reduced stream flow also has the potential to impact riparian vegetation and potential groundwater dependent activities.

The technical works monitoring program is designed to address knowledge gaps to better understand potential impacts from the borefield. The program is underpinned by scientific rigor using multiple lines of evidence-based techniques to establish the relationship between cause and effect for potential impacts caused by groundwater extraction.

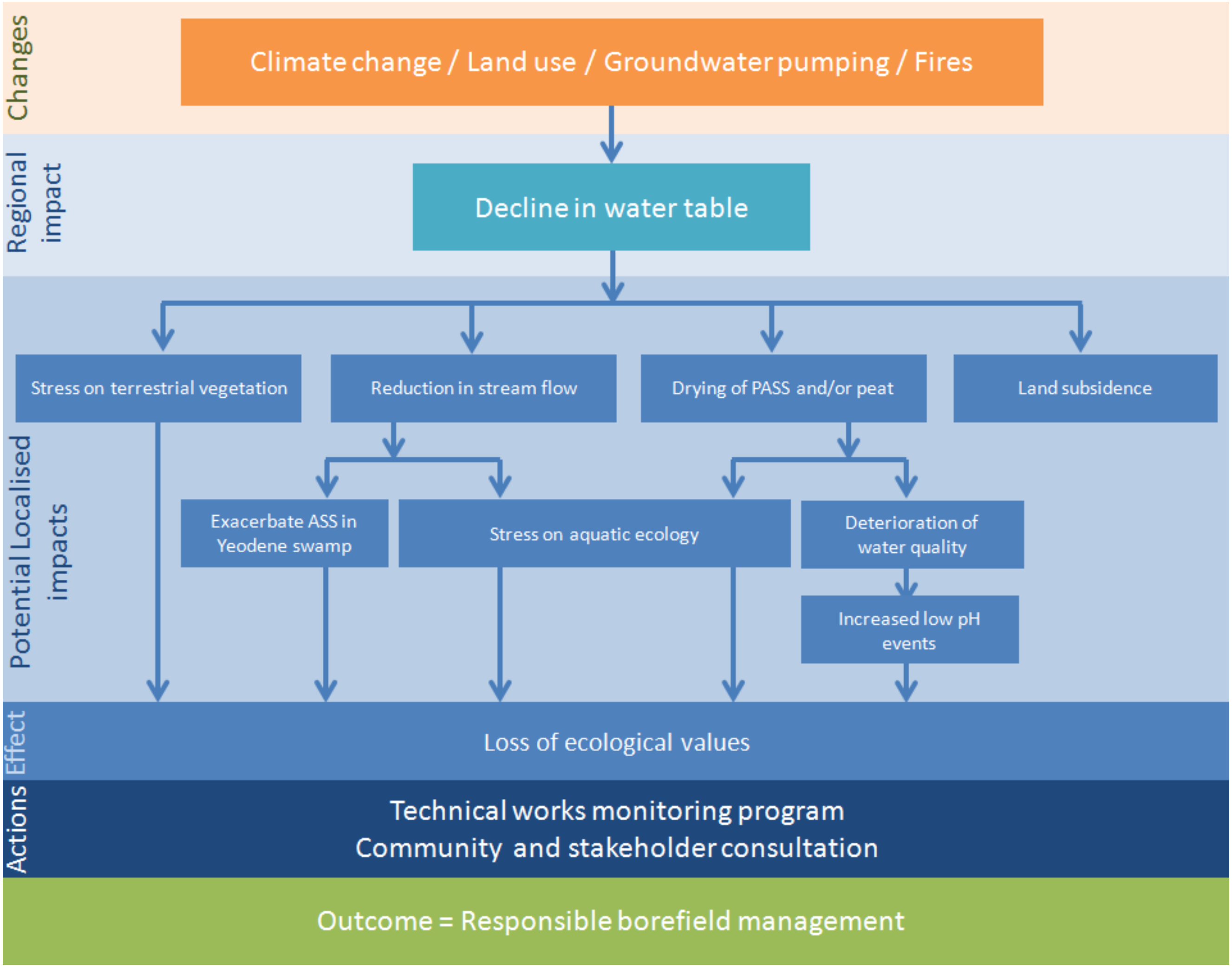


Figure 1-5 Potential impacts in the catchment from changes in the catchment.

1.6 This report

1.6.1 Background

The calibrated groundwater numerical model for Barwon Downs was revised in June 2017. This model was used to assess the likely historical impacts on groundwater level and river baseflow of pumping from the Barwon Downs borefield. The model has also been used to generate an estimated groundwater level that would have been seen, if pumping had not occurred. This report documents the results of using the calibrated numerical model to predict future potential groundwater effects (and then to provide an indication of any follow on environmental effects) from different operating regimes of the Barwon Downs borefield.

1.6.2 Objectives

The objectives of this study are to:

- Inform Barwon Water's upcoming licence application by using the groundwater model to predict potential impacts of future pumping on groundwater levels and environmental receptors in the Gerangamete region.
- Assess the level of risk associated with the predicted potential impacts of future pumping using an approach based on the Ministerial Guidelines for Groundwater Licensing and Protection of Groundwater Dependent Ecosystems (DELWP, 2015)
- Provide recommendations for:

- Appropriate triggers / off set measures where environmental receptors are at risk of future pumping, and
- The sustainability of the proposed pumping regimes for the duration of the next licence.

This report summarises possible impacts of future pumping to key environmental receptors in the Gerangamete region. Findings are based on analysis and interpretation of modelling scenarios run using the recently updated groundwater model which include:

- Two different pumping regimes (constant and intermittent pumping),
- Two no-pumping regimes to be used as a baseline with which to compare the impacts of the pumping scenarios,
- A range of climate change scenarios as per the DELWP Guidelines for assessing climate change on water availability (DELWP, 2016).

The risks associated with the predicted impacts have been assessed using a method based on the Ministerial Guidelines for Groundwater Licensing and Protection of Groundwater Dependent Ecosystems (DELWP, 2015).

1.6.3 Report structure

The structure of this report is as follows:

- Chapter 2 outlines the approach used to model the predictive scenarios
- Chapter 3 describes the potential impacts on the Lower Tertiary Aquifer
- Chapters 4 outlines the risk assessment framework used to determine the risk associated with the predicted drawdown.
- Chapters 5, 6 and 7 provide a detailed description of the risk assessment results for groundwater-surface water interaction, vegetation and potential acid sulfate soils.
- Chapter 8 details the recommended trigger levels.
- Chapter 9 outlines the conclusions and recommendations.

2. Model Scenarios

2.1 Chapter overview

The objective of this chapter is to describe the development of the model scenarios. Different climate scenarios and pumping scenarios were used to understand the range of potential impacts.

Four climate change scenarios were applied to four pumping scenarios to determine the influence of climate. The climate change scenarios are consistent with the Guidelines for Assessing Climate Change on Water Availability in Victoria (DELWP, 2016) and influence the volume of recharge to the aquifer and the timing for when the Barwon Downs borefield is predicted to be required.

Four pumping scenarios were developed in consultation with Barwon Water. Two scenarios assumed no pumping and were used to assess the impacts from pumping and the rate of recovery assuming there is no future pumping. Two scenarios assumed pumping at different rates and were used to compare the impacts of operating the borefield at a constant low rate or at higher rates on an intermittent basis.

The model scenarios are outlined in Table 2-1 and described in more detail in the following sections.

Table 2-1 Overview of model scenarios

Model scenarios	Description	Climate assumptions
Scenario 0 (no pumping)	Baseline scenario assumes no past or future pumping to understand the influence of climate only	Low climate change Moderate climate change High climate change Step change climate change
Scenario 1 (no future pumping)	Assumes no future pumping to understand the rate of recovery of the aquifer system from historical pumping	
Scenario 2 (constant future pumping)	Assumes a constant pumping rate until 2067	
Scenario 3 (intermittent future pumping)	Assumes an intermittent pumping rate until 2067 which is a similar operating regime to the past.	

2.2 Overview of the numerical 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).

2.3 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 2-2. 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 2-2: 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

2.4 Aquifer volume

The estimated total volume of the Lower Tertiary Aquifer is 3,000,000 ML.

The maximum annual volume extracted during the constant rate pumping scenario is 4,000 ML or 0.1% of the total aquifer volume. The maximum annual volume extracted during the intermittent pumping scenario is 12, 000 ML or 0.4% of the total aquifer volume.

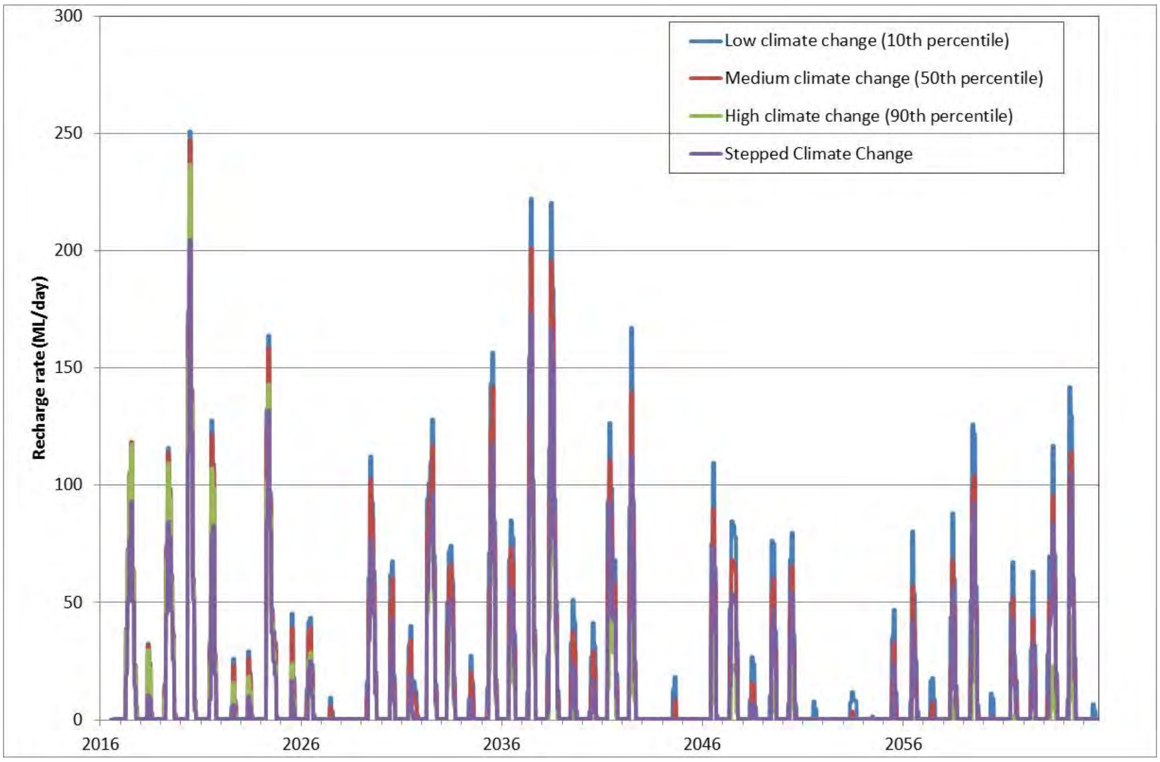
2.5 Recharge to the Lower Tertiary Aquifer

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 2-3 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 2-3: 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 2-1 : Recharge rate variability on the outcropping LTA



2.6 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.

2.6.1 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).

2.6.2 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 2-2.

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.

Table 2-4 illustrates the reduction in volumetric limits that Barwon Water are proposing in the next licencing period in line. A summary of the model scenarios is provided in Table 2-5.

Table 2-4 : 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 2-2 Cumulative groundwater extraction rate for Scenario 2 and 3

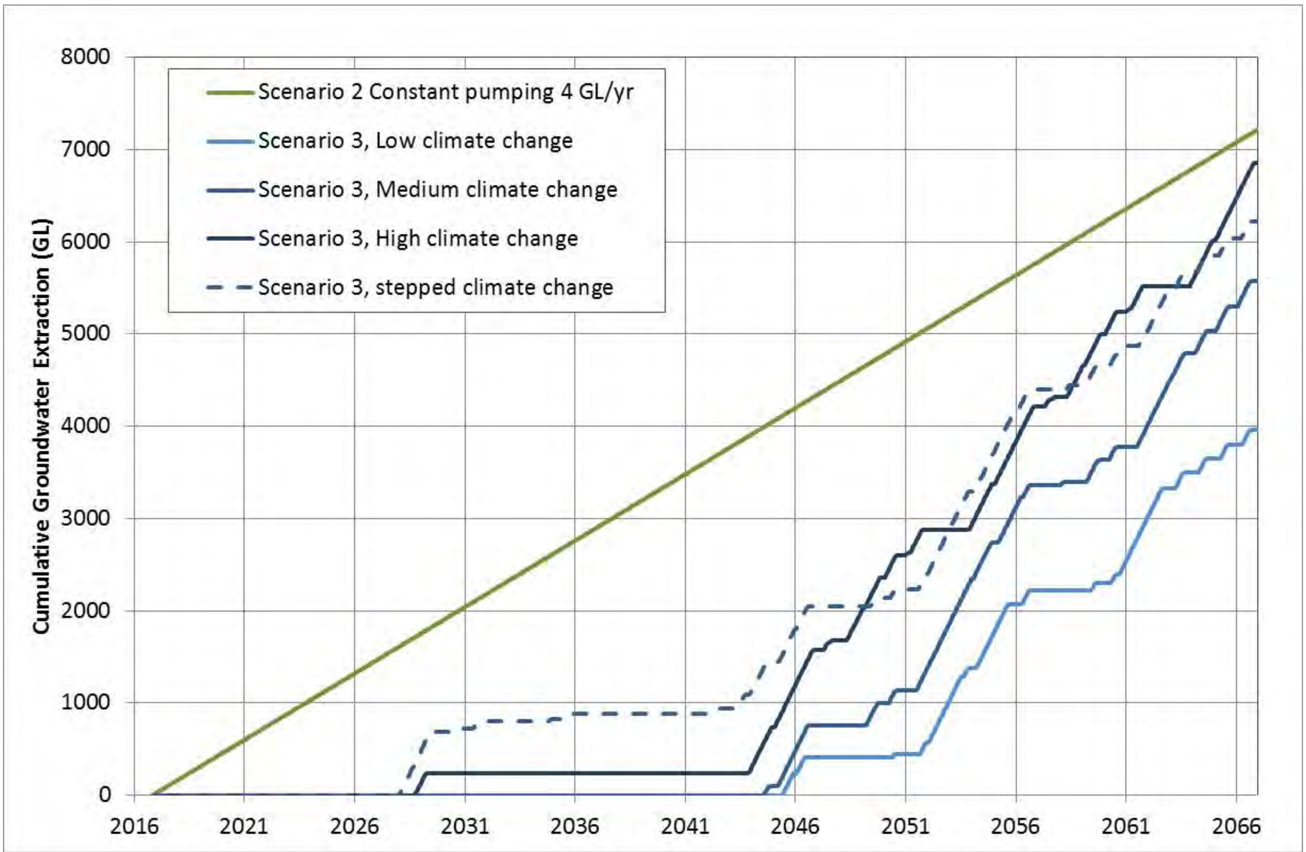


Table 2-5 Overview of the model scenarios

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.

3. Potential impact on the Lower Tertiary Aquifer

3.1 Chapter overview

The purpose of this chapter is to describe the potential adverse effects of the groundwater extraction from the Barwon Downs borefield on the Lower Tertiary Aquifer (LTA) or any other aquifer. Potential adverse impacts were discussed 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.

Drawdown is a key indicator is used to understand the potential impacts such as changes to groundwater availability, aquifer matrix, groundwater quality and impacts to environmental receptors that are dependent on groundwater such as rivers, wetlands and vegetation. This chapter describes the impacts to the aquifer. The relationship between drawdown and impacts to environmental receptors is discussed in the following chapters.

Based on the technical work that has been completed and summarised as part of the Technical Works Monitoring program, it has been concluded that there is no adverse effect on any aquifer likely to arise from the allocation or use as proposed under the licence application. The key findings relating to drawdown in response to pumping are highlighted in Table 3-1.

Table 3-1 Key findings relating to drawdown in response to pumping

Potential impacts	Key Findings
Groundwater mining	• Groundwater mining occurs when groundwater extraction rates exceed recharge rates, so that groundwater levels decline over the long term (50 to 100 years). • Groundwater mining is not predicted to occur in Barwon Downs as the proposed extraction rates do not exceed the recharge. • The aquifer will return to its-predevelopment condition when the borefield is no longer operational. • Groundwater levels close to the borefield have recovered approximately 80% since 2010 when the borefield was last used. Groundwater levels are predicted to reach 90% recovery within 10 years if there is no future pumping. • Typical of an aquifer recovering, the rate of recovery is slower further away from the borefield. At Boundary Creek, groundwater levels would take between 20 to 30 years to recover if there is no future pumping.
Irreversible changes to the aquifer	• Drawdown in an aquifer as a result of pumping can reduce pressure in confined aquifers which can subsequently cause settlement (subsidence) in an aquifer. This can impact on the aquifer's capacity to store water. • Most instances of subsidence arising from groundwater extraction occur as a result of compaction of clay rich aquitards overlying the aquifer. • There is no evidence to suggest that the aquifer matrix of the LTA has been impacted by pumping. The predicted drawdown in the future is similar to historical and for this reason pumping is not expected to cause changes to the aquifer matrix in the future.
Effect on water quality	• Groundwater salinity has been monitored annually. While there has been some variability in groundwater salinity, operating the borefield has not had an adverse impact on the groundwater quality.
Effect on land subsidence	• Land subsidence has been monitored annually at various locations. The reported subsidence has not exceeded the limits specified in the licence conditions. The predicted drawdown in the future is similar to historical, and for this reason land subsidence is expected to be similar to historic levels.

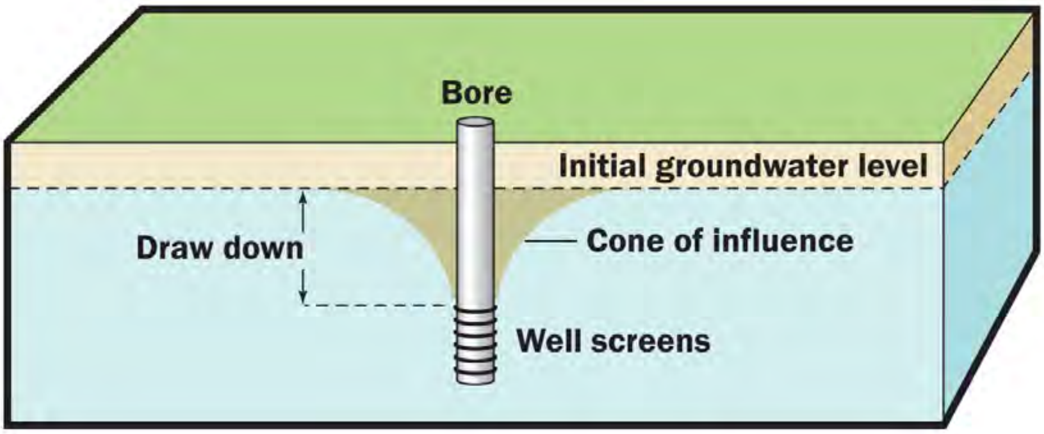
3.2 What is drawdown?

Drawdown in response to pumping is used to assess the sustainability of the groundwater supply and potential impacts to the groundwater dependent ecosystems (GDEs) such as rivers, wetlands and vegetation. Groundwater pumping always induces drawdown in the aquifer which can adversely impact nearby groundwater users and GDEs if groundwater levels decline too much. In the case of Barwon Downs, there are no other groundwater users in the aquifer. However, there are many ecosystems that are dependent on groundwater, so it is important to understand what impact the predicted drawdown with have on these.

Groundwater level across the catchment fluctuates in response to climate conditions and groundwater extraction. When the borefield is operational, the drawdown cone spreads in an elongated ellipse along the axis of the graben (northeast to southwest). The cone of depression is generally steep which reflect the low regional transmissivity of the aquifer (Witebsky, 1995).

The drawdown has been calculated as the difference between the predicted groundwater level assuming no pumping (Scenario 0) and the predicted groundwater levels after pumping (Scenarios 2 and 3). A conceptual diagram showing the drawdown generated by a pumping bore is illustrated in Figure 3-1, which shows drawdown in an unconfined aquifer. Drawdown in a confined aquifer will induce drawdown in overlying aquifers and aquitards, however this takes significantly longer (i.e. years) to eventuate.

Figure 3-1 Illustration of drawdown and cone of influence generated from a pumping bore



3.3 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 3 2. 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 3 2: 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

3.4 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 3 3. This framework has been adopted to determine the impact of drawdown from the Barwon Downs borefield on the aquifer.

Table 3 3: 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.

3.4.1 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 3 3 and shown in Figure 3.2 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 3.2 and Figure 3.3 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 3.2: Contours of predicted drawdown in the confined LTA for the intermittent pumping scenario (moderate climate change)

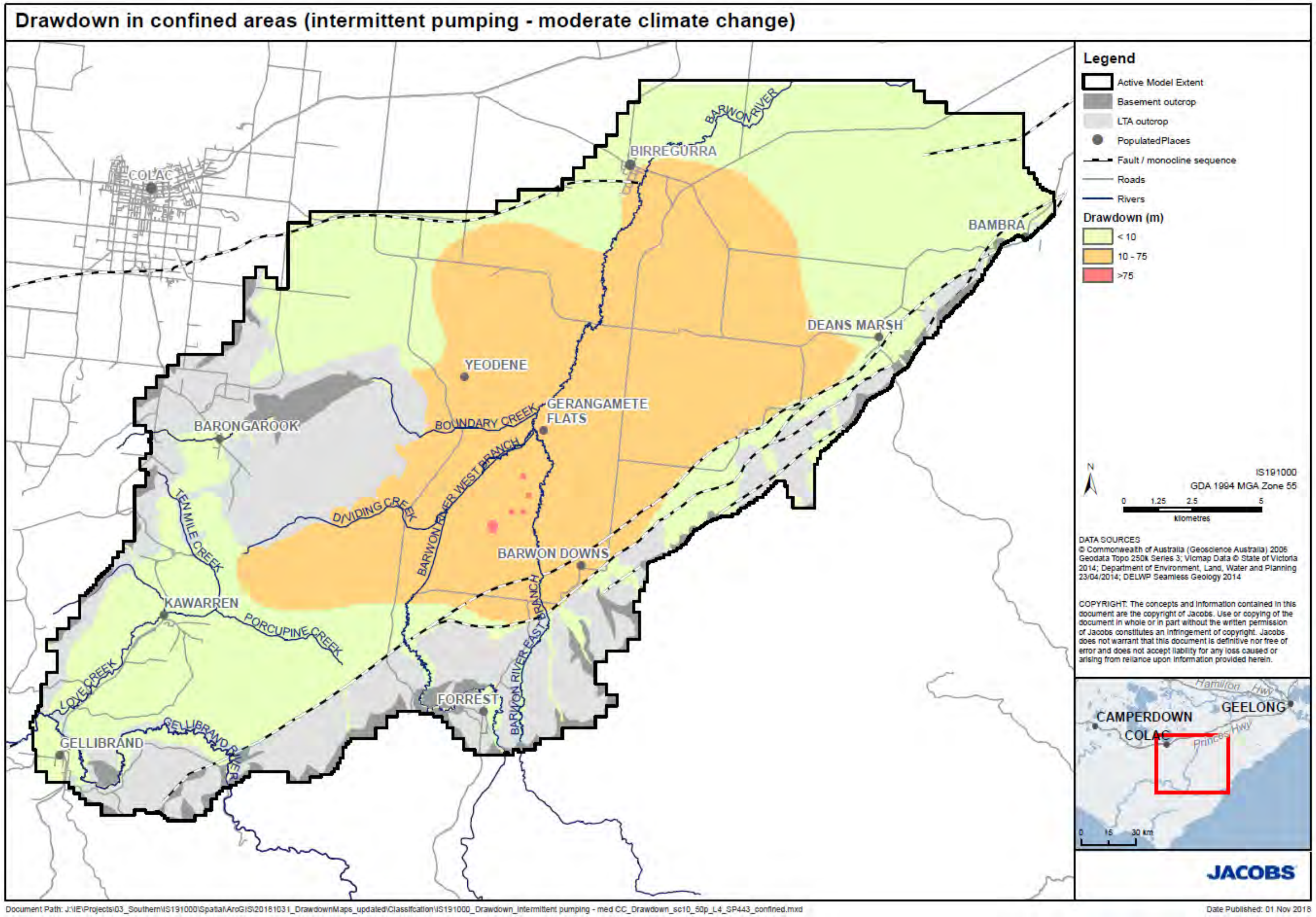


Figure 3.3: Contours of predicted drawdown in the confined LTA for the constant pumping scenario (moderate climate change)

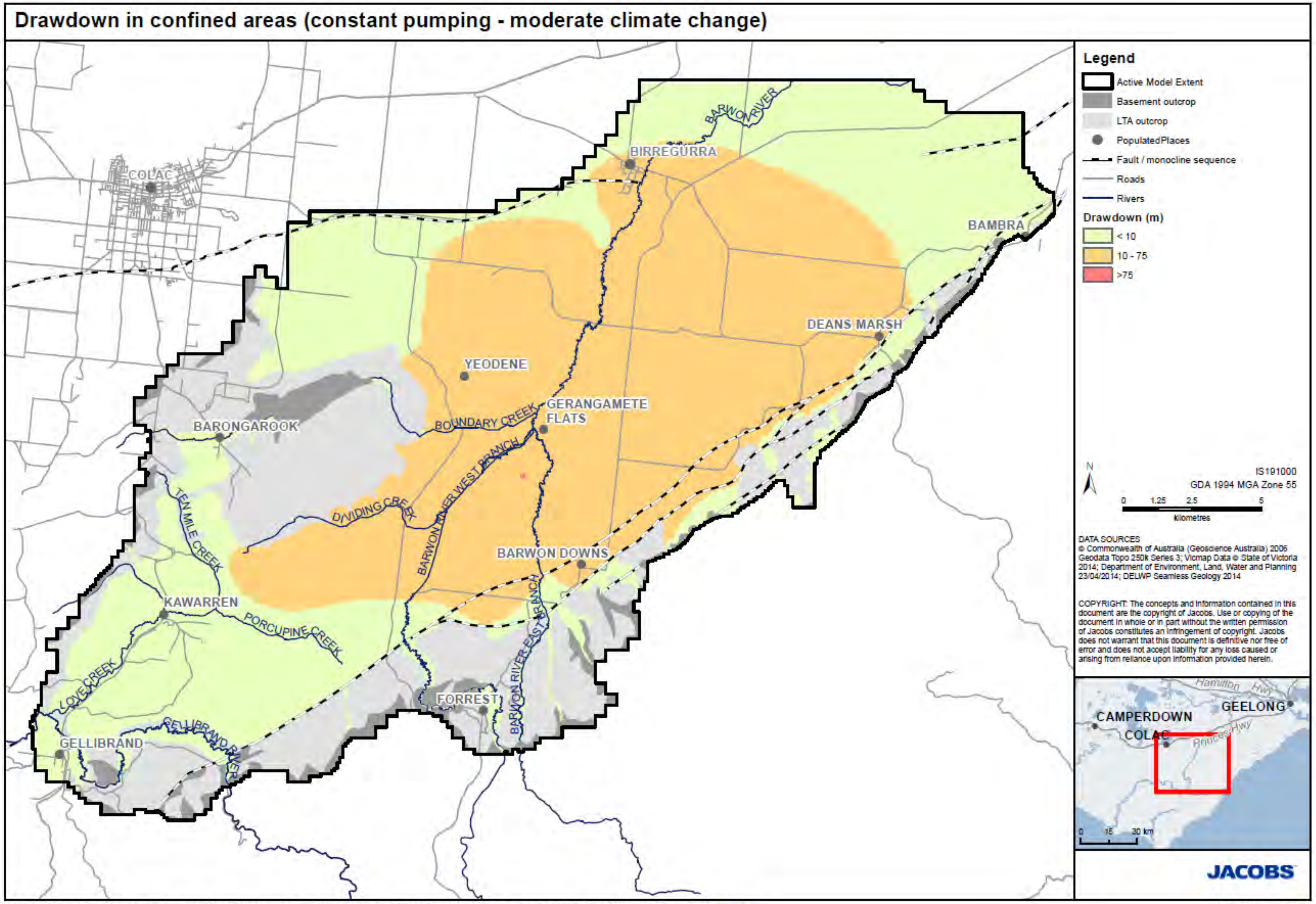


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Figure 3.4: Contours of predicted maximum drawdown in the unconfined LTA for the intermittent pumping scenario (moderate climate change)

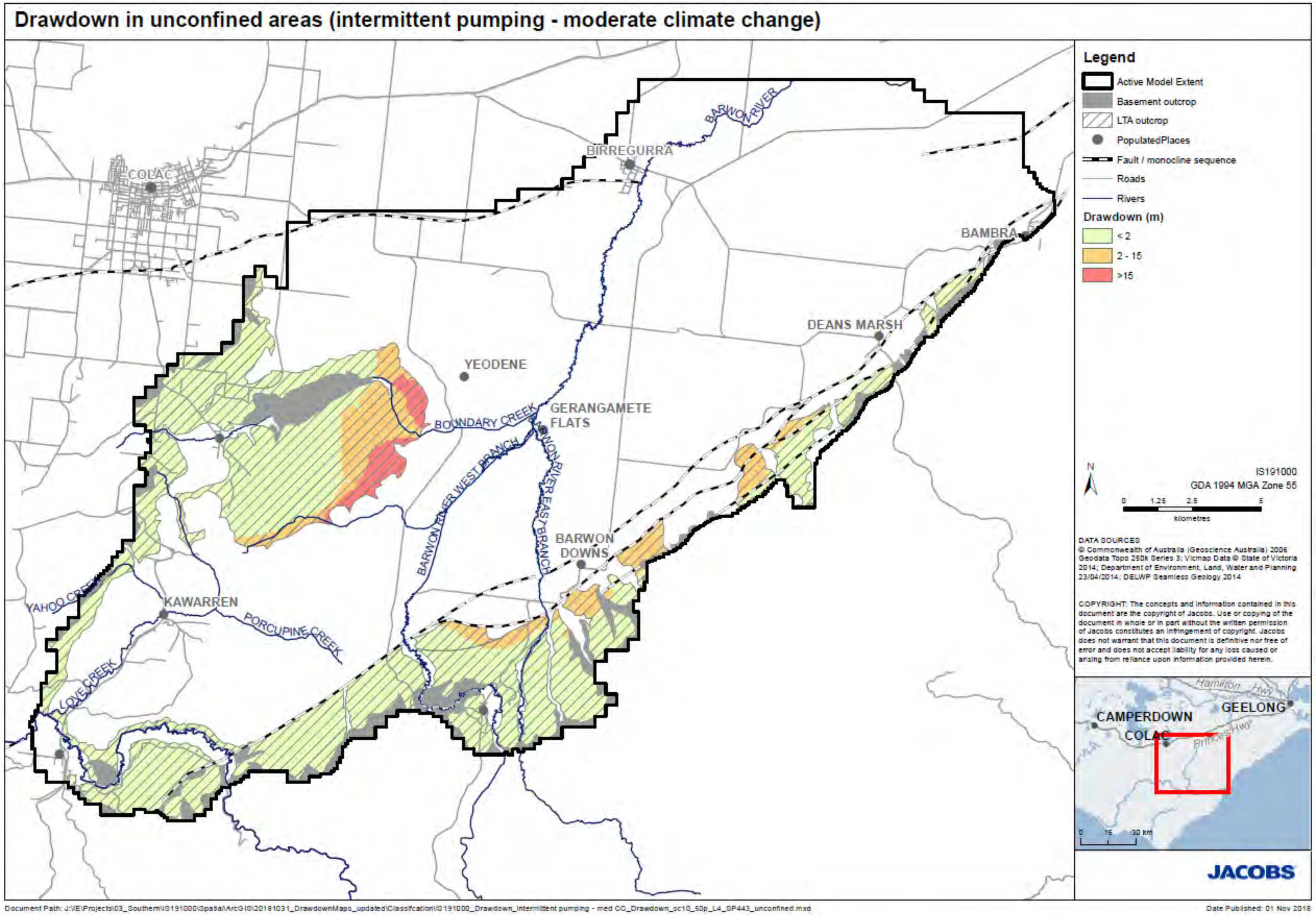
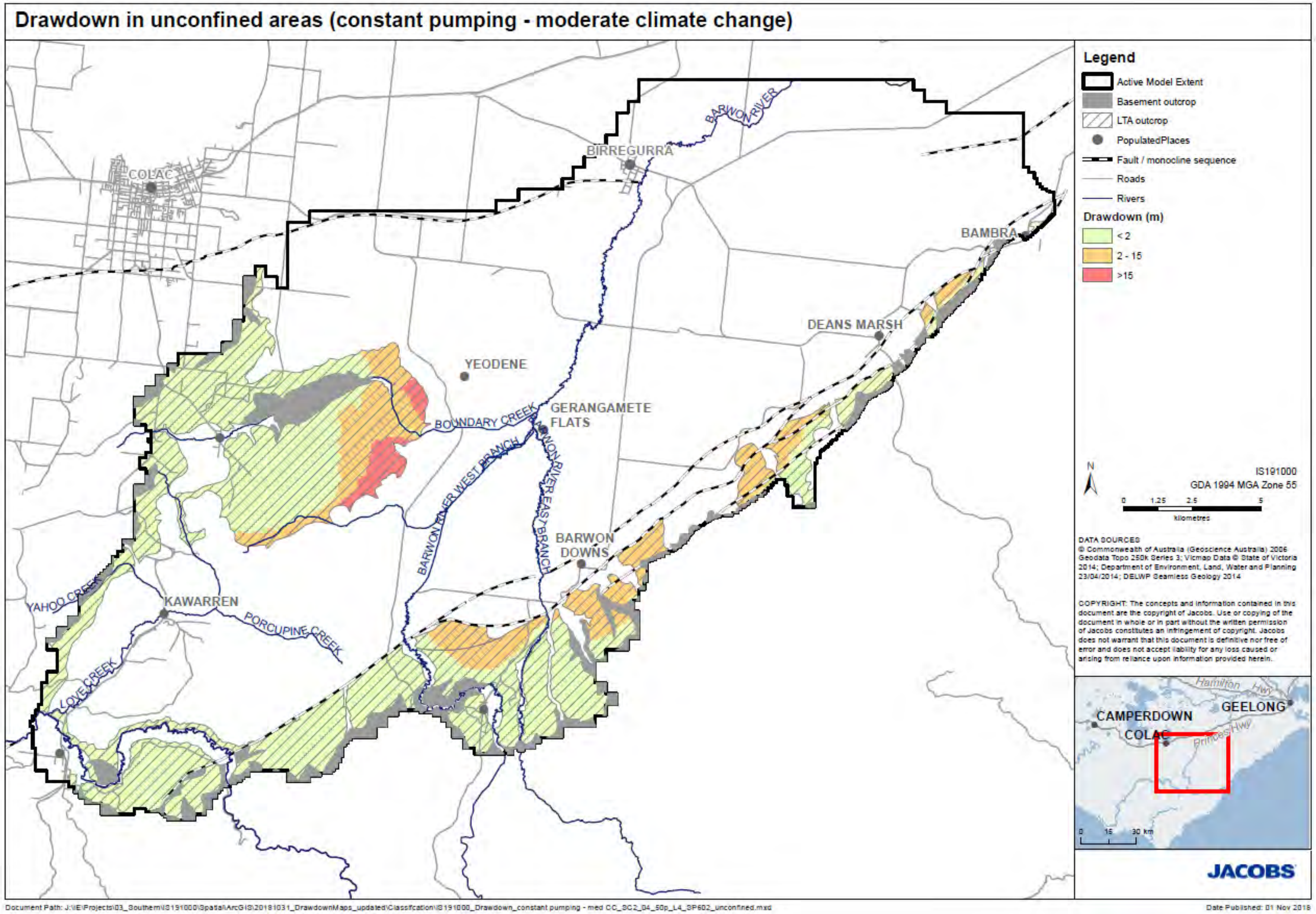


Figure 3.5: Contours of predicted maximum drawdown in the unconfined LTA for the constant pumping scenario (moderate climate change)



3.4.2 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 3-6 shows the predicted recovery of groundwater levels in selected bores around the model domain.

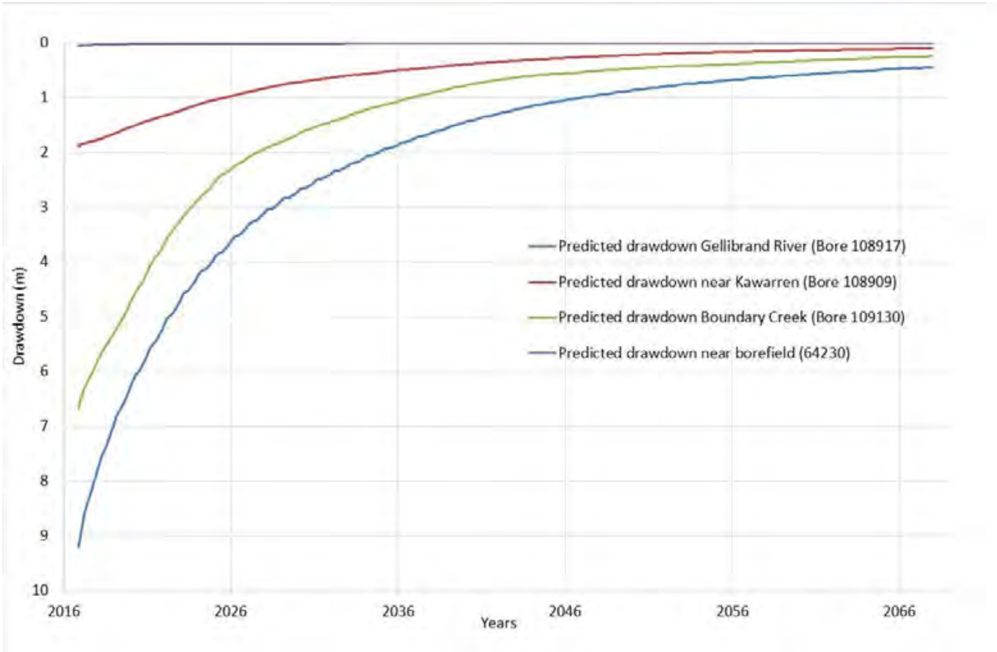
Water levels near the borefield (Bore 64230) show that the residual drawdown in 2016 was around 10 m. The maximum drawdown in this bore from historical pumping was 58 m, which highlights that the water levels had recovered over 80% in 2016. The aquifer is expected to have recovered to 90% (5-6 m drawdown) 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 3-6 Predicted water level recovery from 2016 assuming no future pumping for the moderate climate change scenario



3.5 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 3.7. 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 3.8 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 3.7: Groundwater salinity measurements in bores monitored as a condition of the current licence

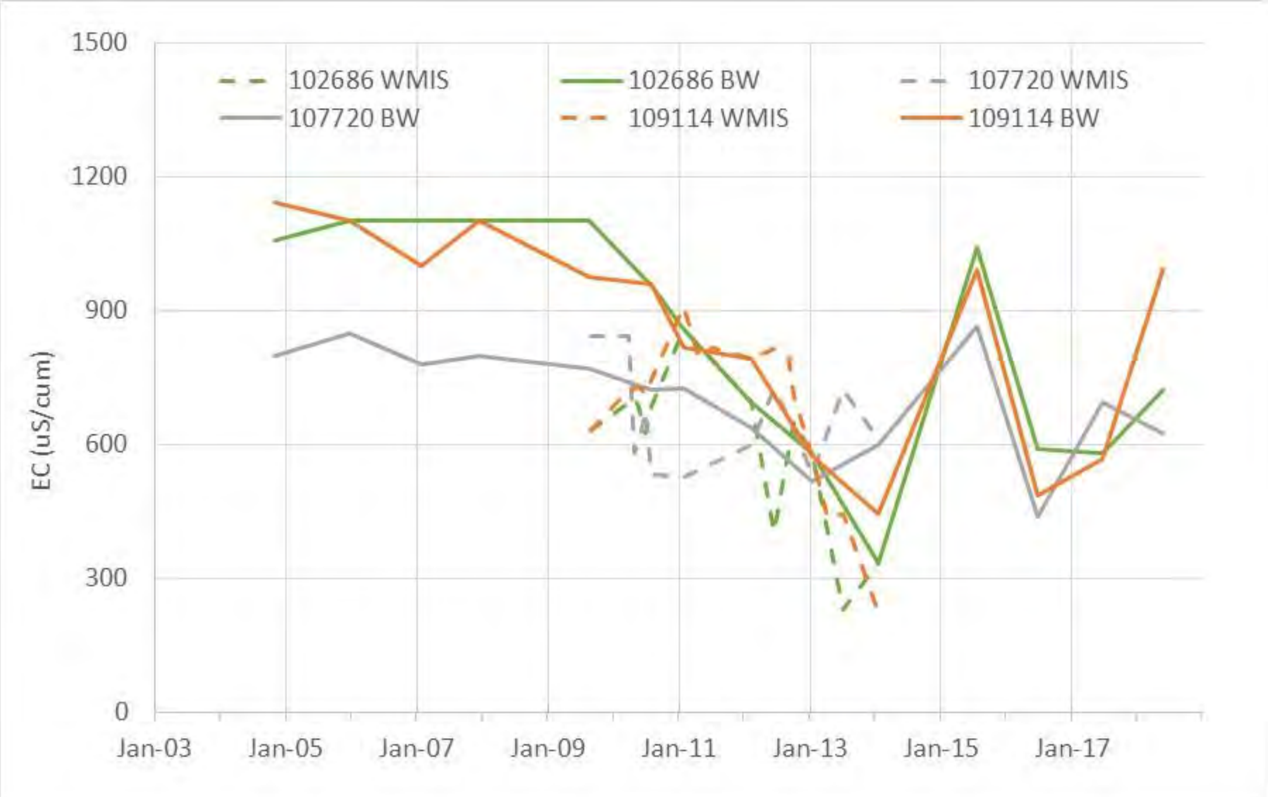
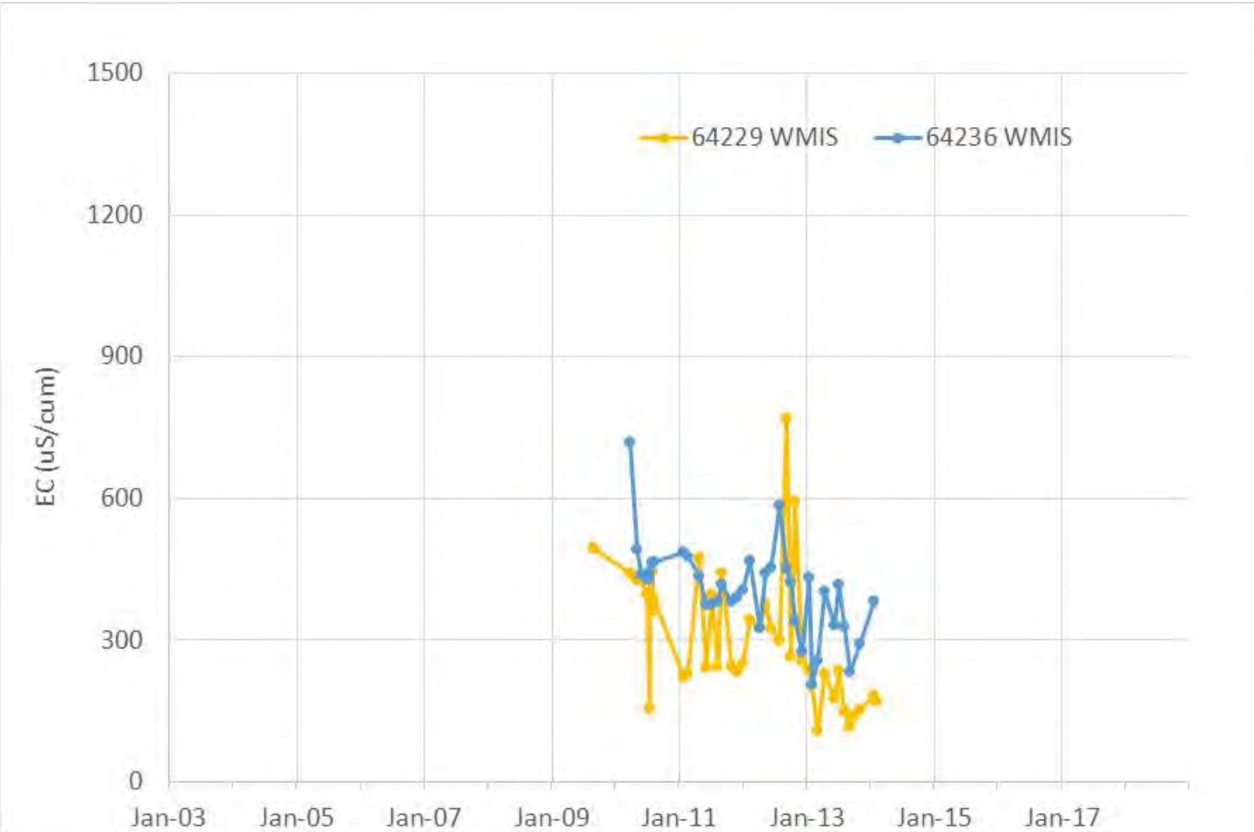


Figure 3.8: Groundwater salinity measurements from WMIS



3.6 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.

4. Risk assessment framework for receptors

4.1 Chapter Overview

This chapter outlines the risk assessment framework used to determine the risk to groundwater dependent environmental receptors such as rivers, creeks, vegetation and potential acid sulfate soils (PASS) from groundwater pumping.

The risk assessment framework has been adopted from Victoria's Ministerial Guidelines for Groundwater Licensing and the Protection of High Value Groundwater Dependent Ecosystems (DELWP, 2015). The level of risk is based on the likelihood of connection to groundwater and the consequence of the predicted impact in terms of drawdown or comparison to streamflow. The framework incorporates conservative guidelines regarding drawdown to ensure that any potential risk is identified.

The risk assessment framework does not include potential acid sulfate soils as these are not a high value groundwater dependent ecosystem (GDE). However, they are dependent on groundwater to ensure they remain saturated and do not release acid. Consequently, the risk assessment framework for vegetation has also been adapted and used for PASS.

The risk assessment framework is tailored for each receptor and the key components are outlined in Table 4-1.

Table 4-1 : Key components of the risk assessment framework for each receptor

Receptor	Likelihood	Consequence
Rivers	Likelihood based on depth to watertable	Consequence is based on predicted reduction in streamflow and expressed as a percentage of low flow.
Vegetation		Consequence is based on the drawdown induced by groundwater pumping
PASS		Consequence is based on the drawdown induced by groundwater pumping

4.2 Ministerial Guidelines

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.

4.3 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:

- o Likelihood x Consequence = Risk

These are described in more detail below.

4.3.1 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 4-2):

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

Table 4-2 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

4.3.2 Consequence

The **consequence** of pumping has been considered using both measures outlines in Table 4-3:

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 4-3).

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 4.2.

Table 4-3 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 4.1: Likelihood of surface water connection to groundwater

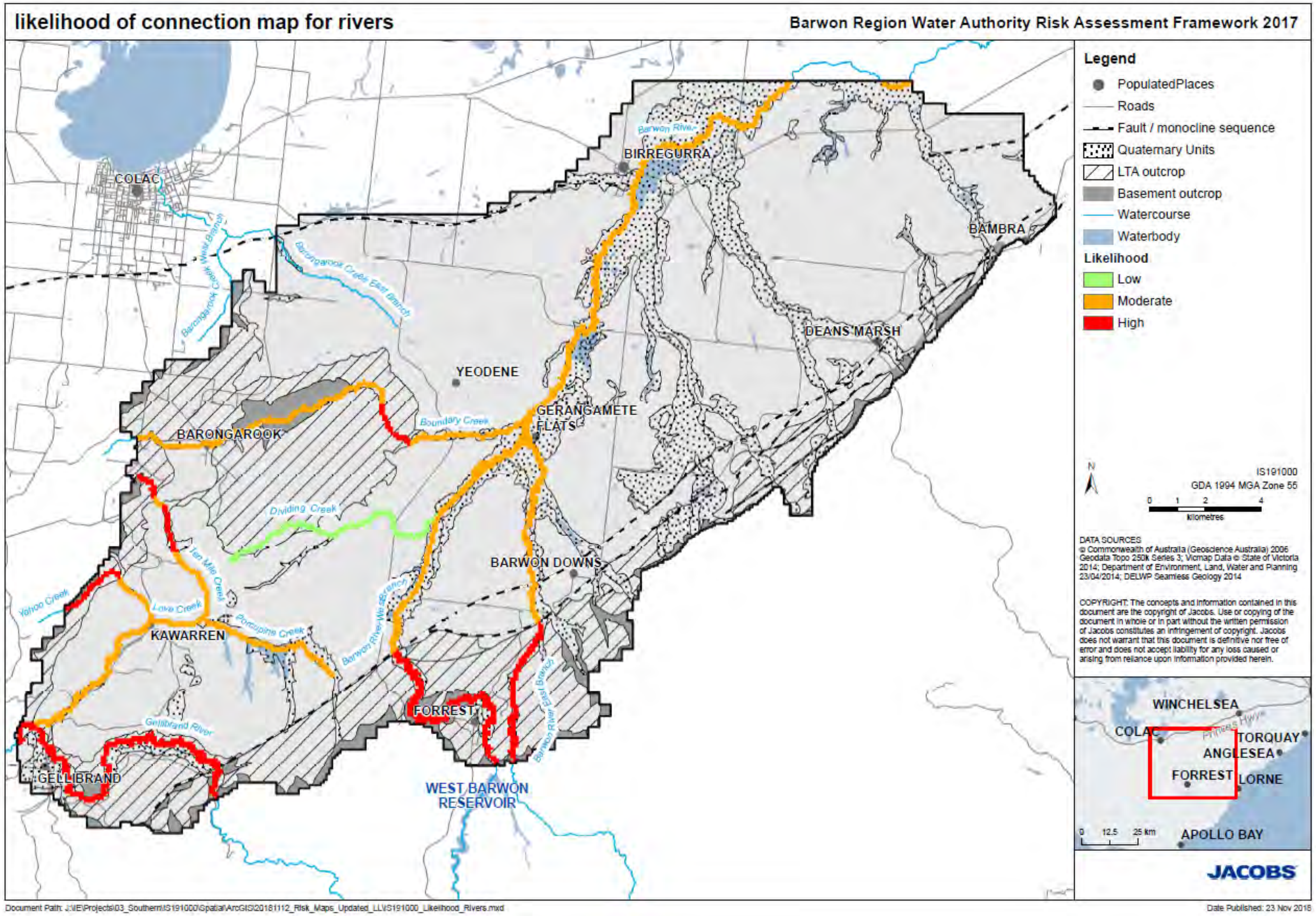
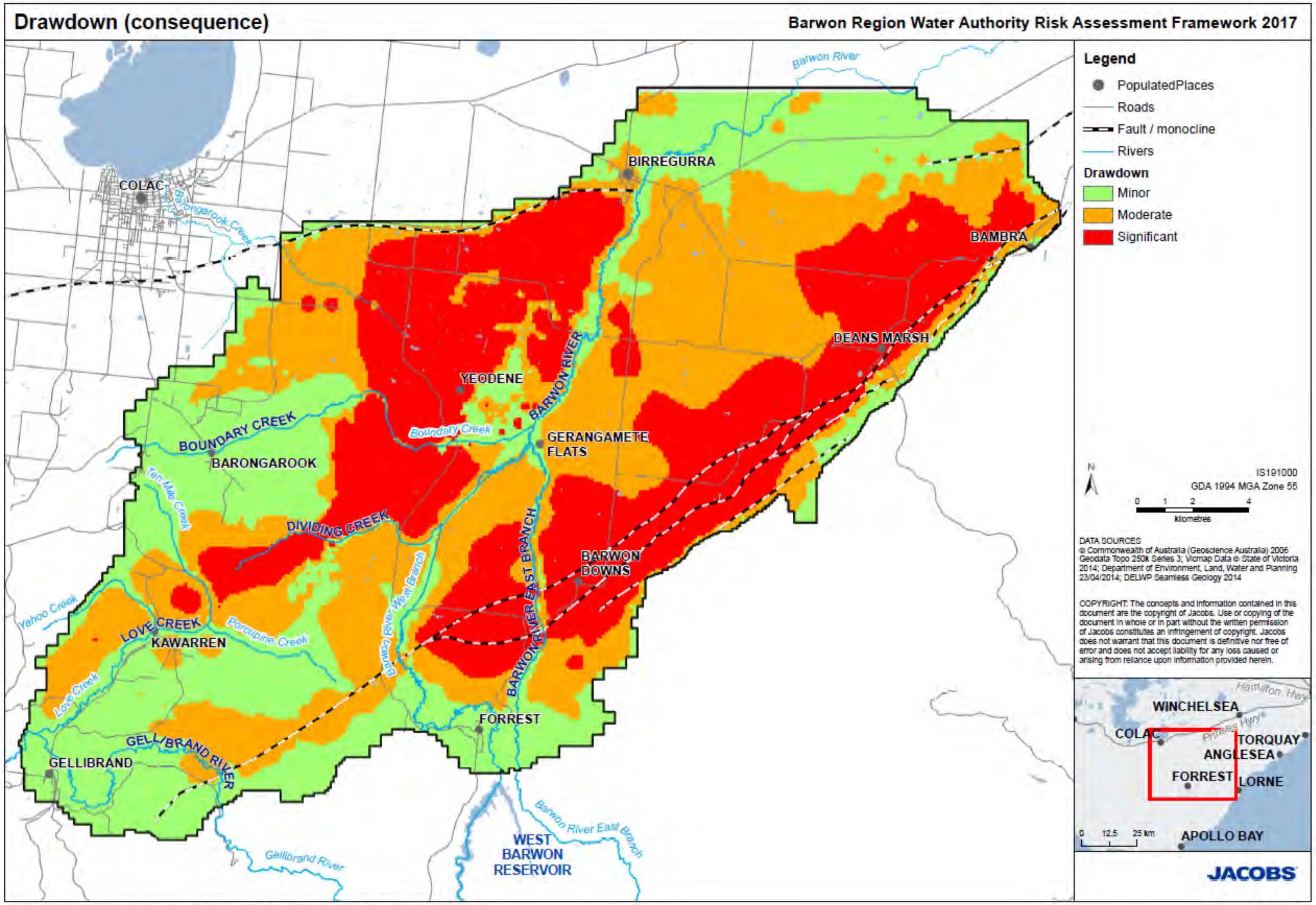


Figure 4.2: Drawdown in the model watertable aquifers as a measure of consequence of impact of the borefield



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4.3.3 Risk

The risk assessment framework is shown in Table 4-4.

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 4-4 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		

4.4 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 4-5)
- **Consequence** of the proposed groundwater extraction on the feature defined by the drawdown in the regional aquifer (see Table 4-6)
- **Risk** is considered in terms of low, medium, high risk using the following equation (see Table 4-7):
  - Likelihood x Consequence = Risk

Table 4-5 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 4-6 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 4-7 Risk assessment framework

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

5. Potential risk to rivers

5.1 Chapter overview

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
- Dividing Creek
- Gellibrand River – including tributaries Porcupine Creek, Ten Mile Creek, Yahoo and Loves Creek
- Barongarook Creek.

This chapter describes the predicted impacts of potential drawdown from future groundwater pumping on groundwater baseflow to rivers in the model domain. The associated risk using the risk assessment framework outlined in the Ministerial Guidelines for High Value GDEs is also outlined. An overview of the risk assessment framework and the implications of drawdown on groundwater surface water interactions across the catchment is described in the following sections as well as a brief summary of the current streamflow monitoring network. The key findings are outlined in Table 5-1.

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).

Table 5-1 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.	High

Environmental receptors	Risk assessment outcomes	Residual risk ranking
	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.	
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. 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, 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

Environmental receptors	Risk assessment outcomes	Residual risk ranking
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

5.2 Available surface water flow monitoring data

Streamflow monitoring data varies across the model domain. Table 5-2 summarises the streamflow data and the location of the streamflow monitoring gauges is shown in Figure 5-2.

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 4-3 in Section 4.3.2).

Table 5-2 : 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

Gauge	Description	Active/ Inactive	Record length	Confidence rating
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 5.1: Location of river reaches in the model

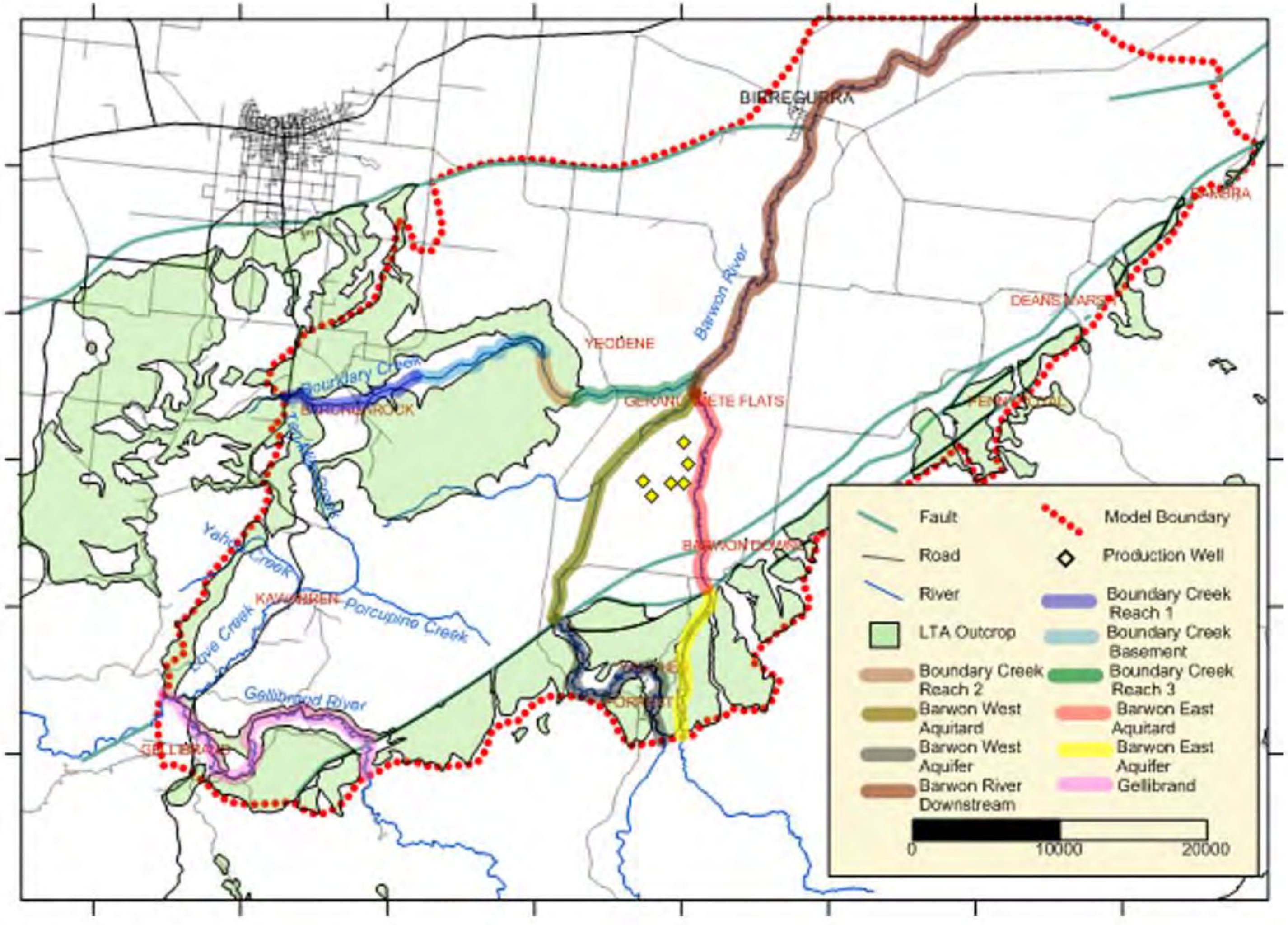
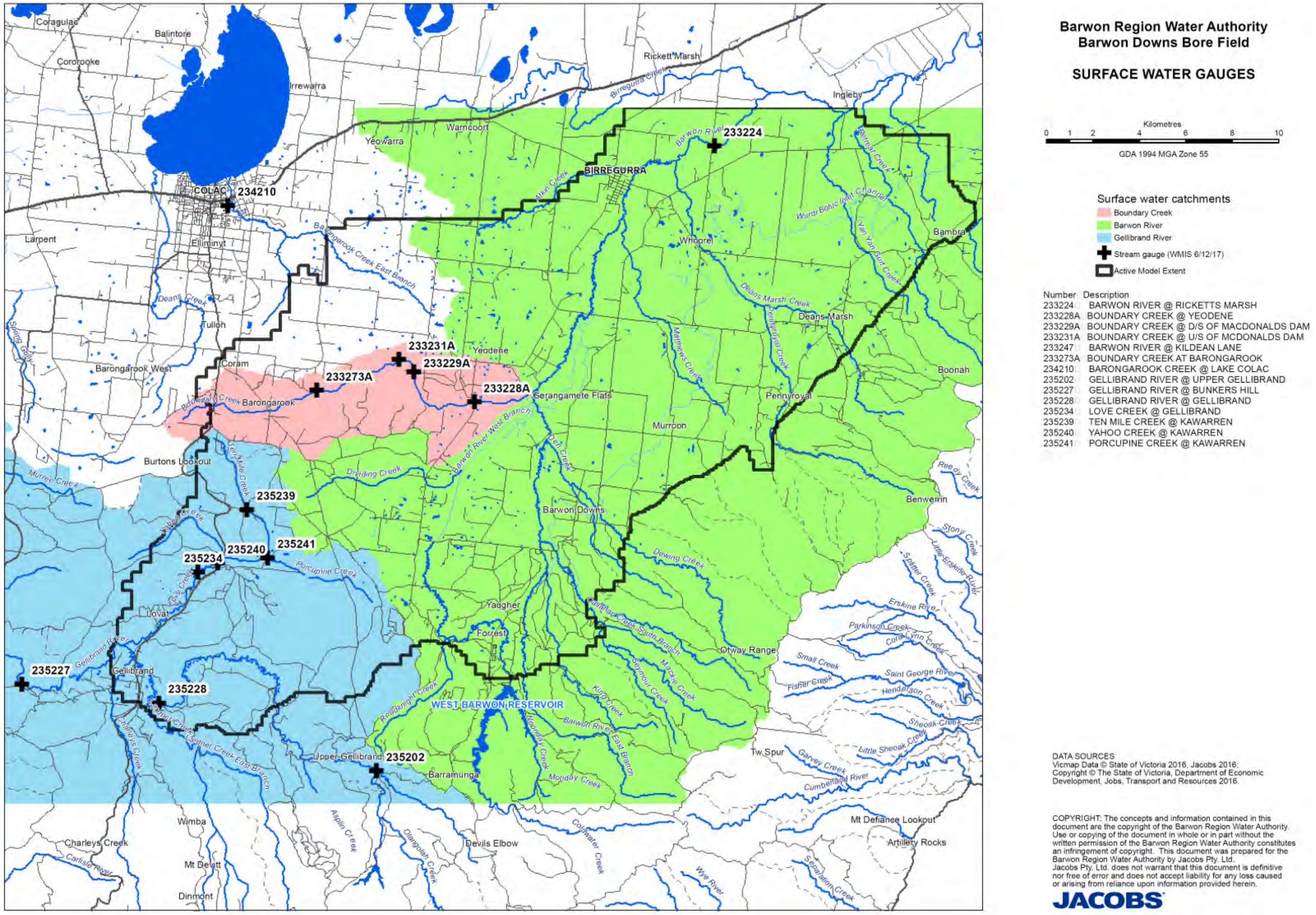


Figure 5-2 Location of relevant streamflow monitoring gauges in the model domain



5.3 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 4.3.

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.

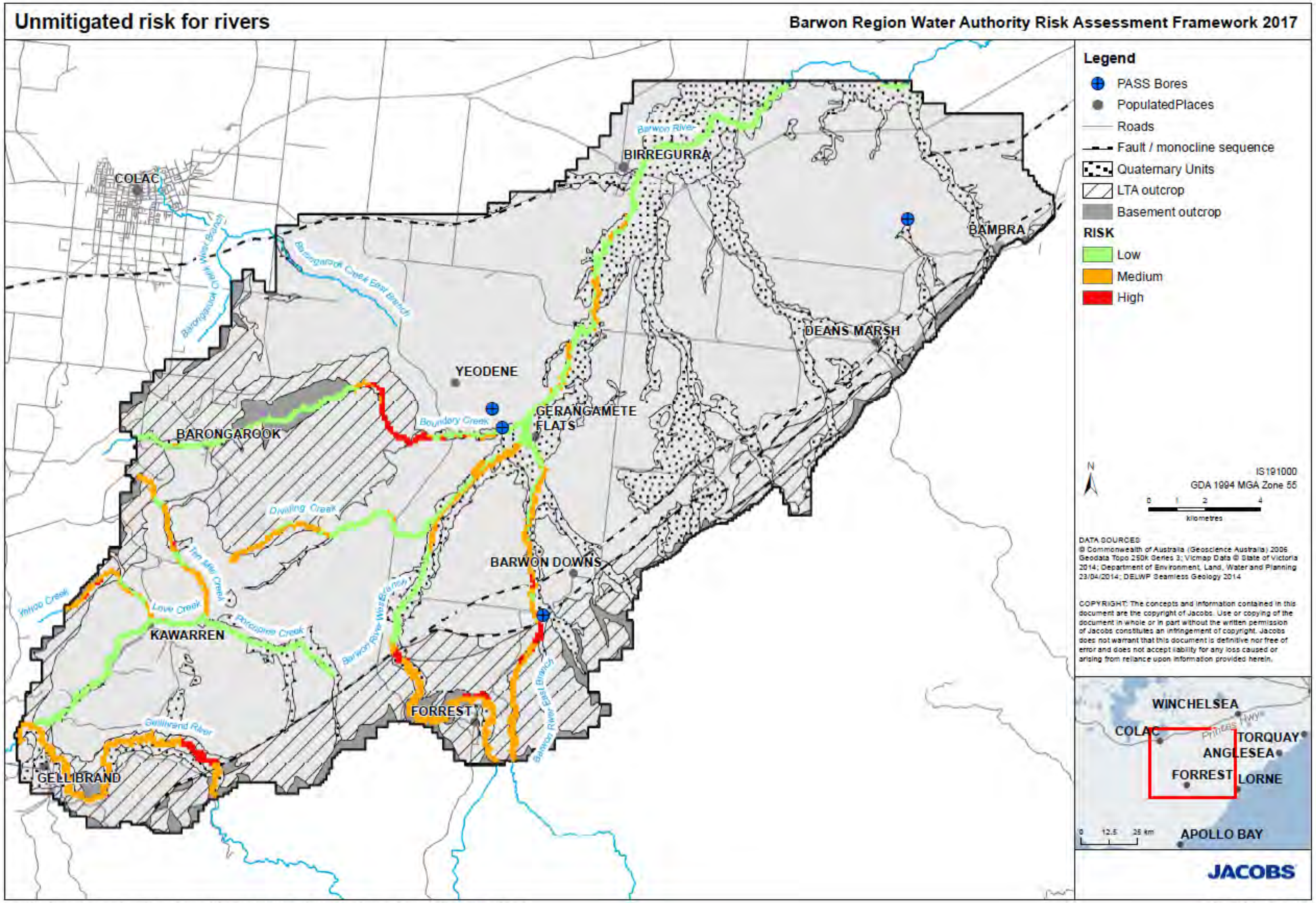
The baseflow contributions is described for three scenarios:

- 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 5-3. Figure 5-4 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.

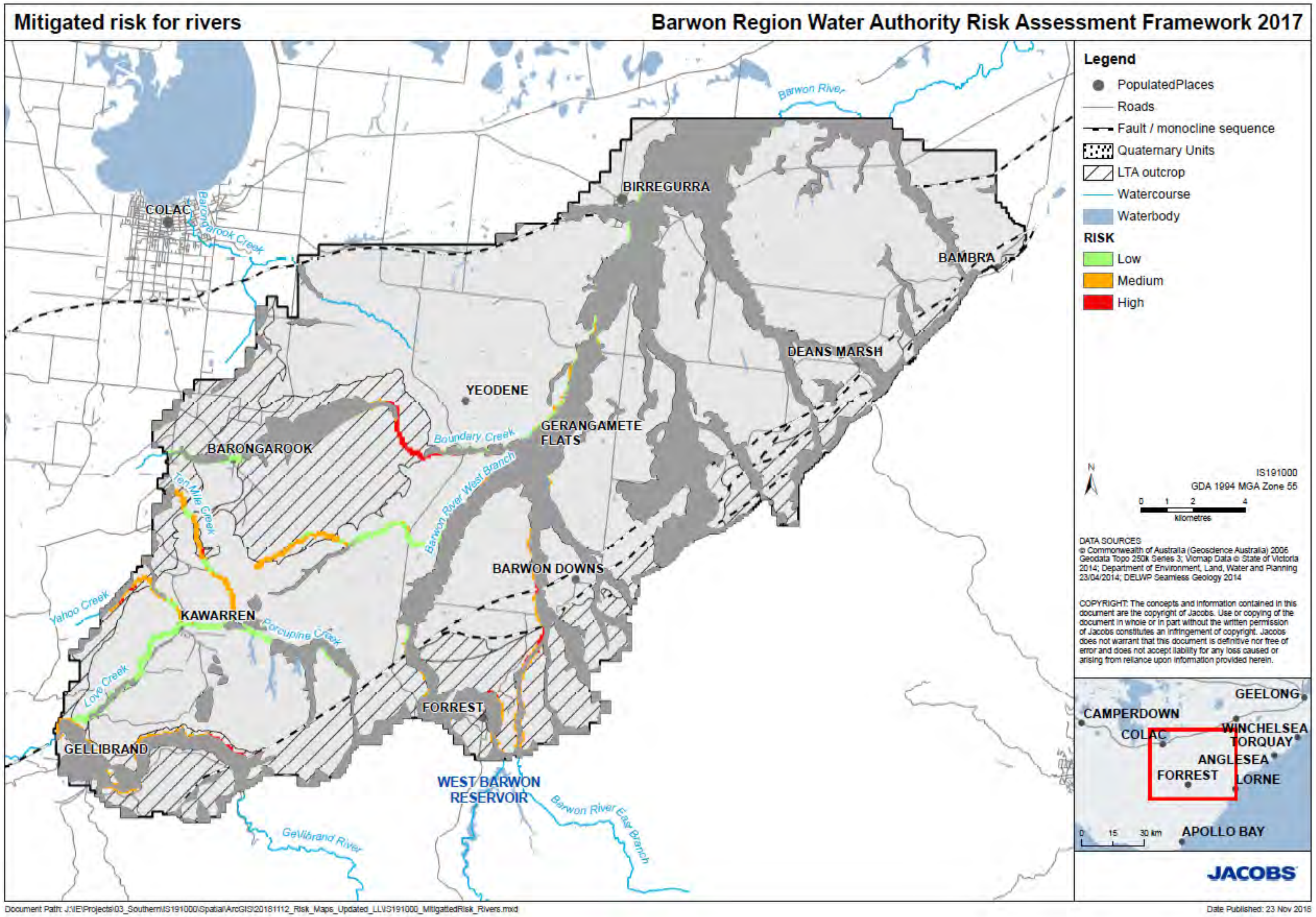
Figure 5-3 Spatial representation of the unmitigated risk to creek or river based on drawdown



Document Path: J:\IE\Projects\03_Southern\IS191000\Spatial\ArcGIS\20181112_Risk_Maps_Updated_LL\IS191000_UnmitigatedRisk_Rivers.mxd

Date Published: 26 Nov 2018

Figure 5-4 Spatial representation of the mitigated risk to creek or river based on drawdown



5.3.1 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 5-5.

Figure 5-5 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 5-3 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 5-5 Predicted change in groundwater contribution to Boundary Creek for the calibration and predicted model assuming intermittent pumping and moderate climate change

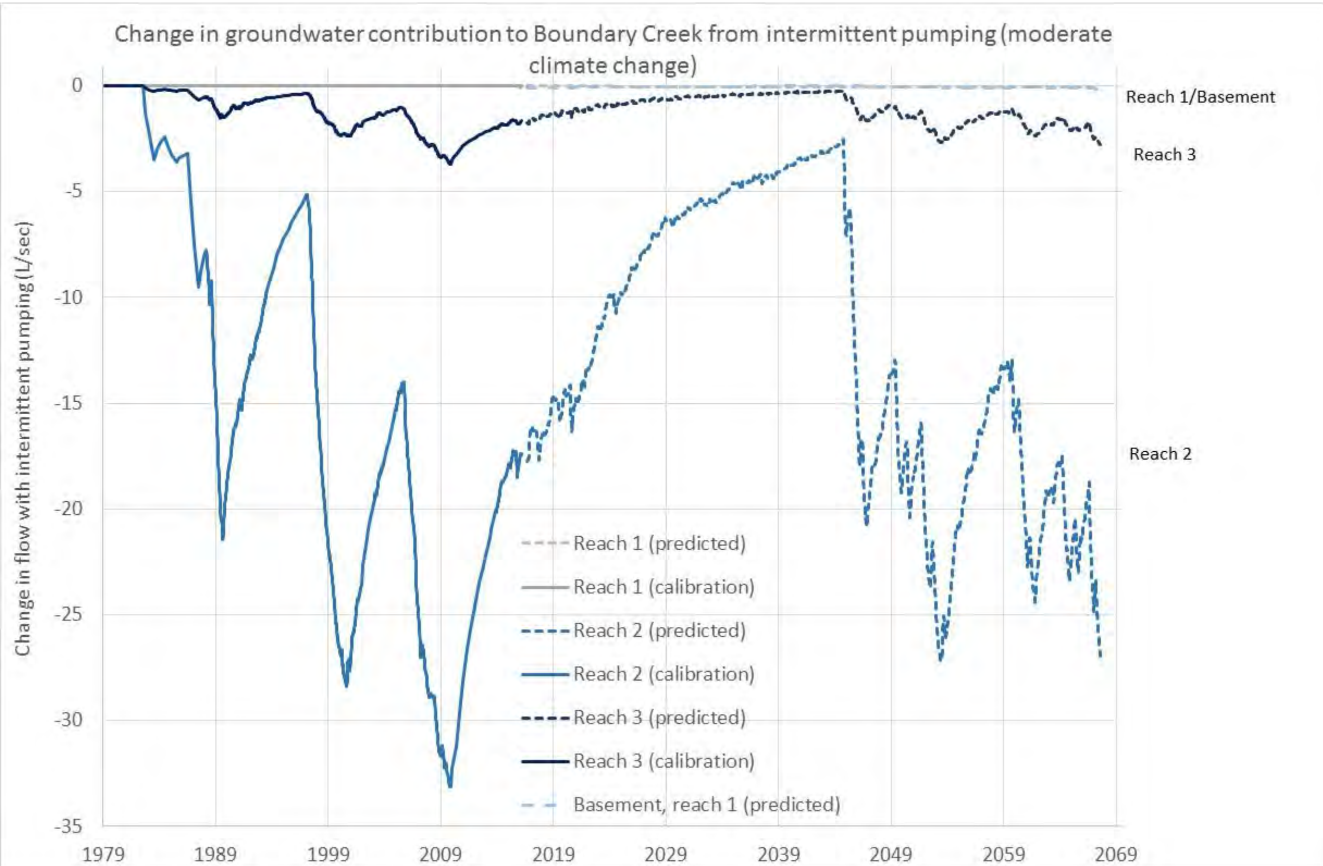


Table 5-3 Risk to Boundary Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

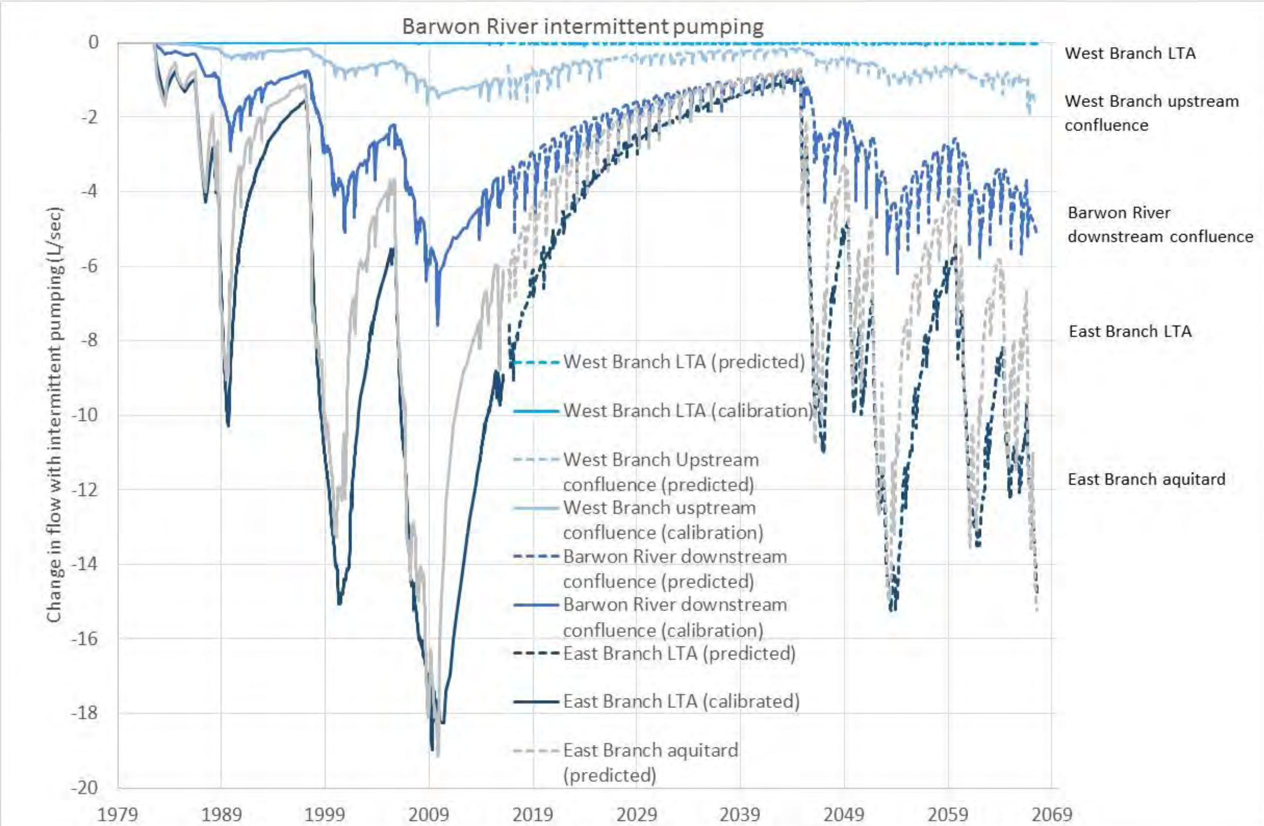
5.3.2 Barwon River

The predicted change in groundwater contributions to the Barwon River for both the calibration and predictive models is shown in Figure 5-6. This illustrates the impacts of historical and potential future pumping, assuming moderate climate change and a constant pumping regime.

Figure 5-6 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 5-6 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 5-4 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 5-4 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**

5.3.3 Dividing Creek

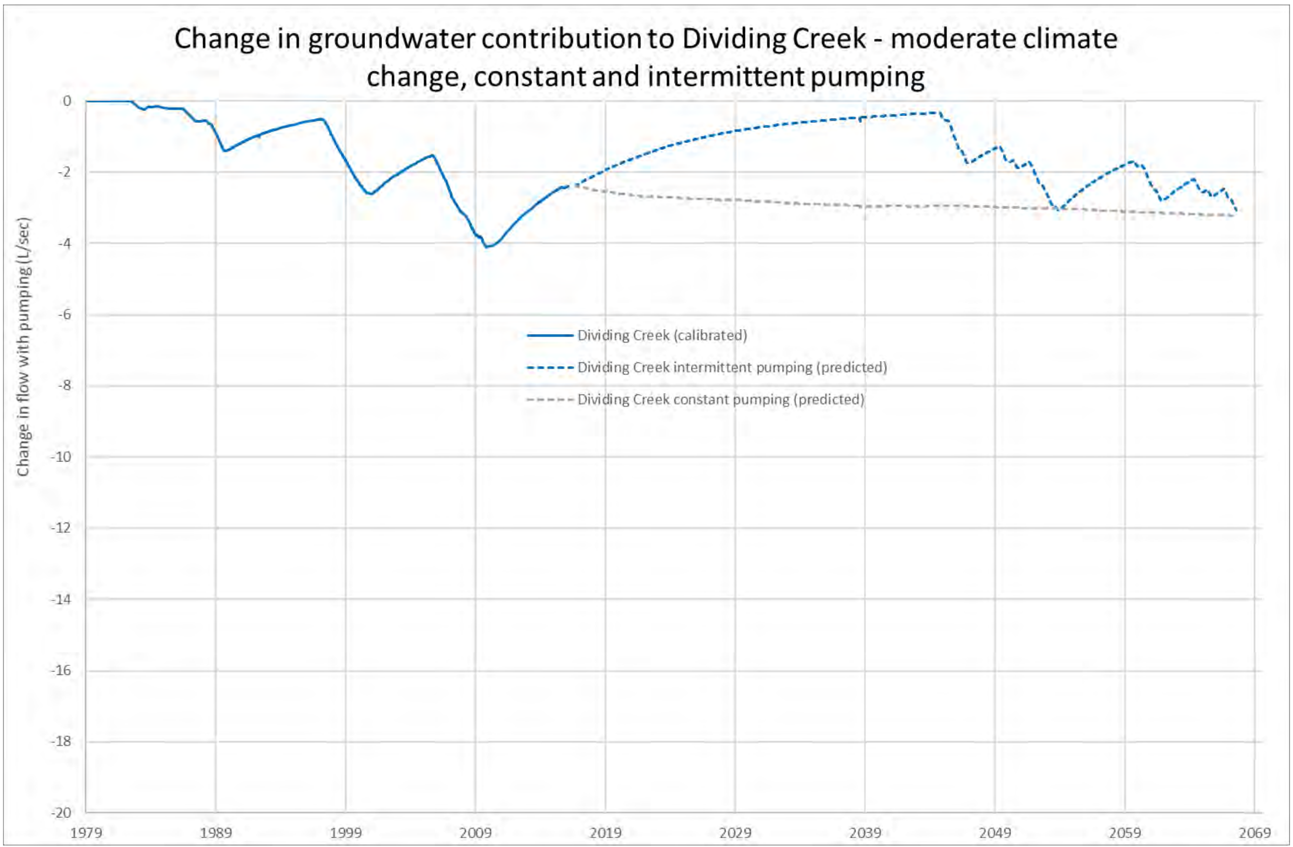
The predicted change in groundwater contribution to the Dividing Creek is shown in Figure 5-7 for both the calibration and predictive models. This shows that the predicted maximum impact of future pumping is ~3 L/sec (0.3 ML/day), which is slightly less than the maximum historical impact ~4 L/sec.

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 5-5 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 5-7 Change in groundwater contribution to Dividing Creek (calibrated and predicted for intermittent pumping and moderate climate change)



5.3.4 Gellibrand River

The predicted change in groundwater contribution to the Gellibrand River for both the calibration and predictive models is shown in Figure 5-8. 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 5-4).

Figure 5-8 Change in groundwater contribution to Gellibrand River (calibrated and predicted for moderate climate change with constant and intermittent pumping)

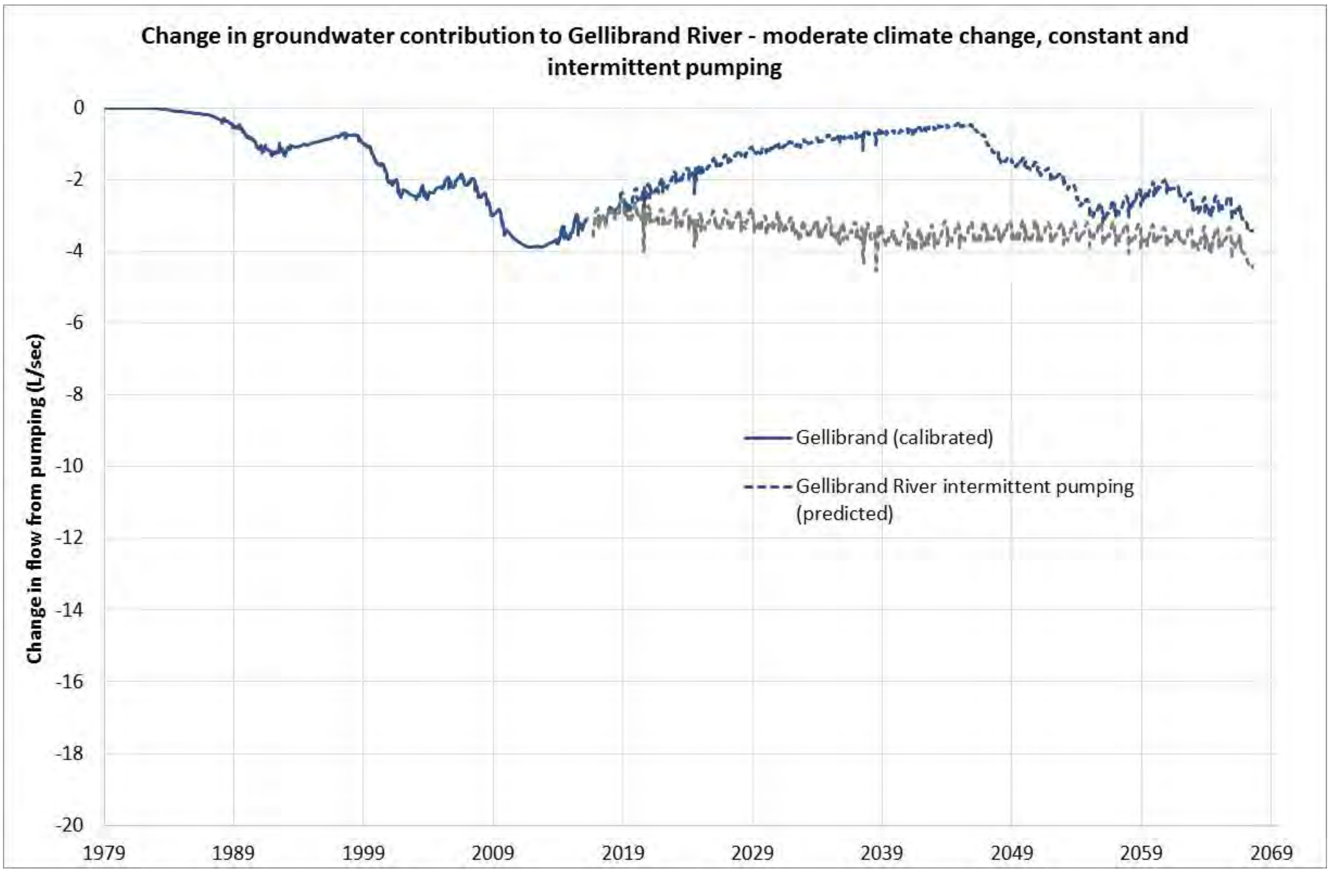


Table 5-6 Risk to the Gellibrand River from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

5.3.5 Porcupine Creek

The predicted change in groundwater contributions to Porcupine Creek for both the calibration and predictive models is shown in Figure 5-9. 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 5-9 Change in groundwater contribution to Porcupine Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

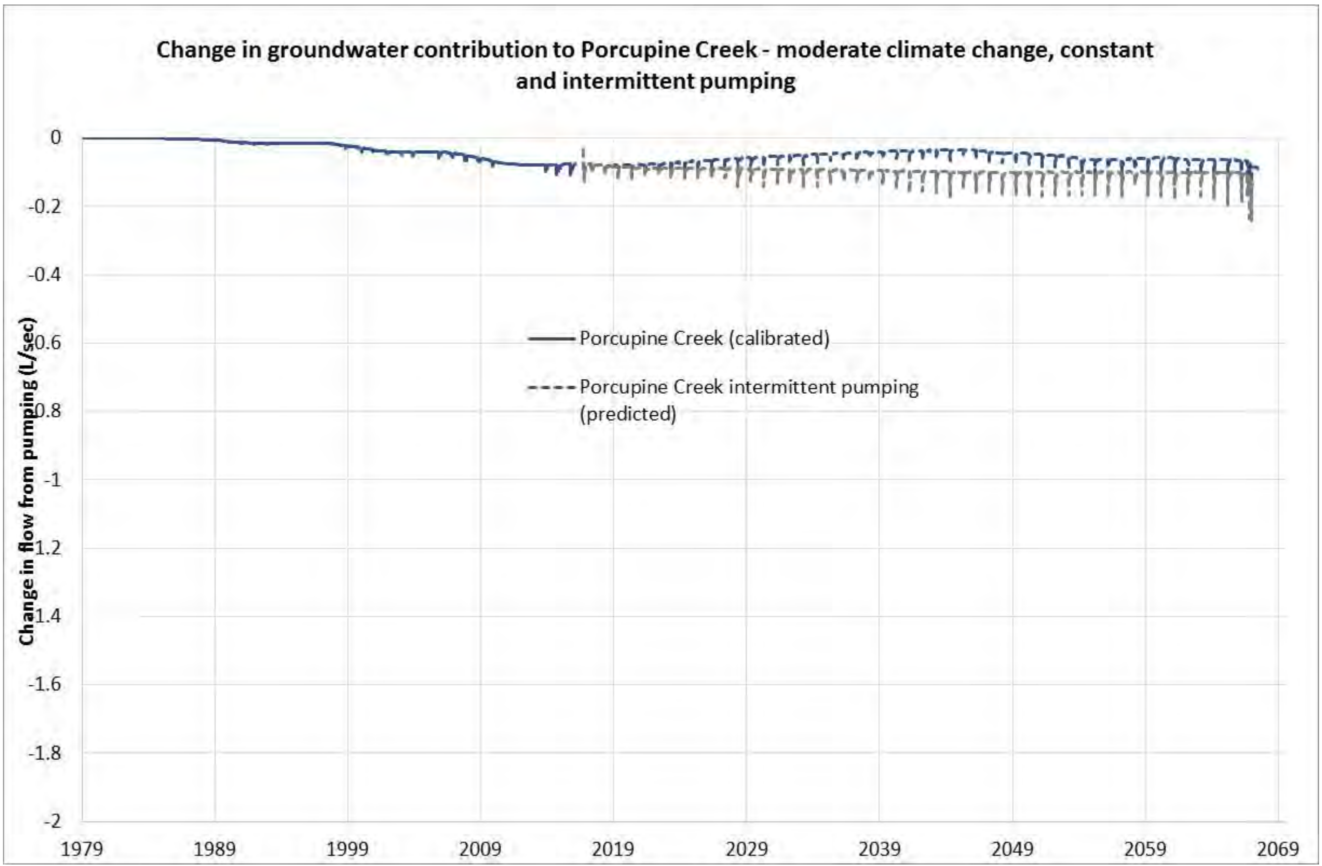


Table 5-7 Risk to Porcupine Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

5.3.6 Ten Mile Creek

The predicted change in groundwater contributions to Ten Mile Creek for both the calibration and predictive models is shown in Figure 5-10 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 4-3).

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 5-10 Change in groundwater contribution to Ten Mile Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

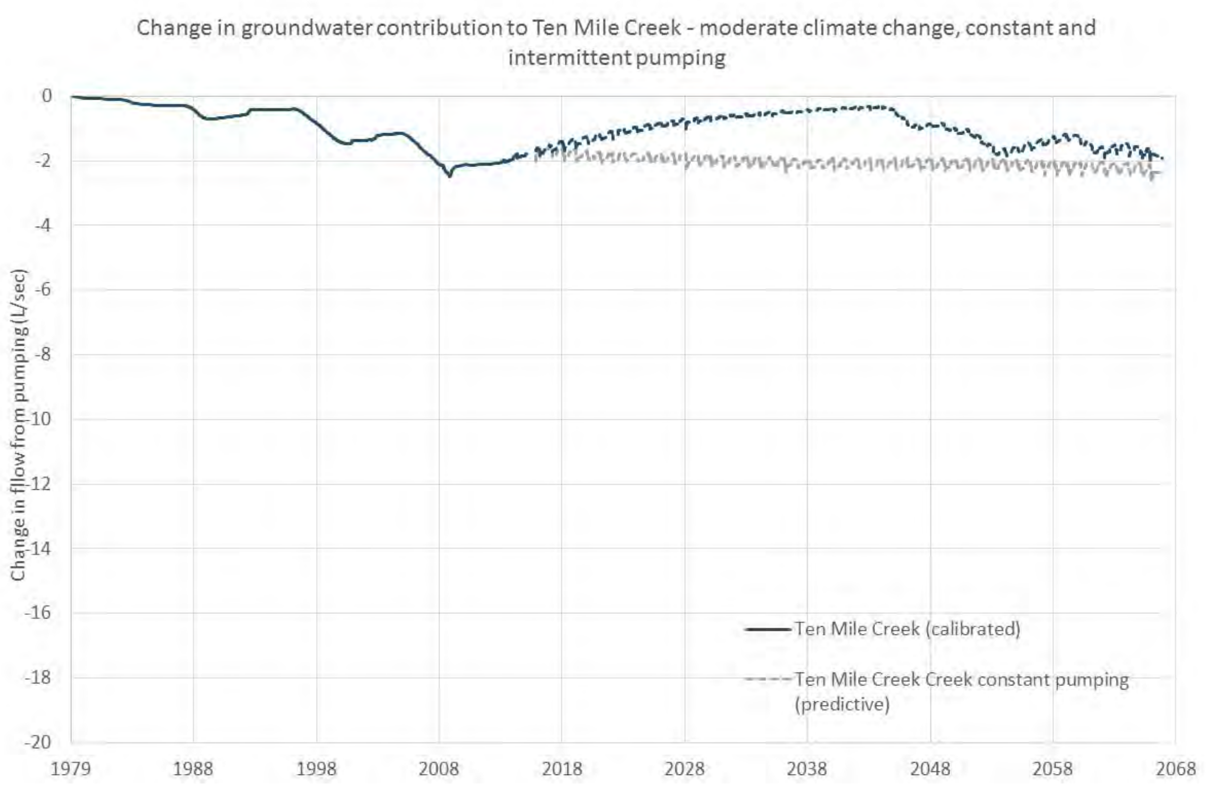


Table 5-8 Risk to Ten Mile Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

5.3.7 Yahoo Creek

The predicted change in groundwater contributions to Yahoo Creek for both the calibration and predictive models is shown in Figure 5-11 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 5-11 Change in groundwater contribution to Yahoo Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

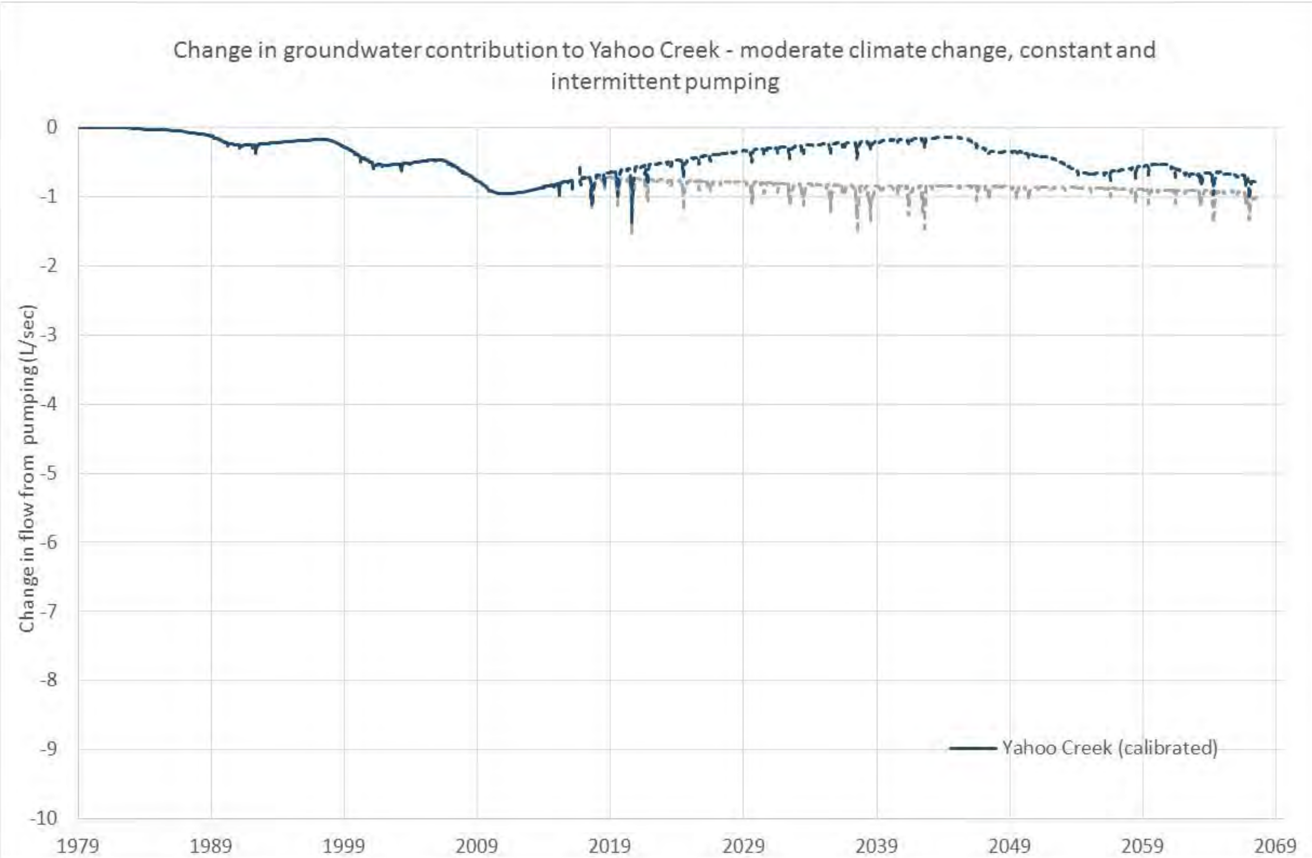


Table 5-9 Risk to Yahoo Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

5.3.8 Loves Creek

The predicted change in groundwater contributions to Loves Creek for both the calibration and predictive models is shown in Figure 5-12 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 5-12 Change in groundwater contribution to Loves Creek (calibrated and predicted for moderate climate change with constant and intermittent pumping)

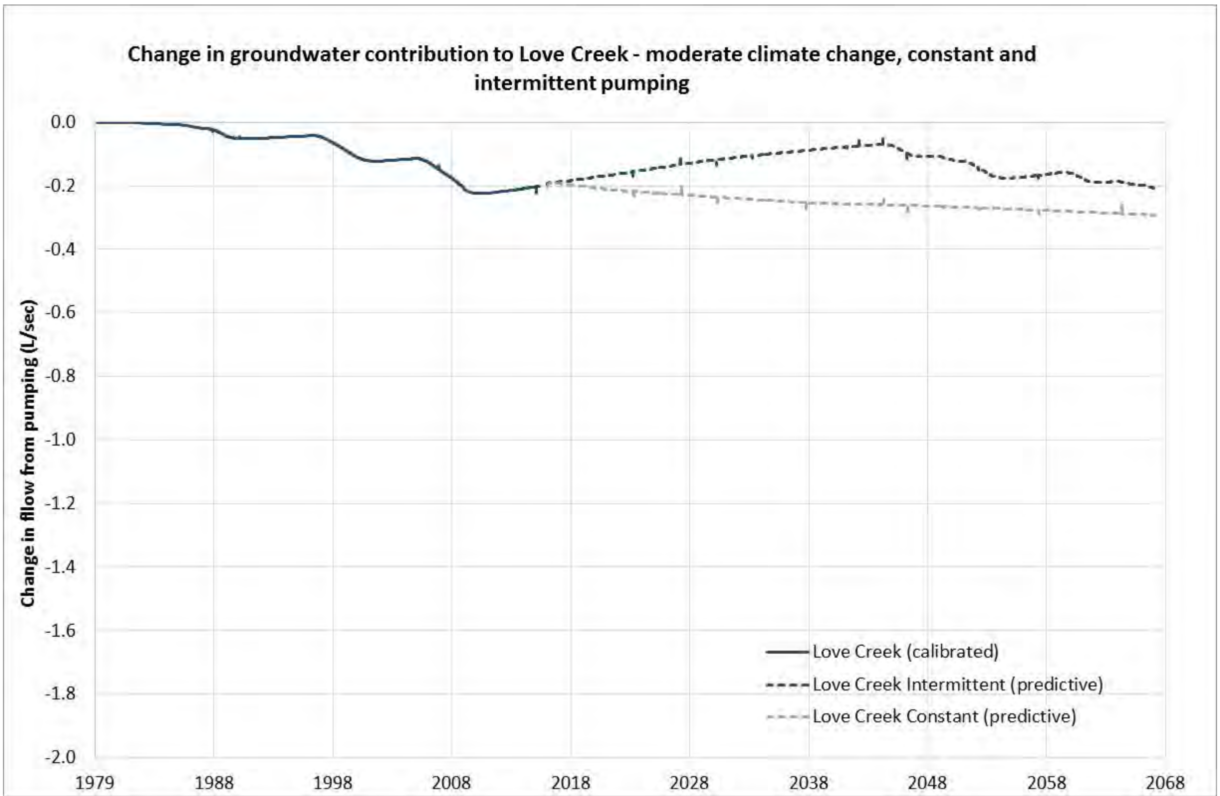


Table 5-10 Risk to Loves Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

5.3.9 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 5-13 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 5-13 Change in groundwater contribution to Barongarook Creek (predicted for moderate climate change with constant and intermittent pumping)

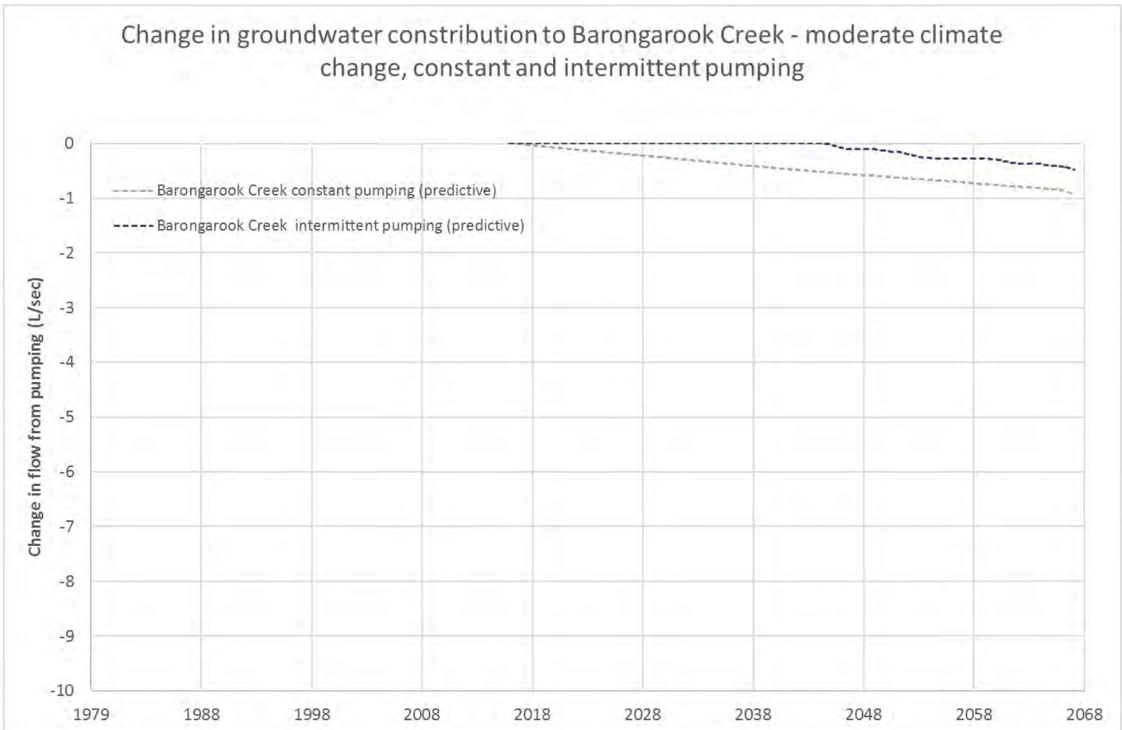


Table 5-11 Risk to Barongarook Creek from the Barwon Downs borefield (see Appendix B for modelled groundwater flux)

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

6. Potential risk to terrestrial groundwater dependent ecosystems (vegetation)

6.1 Chapter overview

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.

The objective of this chapter is to use the risk assessment framework outlined in the Ministerial Guidelines for High Value GDEs to understand the risk of pumping on groundwater dependent vegetation. This chapter also describes the predicted impacts of potential drawdown from groundwater pumping on vegetation in the model domain and at the 14 vegetation monitoring locations. A summary of the risk to groundwater dependent vegetation is outlined in Table 6-1.

Table 6-1 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.

6.2 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 6-1). 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 6-1. 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 6-1 Overview of vegetation surveys in the Otways region

1980s Various studies describe vegetation species in Otways → **Carr & Muir 1994** Surveyed 82 quadrats → **Carr 2002** Surveyed 24 quadrats → **SKM & EA 2008** Surveyed 8 quadrats, including 3 from 1994 and 2002 (sites 1, 2, 6) → **Jacobs 2015 and 2016** 14 transects surveyed, including 3 from 2008 (sites 1, 3, 5)

6.3 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 4.4.

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.

6.3.1 Vegetation across the study area

The **unmitigated risk** for vegetation across the study area is shown in Figure 6-2. 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 6-3 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 4.4, 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 6-4 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.

6.3.2 Vegetation monitoring sites

The location of the 14 vegetation monitoring sites is shown in Figure 6-4. 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 6-2 Unmitigated risk to vegetation across the model domain based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)

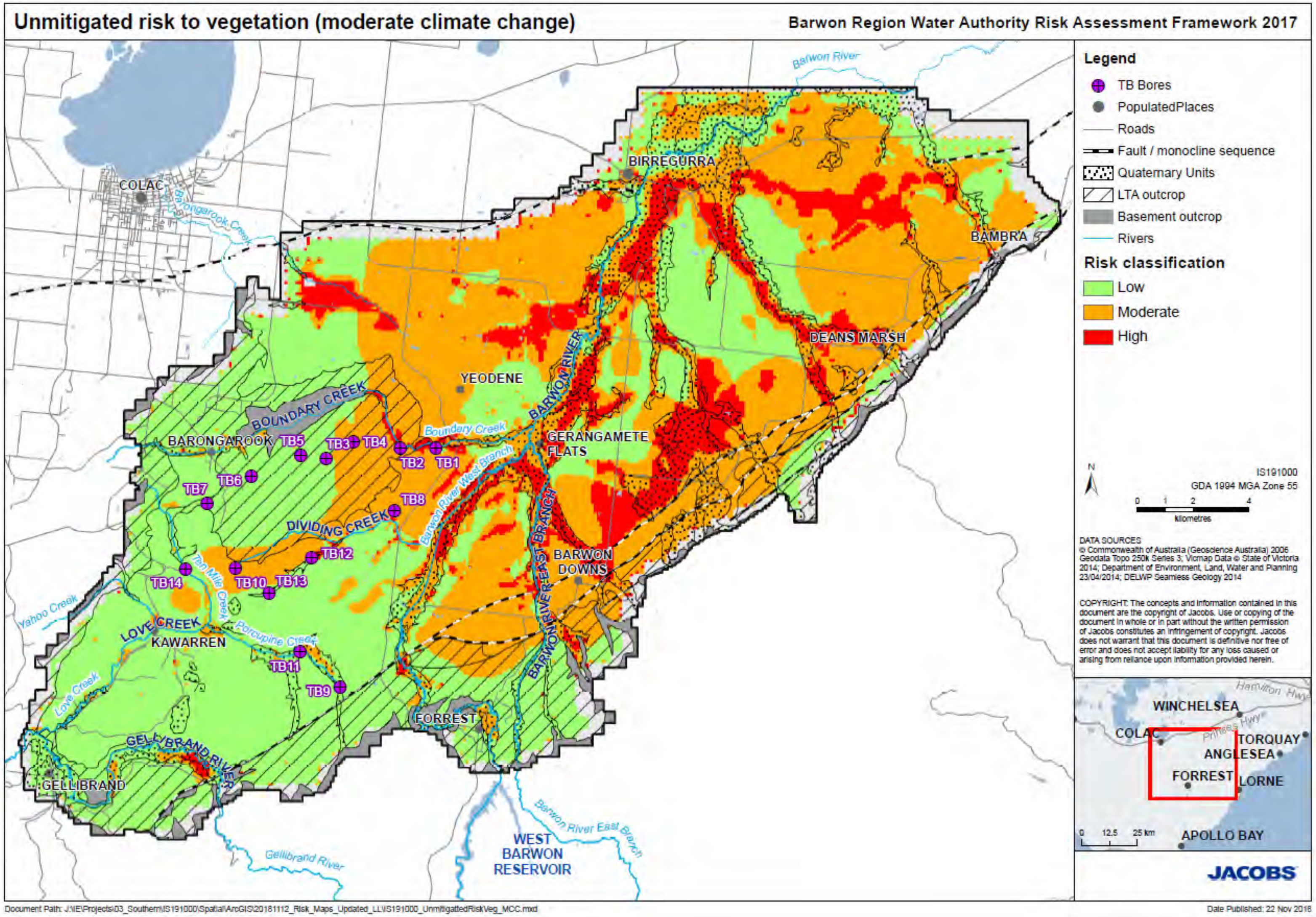


Figure 6-3 Mitigated risk to vegetation across the model domain considering physical mitigating factors (moderate climate change)

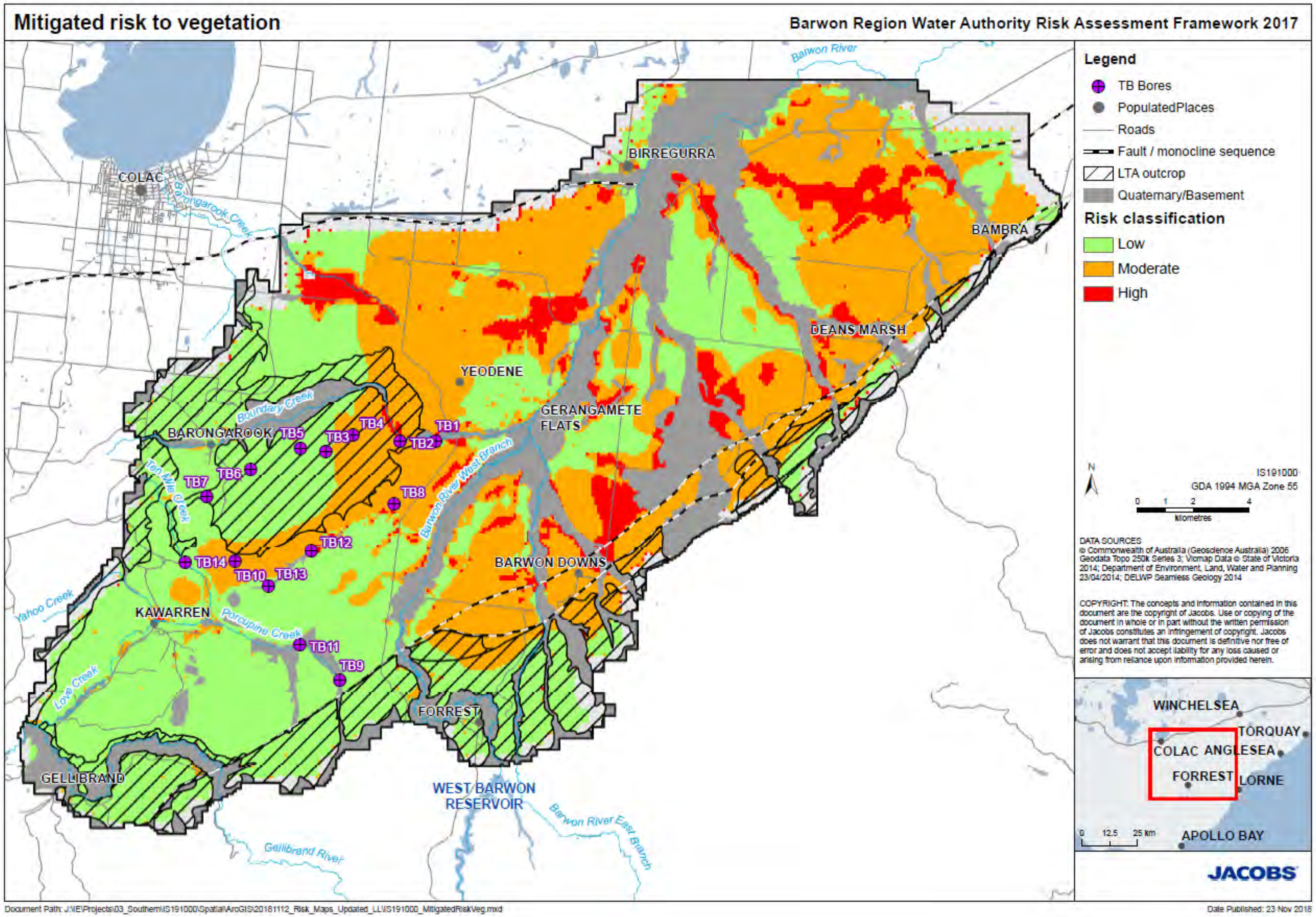
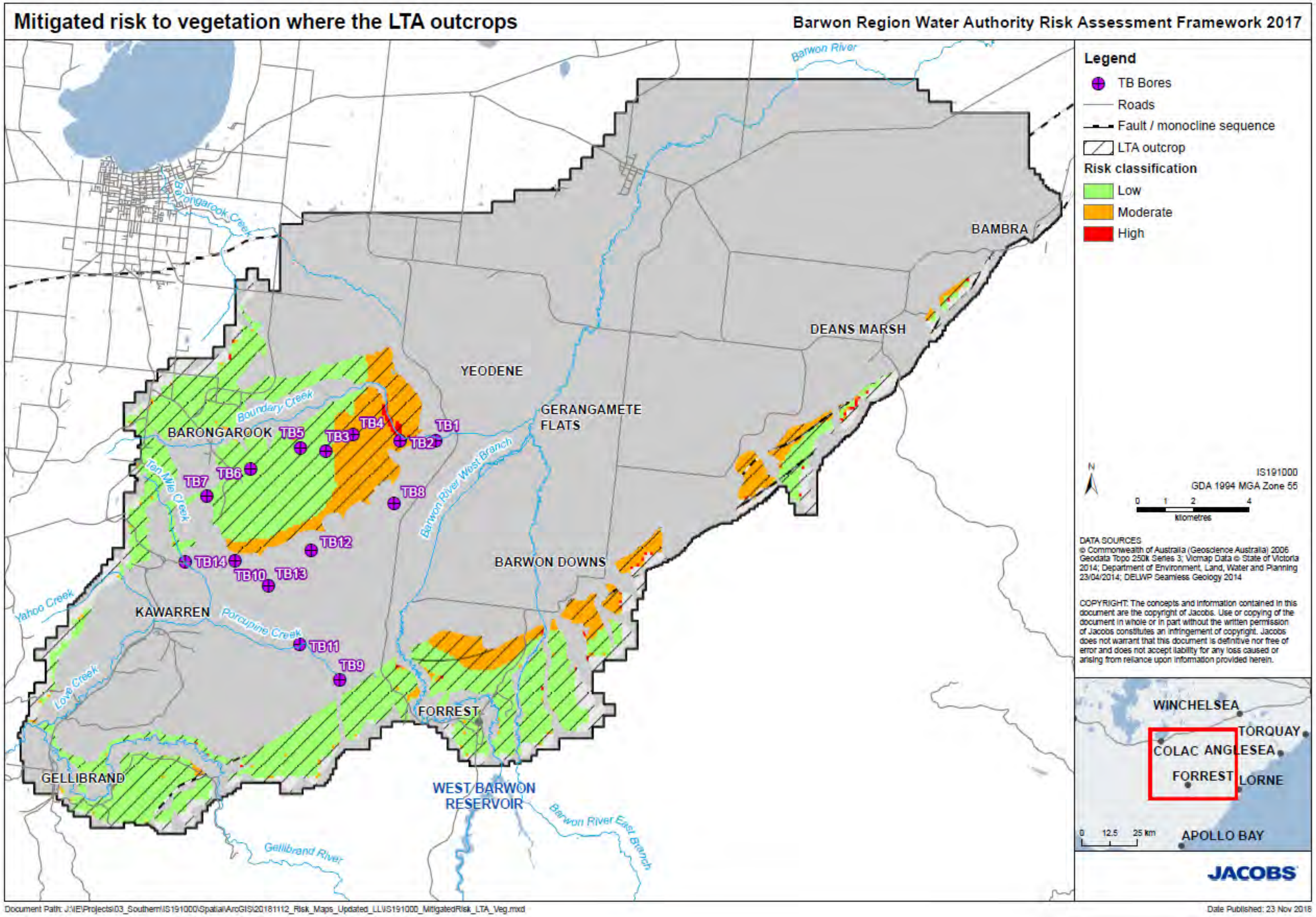


Figure 6-4 Mitigated risk to vegetation where the LTA outcrops considering physical mitigating factors (moderate climate change)



7. Potential risk to PASS

7.1 Chapter overview

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. The key findings are outlined in Table 7 1.

Table 7 1: Key findings relating to predicted impacts to PASS

Environmental receptors	Risk assessment outcomes	Maximum residual risk ranking
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. 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.	High risk in Reach 2 of Boundary Creek and Barwon River East Branch.

7.2 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 7-1 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).

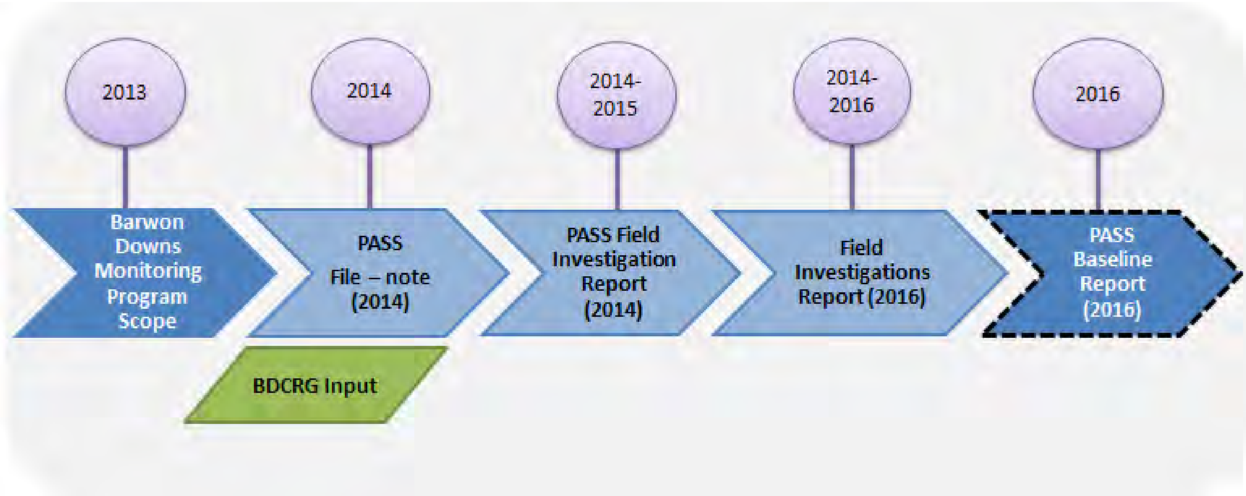


Figure 7-1 : Overview of the PASS program

7.3 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 4.4.

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.

7.3.1 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 7.2 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 4.4, 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 7.2 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 7.3 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.

7.3.2 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.

Figure 7.2: Mitigated risk to PASS across the model domain based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)

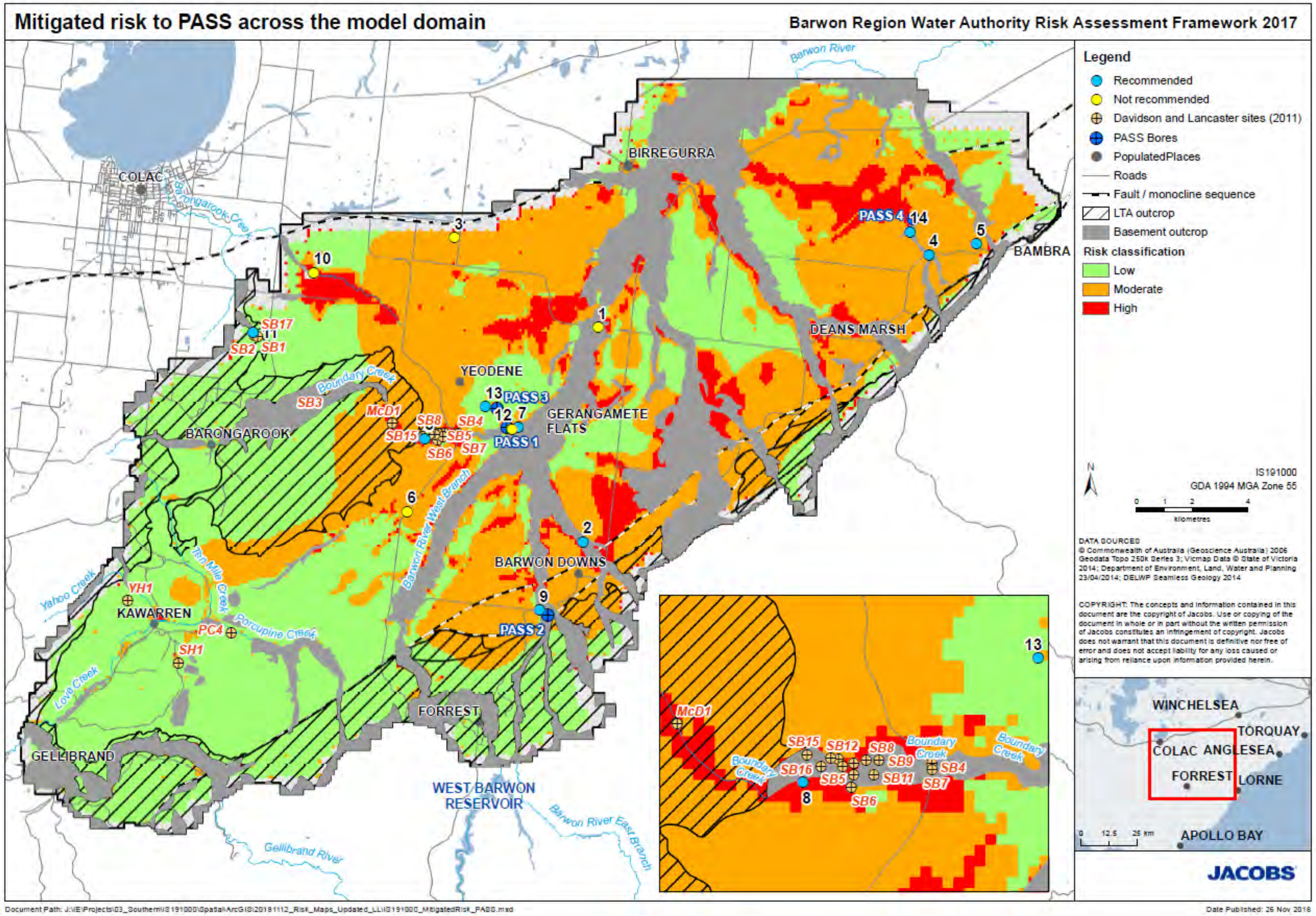
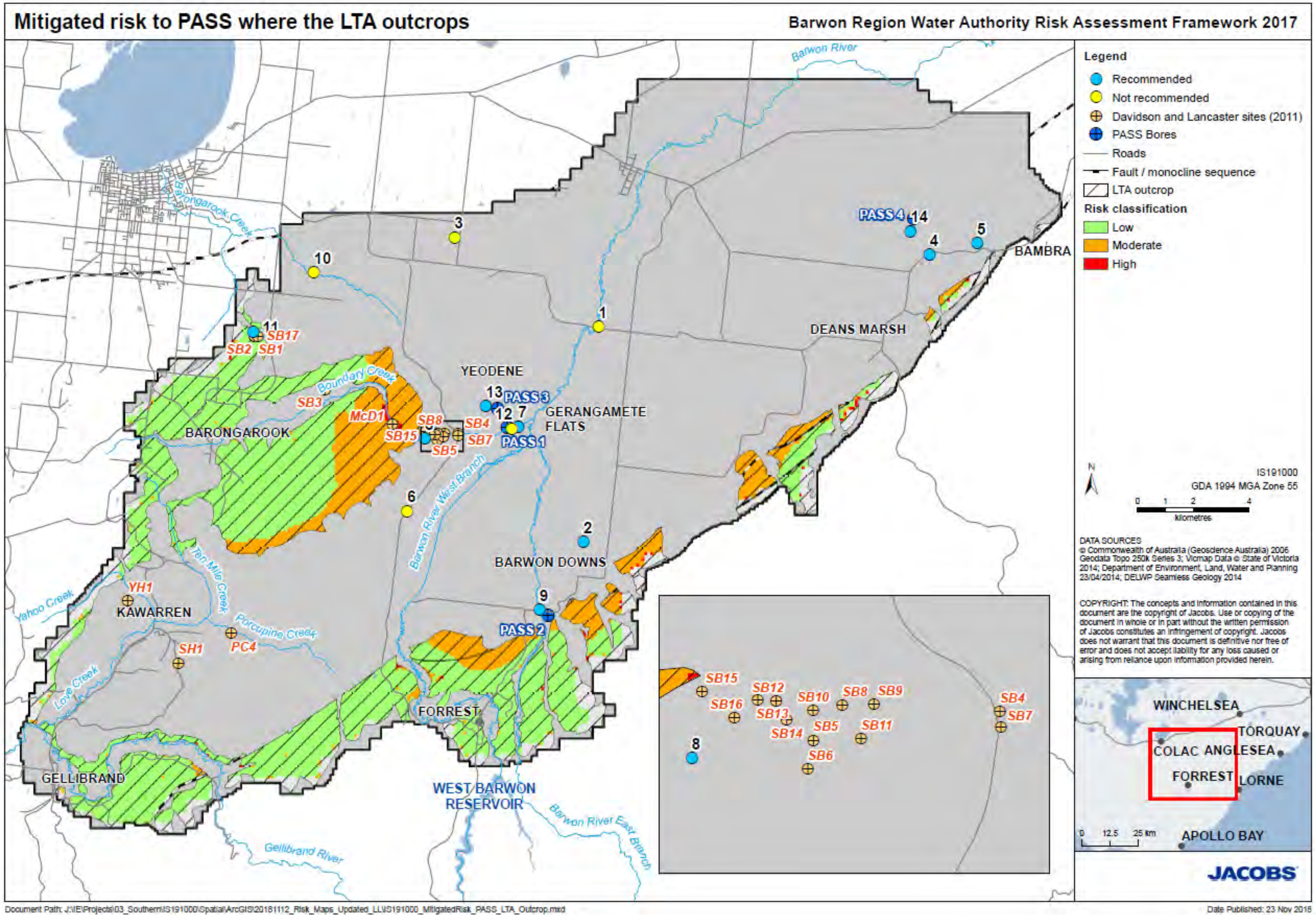


Figure 7.3: Mitigated risk to PASS where the LTA outcrops based on predicted depth to watertable and drawdown in the regional aquifer (moderate climate change)



8. Environment Protection Program

8.1 Chapter overview

The purpose of this chapter is to identify potential groundwater trigger levels for 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 will trigger a management action or response which is designed to prevent the impact. The management action may be to stop pumping, or it could be to provide an additional water source to the receptor.

Table 8.1 provides an overview of the recommended trigger levels and more detail is provided in the following sections.

Table 8.1 : Summary of trigger levels

<table>
<tr><th>Receptor</th><th>Intent of trigger</th><th>Trigger</th><th>Management action</th></tr>
<tr><td rowspan="4">Regional groundwater levels</td><td rowspan="4">• To avoid excessive drawdown in the regional aquifer</td><td>• Groundwater observation bore 64229 (G13) to be set at 85.2 mAHD</td><td rowspan="4">• Reduce pumping rates until the groundwater level has recovered above the trigger value</td></tr>
<tr><td>• Groundwater observation bore 64236 (G20) to be set at 98.7 mAHD</td></tr>
<tr><td>• Groundwater observation bore 82844 (M28) to be set at 124.1 mAHD</td></tr>
<tr><td>• Groundwater observation bore 109131 (Yeo40) to be 142.3 mAHD.</td></tr>
<tr><td>Boundary Creek</td><td>• To indicate when supplementary flows are required to ensure a minimum flow in Boundary Creek</td><td>• 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</td><td>• 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.</td></tr>
<tr><td>Gellibrand River</td><td>• To maintain adequate upward gradient to ensure groundwater base flow contribution to the river during summer flow conditions</td><td>• 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</td><td>• Reduce pumping rates until the groundwater level has recovered above the trigger level</td></tr>
<tr><td>Ten Mile Creek</td><td>• To maintain upward gradient into the creek to ensure adequate groundwater base flow contribution to the river</td><td>• Trigger level in bore 113705 to be 0.5m above the average stream bed elevation</td><td>• Reduce pumping rates until the groundwater level has recovered above the trigger level</td></tr>
</table>

Receptor	Intent of trigger	Trigger	Management action
	during summer flow conditions	• Trigger level in bore 113706 to be 0.5m above the average stream bed elevation	
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.		

8.2 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.

8.3 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 8.2 and are discussed more in the following sections.

Table 8.2 : 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.

8.3.1 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 8.1 to Figure 8.4. 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 8.4) 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 8.1: Hydrograph for bore 64229 (predicted pumping scenarios assume moderate climate change)

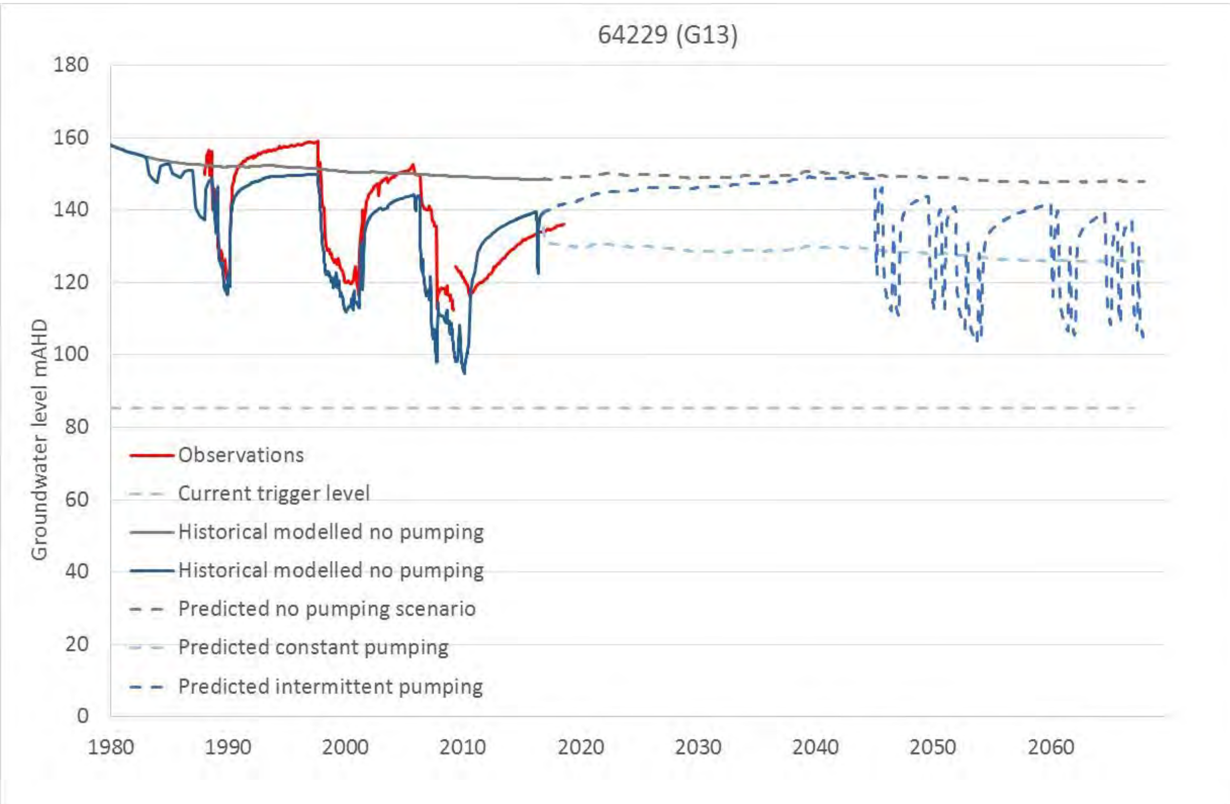


Figure 8.2: Hydrograph for bore 64236 (predicted pumping scenarios assume moderate climate change)

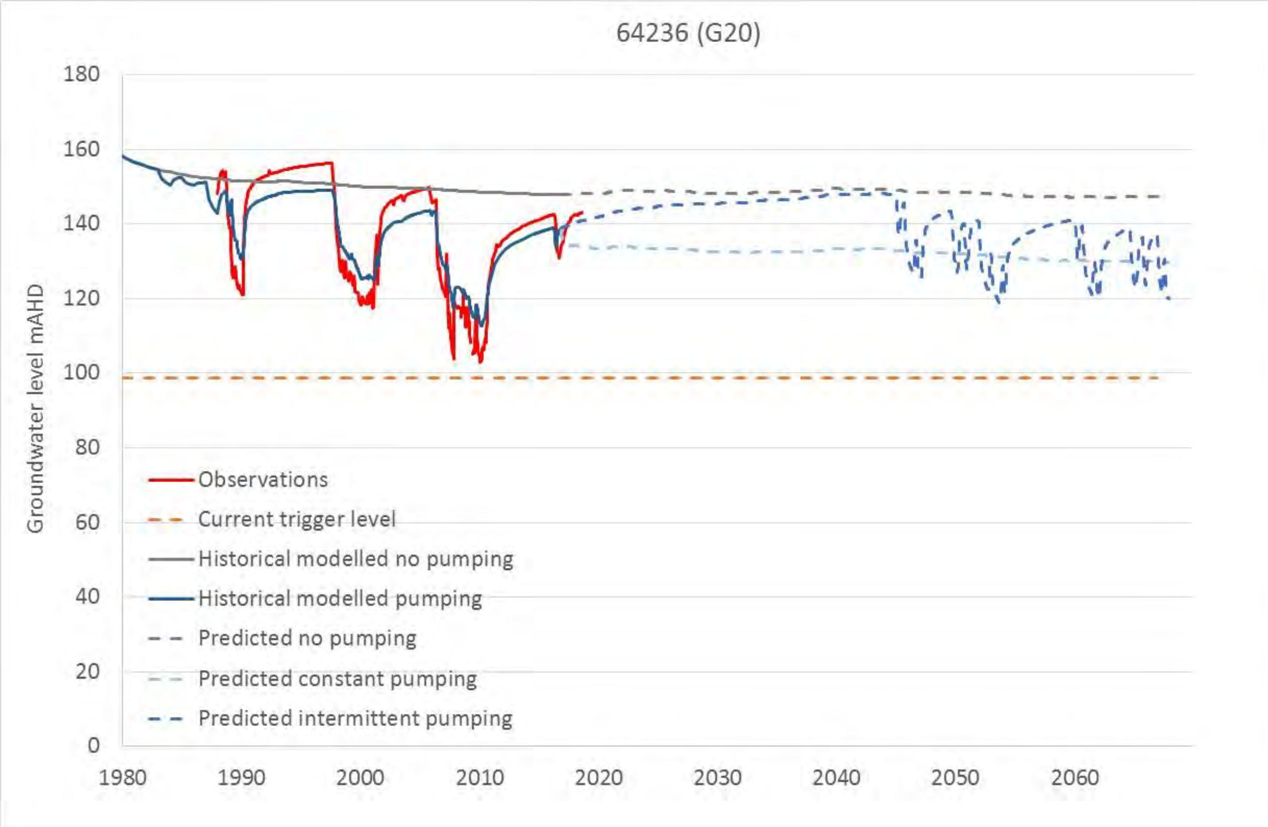


Figure 8.3: Hydrograph for Bore 82844 (predicted pumping scenarios assume moderate climate change)

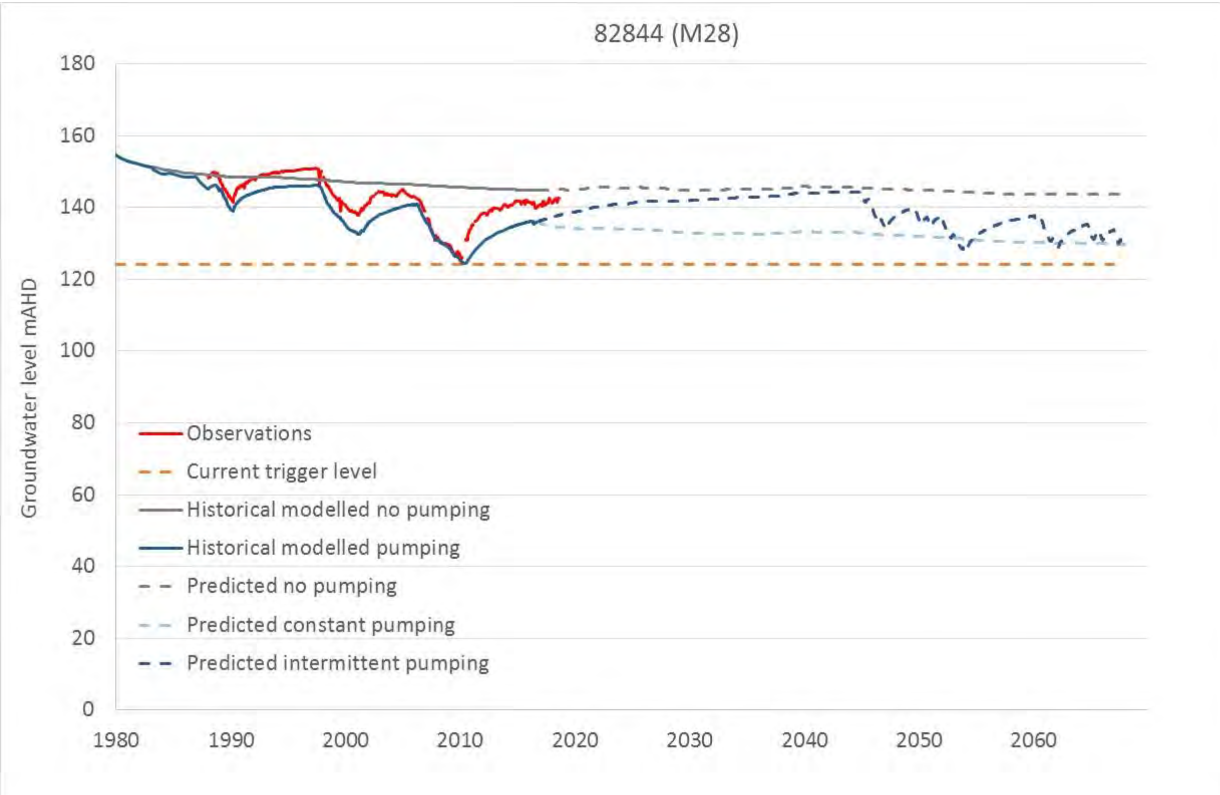
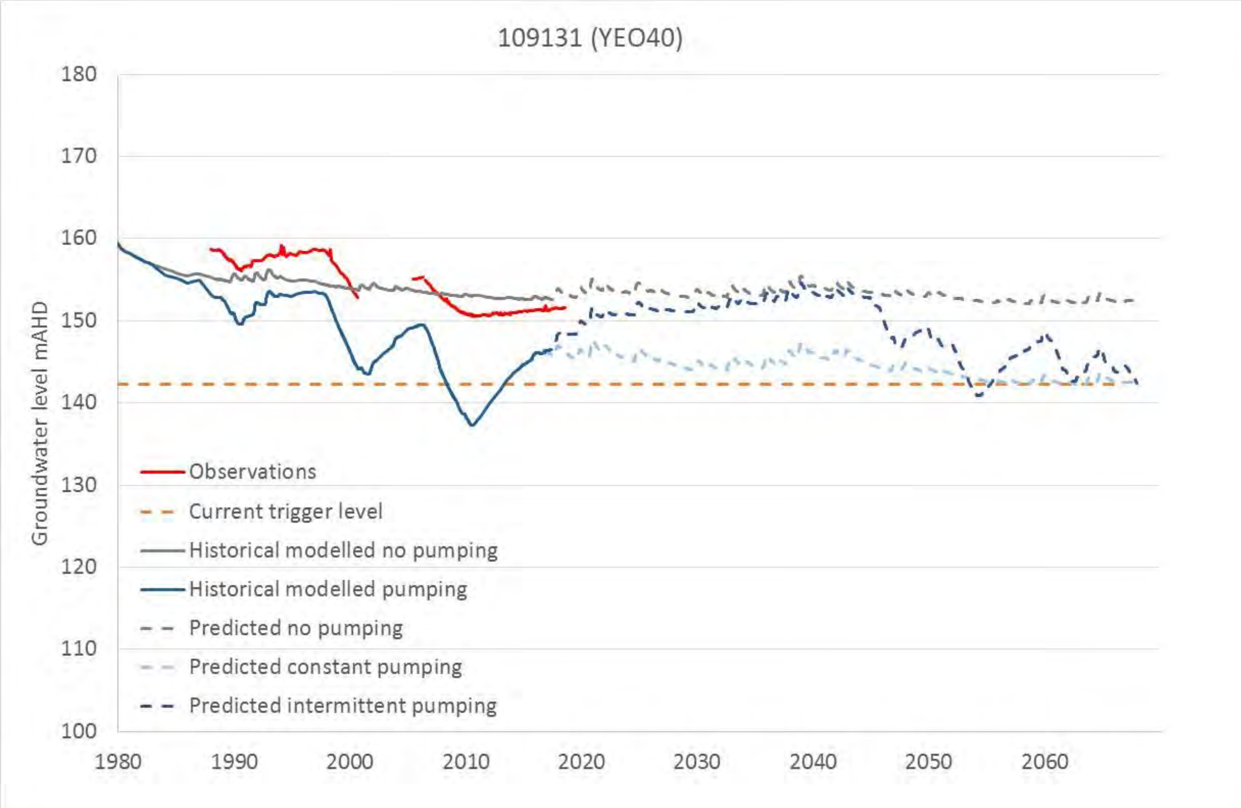


Figure 8.4: Hydrograph for Bore 109131 (predicted pumping scenarios assume moderate climate change). Refer discussion in the text regarding the predicted low point.



8.3.2 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 8.6) and water levels from the Water Management Information System (WMIS) for this bore are shown Figure 8.5.

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 8-3 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 8.5: Observed and modelled waterlevels for Bore 109131 with the trigger level to provide supplementary flow

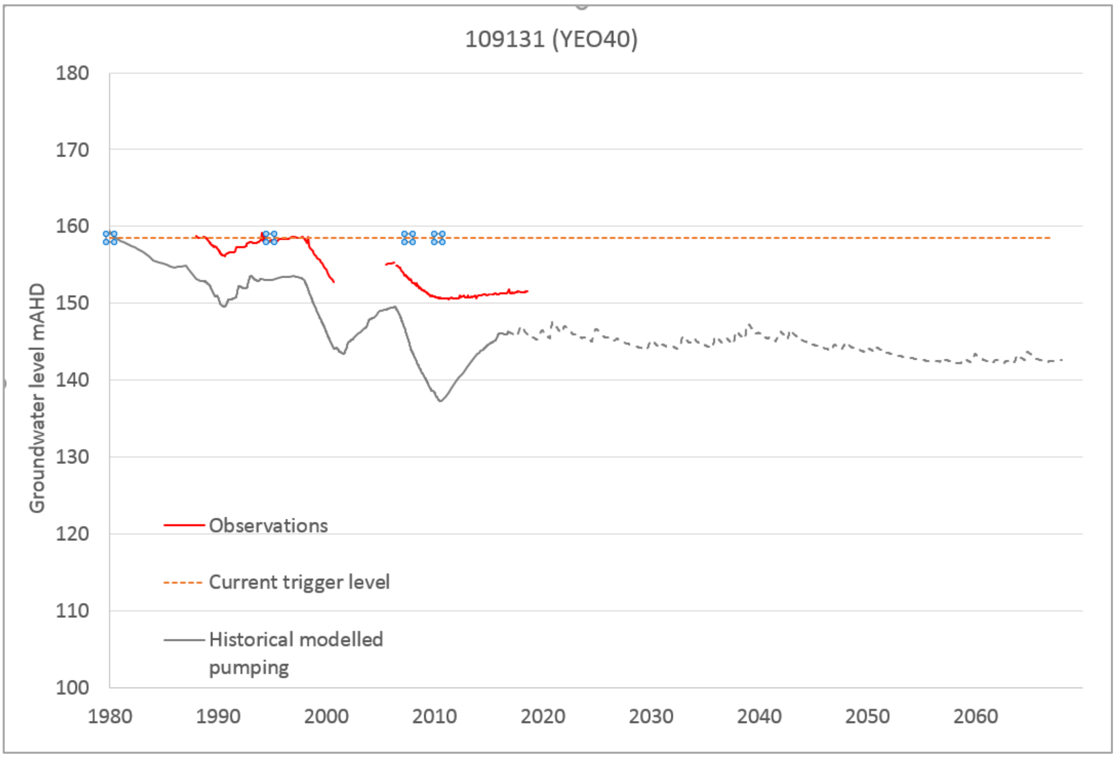
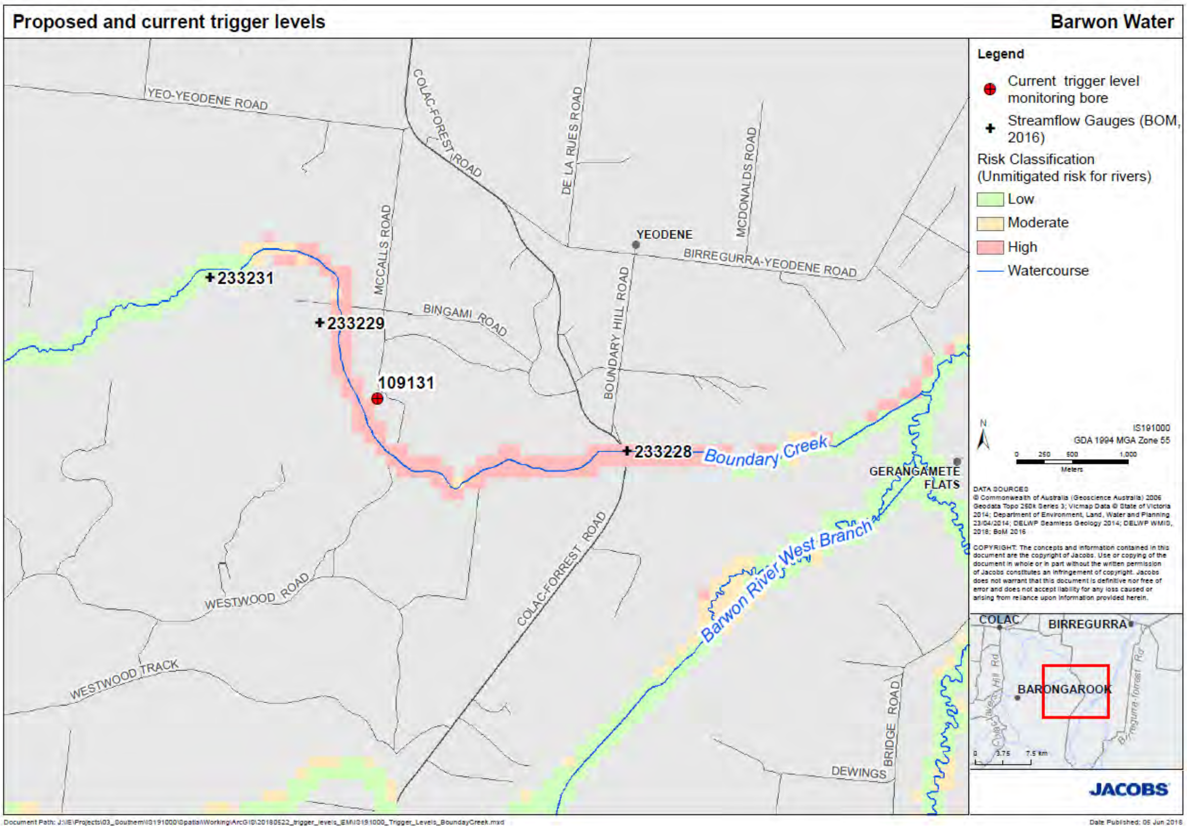


Figure 8.6: Location of existing trigger bore for Boundary Creek



8.3.3 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 8-4 and described below. The locations of these bores is shown in Figure 8.8.

- 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 8-7. 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 8-7. 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 8-4 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 8-7 Observed groundwater levels in bore 108898 and 108917

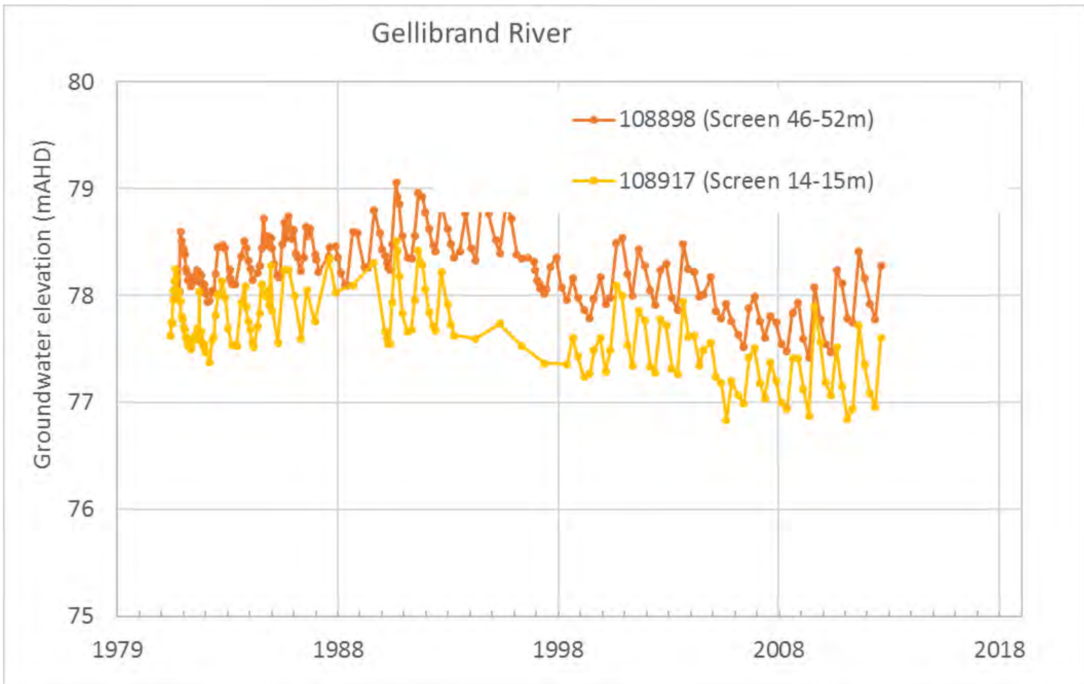
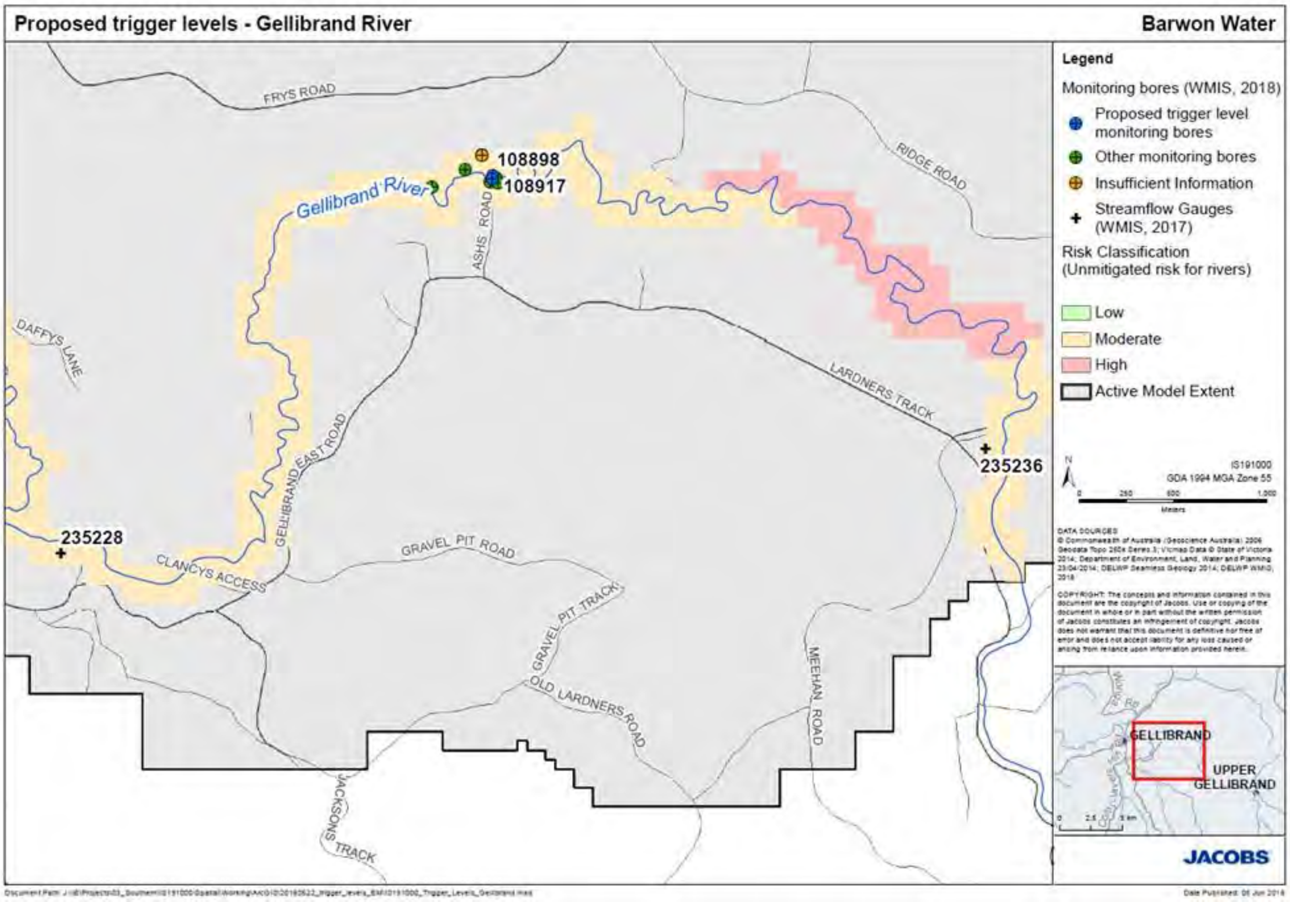


Figure 8.8: Location of proposed trigger bore for Gellibrand River



8.3.4 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 8-9, which shows there is an upward gradient from the regional aquifer to the shallow alluvial aquifer. The location of these bores is shown Figure 8.10.

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 8-9 Observed groundwater levels in bore 48249 and PASS2

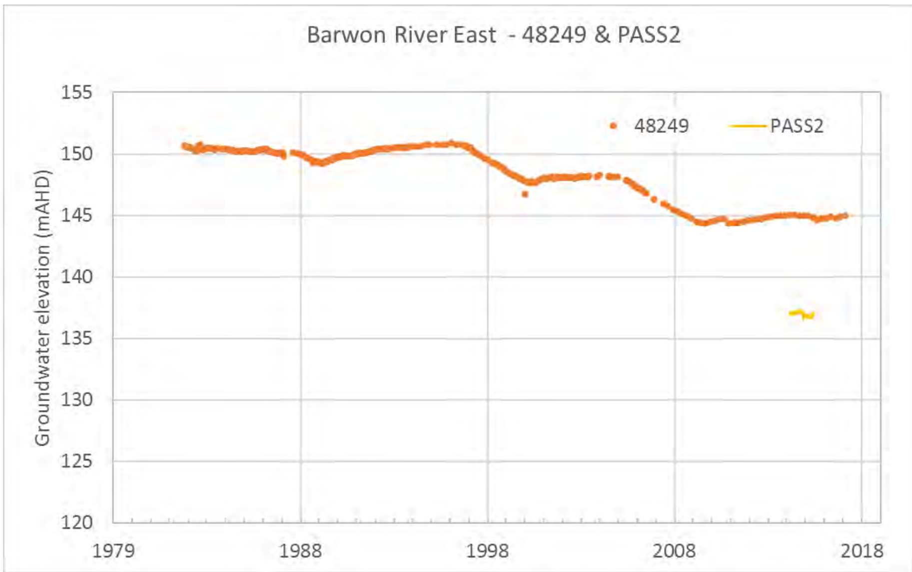
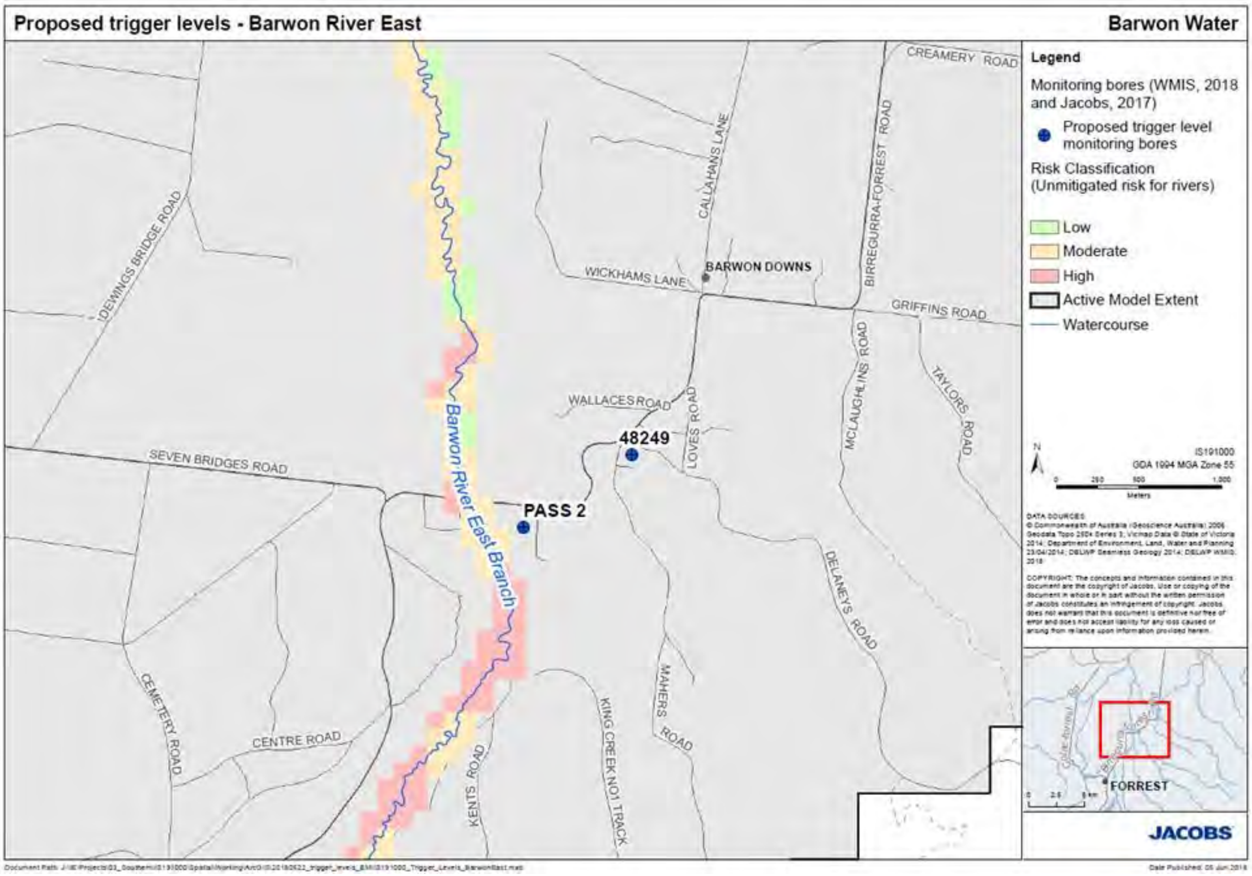


Figure 8.10: Location of proposed trigger bore for Barwon River East Branch



8.3.5 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 8.13). The bores are 139 and 82m deep respectively and typically show an upward gradient in the LTA (see Figure 8.11).

Bores 113705 and 113706 are located further upstream away from the borefield where the LTA is unconfined (Figure 8.13). The bores are 174 and 90m deep respectively and a significant upward gradient exists in the aquifer at this location (see Figure 8.12).

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 8.5 : 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 8.11 : Bores 114168 and 114169 located closer to the borefield where the LTA is confined

Figure 8.12 : Bores 113705 and 113706 located further from the borefield where the LTA is unconfined

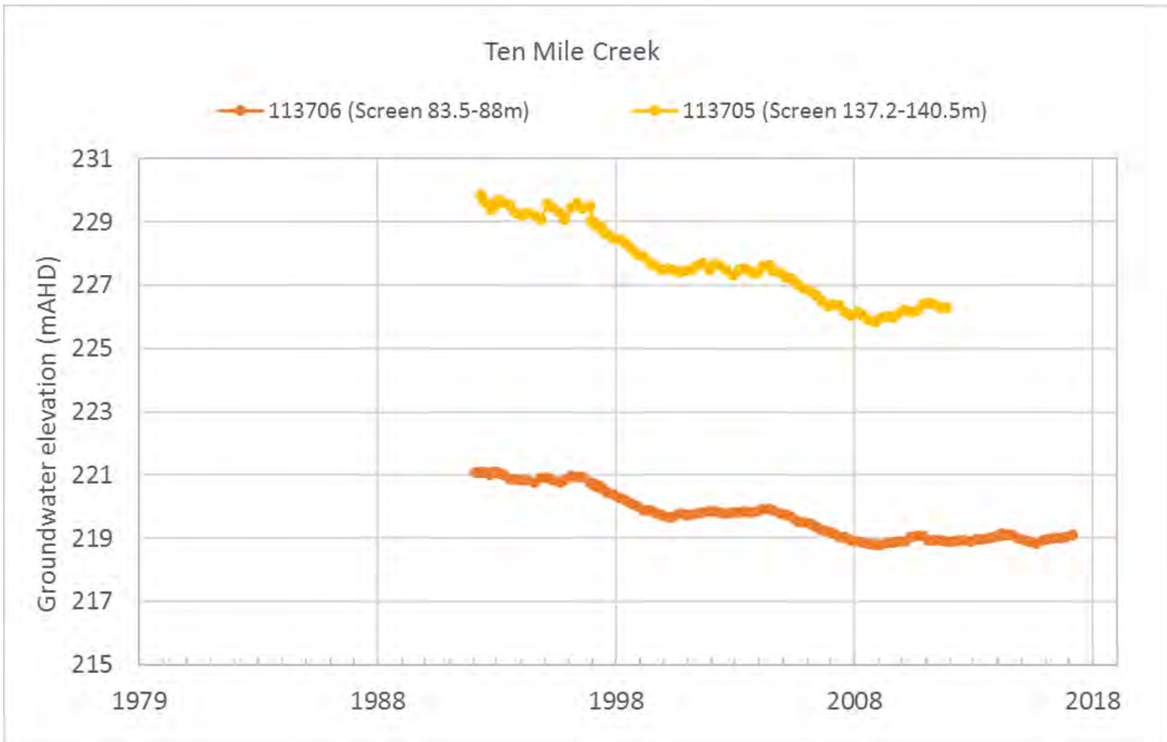
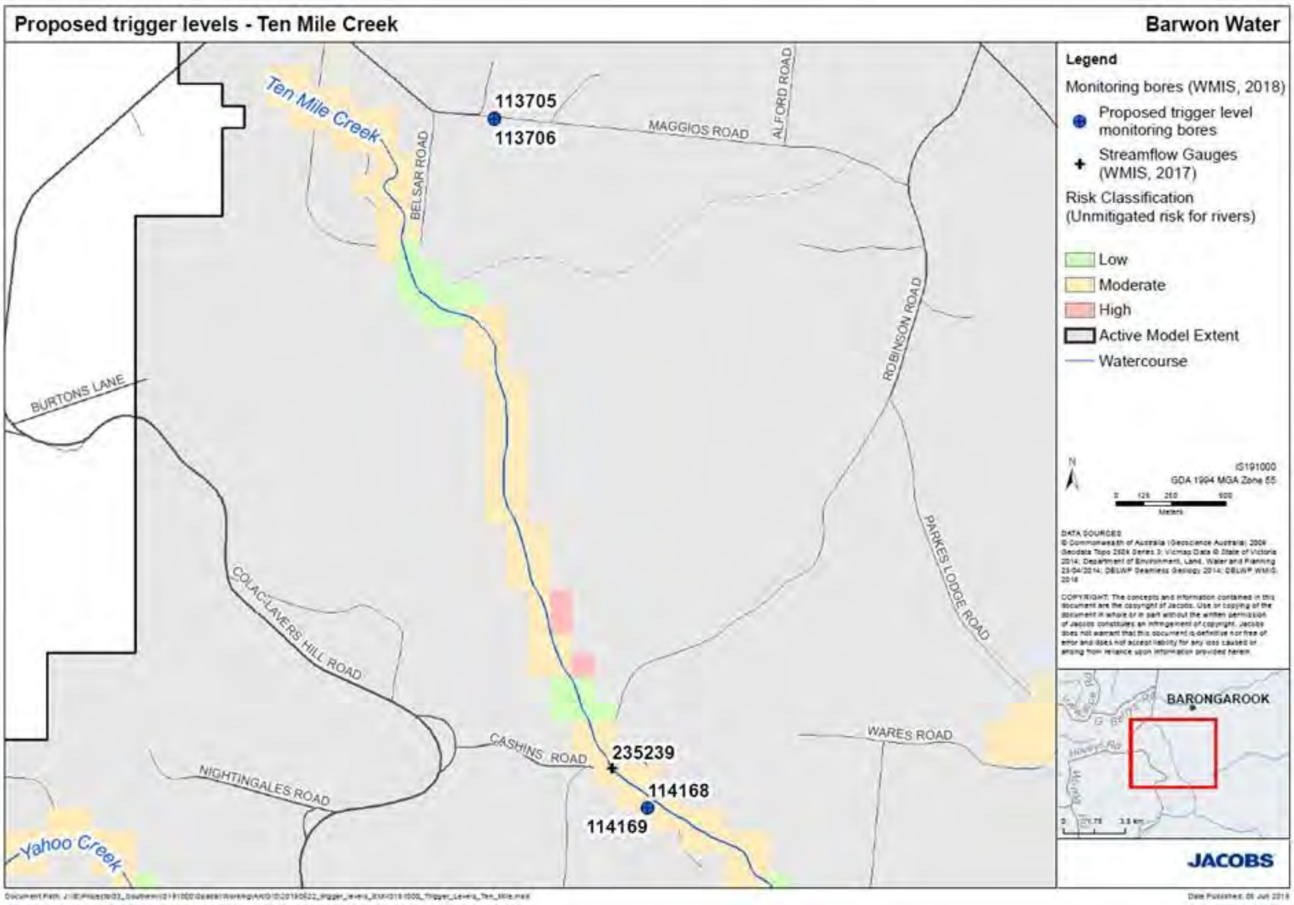


Figure 8.13: Location of proposed trigger bore for Ten Mile Creek



8.3.6 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.

9. Conclusions and Recommendations

9.1 Conclusions

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.

9.2 Recommendations

Recommendations for receptors classified as medium or high risk are outlined in Table 9-1.

Table 9-1 Recommendations for receptors at medium or high risk

Receptor	Recommendations for risk mitigation options
Regional groundwater levels	1. Continue to monitor regional groundwater levels with the existing monitoring network. 2. Complete a review of groundwater monitoring data annually to compare model predictions 3. Recommended trigger levels for action are: • 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.
Vegetation	4. Continue monitoring vegetation monitoring sites every 2 years while the borefield is not operating and every year when the borefield is operating The review should include a vegetation survey and review of groundwater levels to validate the model predictions. If local alluvial aquifers respond to pumping, adaptive management involving preparation of a response plan is required (e.g. establish groundwater trigger levels). 5. The recommended risk mitigation option for sites T1 and T2 is to continue to supply the supplementary flow to Boundary Creek and recommendations as described in Jacobs (2017c). 6. Establish two additional vegetation monitoring sites on south east side of Bambra Fault near Barwon River East and West Branches and add these to the regular vegetation monitoring. 7. Recommended trigger as per trigger for Boundary Creek (see Recommendation 9) to protect groundwater dependent vegetation in Reach 2 of Boundary Creek
PASS	8. Continue monitoring PASS monitoring sites every two years while the borefield is not operating and every year when the borefield is operating Monitoring should include soils, surface water and groundwater quality and groundwater levels. If local alluvial aquifers respond to pumping, adaptive management involving preparation of a response plan is required (e.g. establish groundwater trigger levels) No triggers are recommended for PASS monitoring sites
Rivers	9. Boundary Creek – recommended risk mitigation option is to continue to supply the supplementary flow and recommendations as described in Jacobs (2017c).

Receptor	Recommendations for risk mitigation options
	• Recommended trigger level - 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) 10. Dividing Creek – continue monitoring vegetation sites which include groundwater monitoring bores as per Recommendation 3. 11. Barwon River East and West Branch south east of the Bambra Fault – recommend site specific study to confirm the effectiveness of the alluvial aquifer in maintain baseflow to the rivers and presence of high value GDEs. Additional groundwater or streamflow monitoring and vegetation mapping (see Recommendation 5) may be required as part of this study. 12. Gellibrand River – recommend site specific study is undertaken south of Kawarren to confirm the effectiveness of the alluvial aquifer in maintaining baseflow to the rivers and to confirm the presence of high value GDEs. • If river is gaining in area identified at high risk, recommended trigger level for groundwater level in the regional and alluvial aquifer remains >0.5m above the streambed elevation bed. 13. Ten Mile Creek – Re-instate streamflow monitoring gauge and review streamflow monitoring data every two years together with groundwater levels. • Recommended trigger level in bore 113705 to be 0.5m above the average stream bed elevation • Recommended trigger level in bore 113706 to be 0.5m above the average stream bed elevation 14. Yahoo Creek - Re-instate streamflow monitoring gauge and review streamflow monitoring data every two years together with groundwater levels. 15. Barongarook Creek – recommend site specific study to confirm presence of high value GDEs. As part of this study additional groundwater monitoring and stream flow monitoring may be recommended.
Groundwater model	16. Over the next 15 years, the model should be updated and reviewed every 5 years. Where model predictions vary significantly from those identified here a response plan shall be developed.

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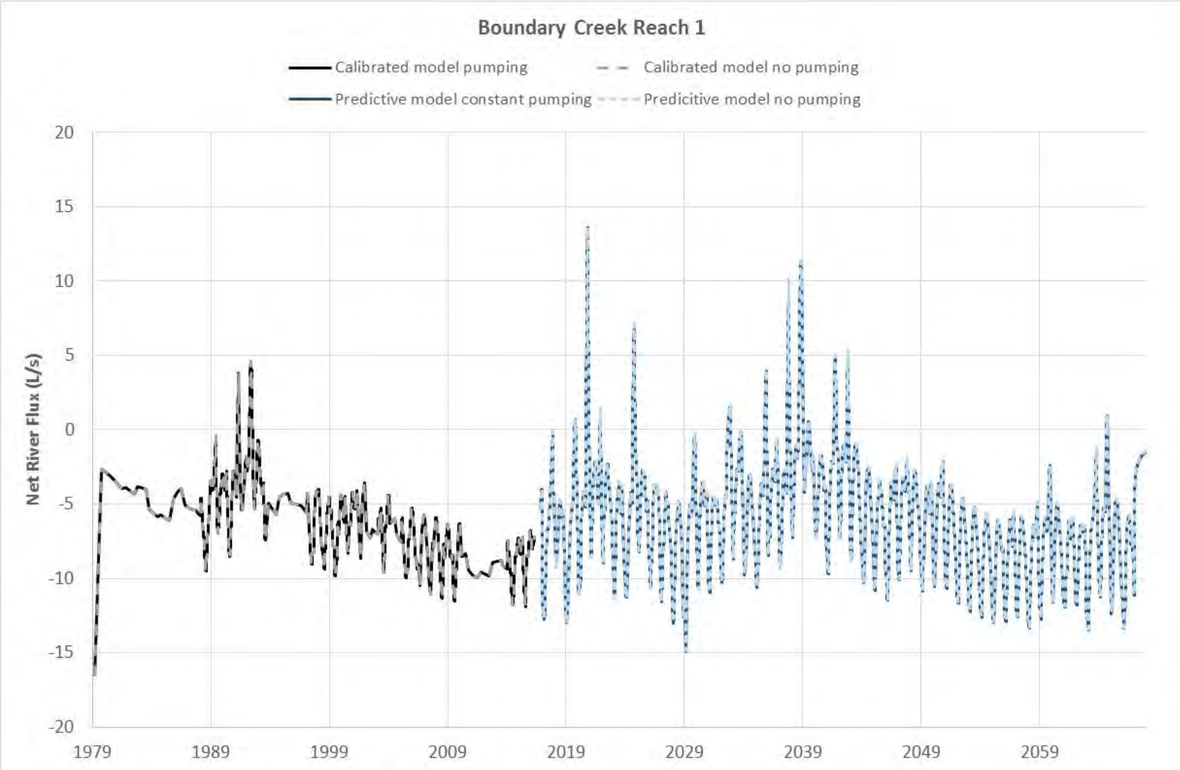
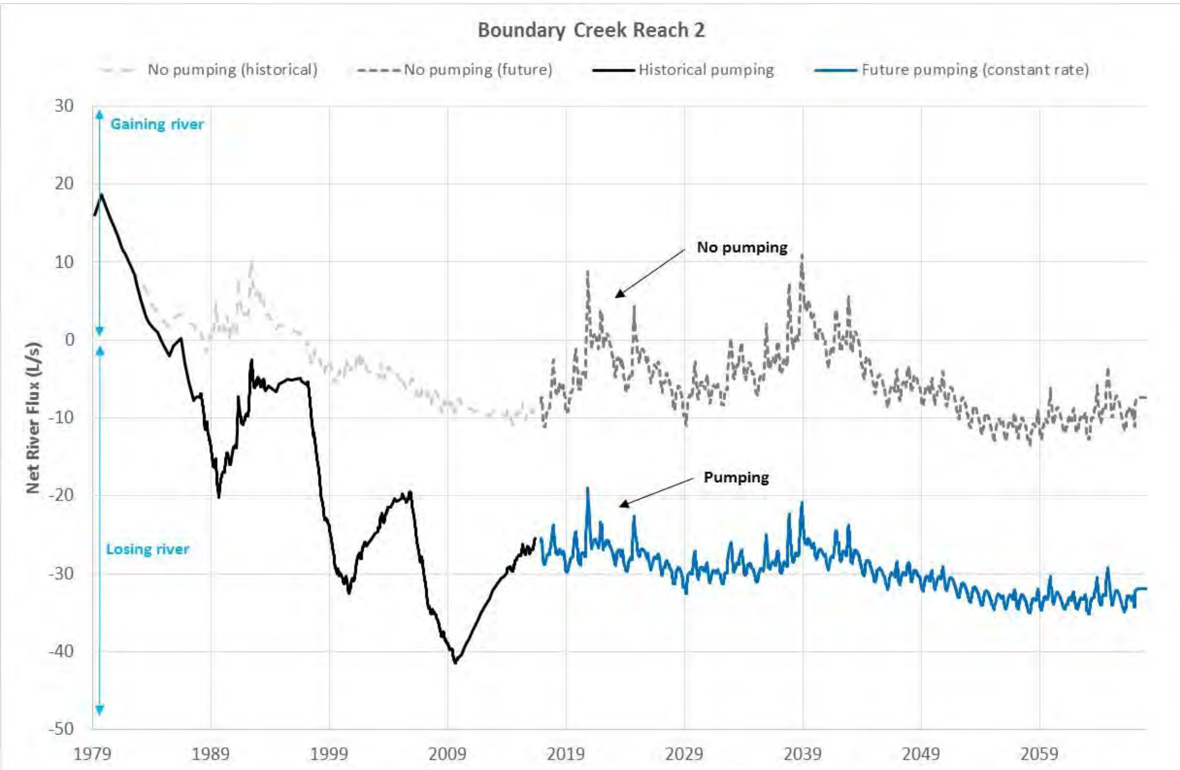
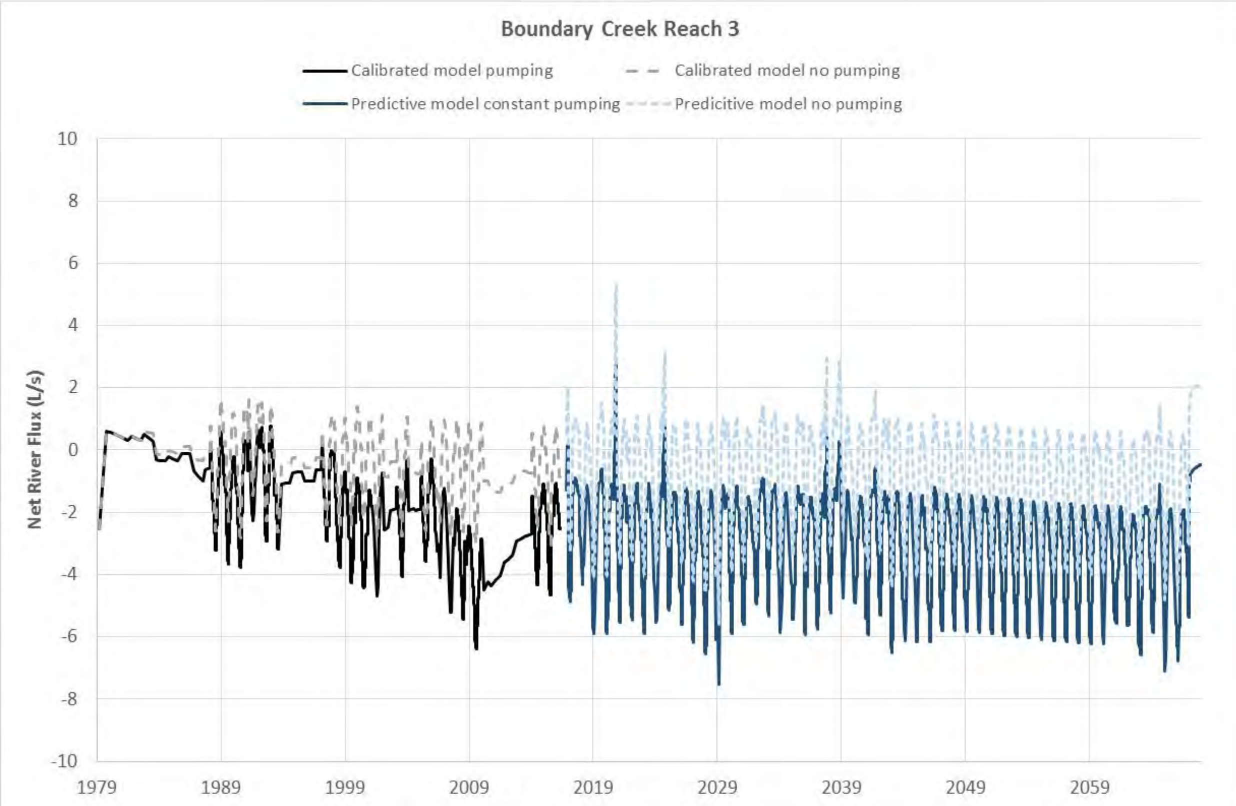
Appendix A. River flux

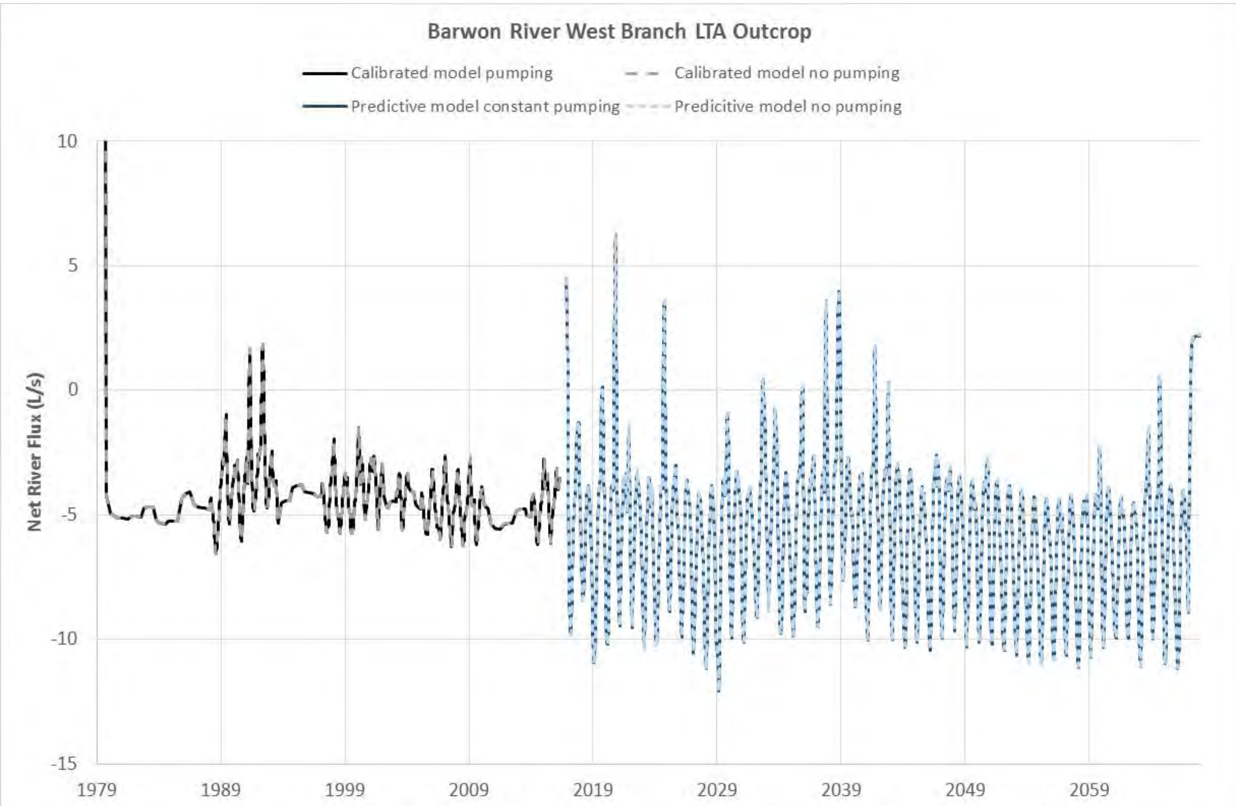
A.1 Boundary Creek

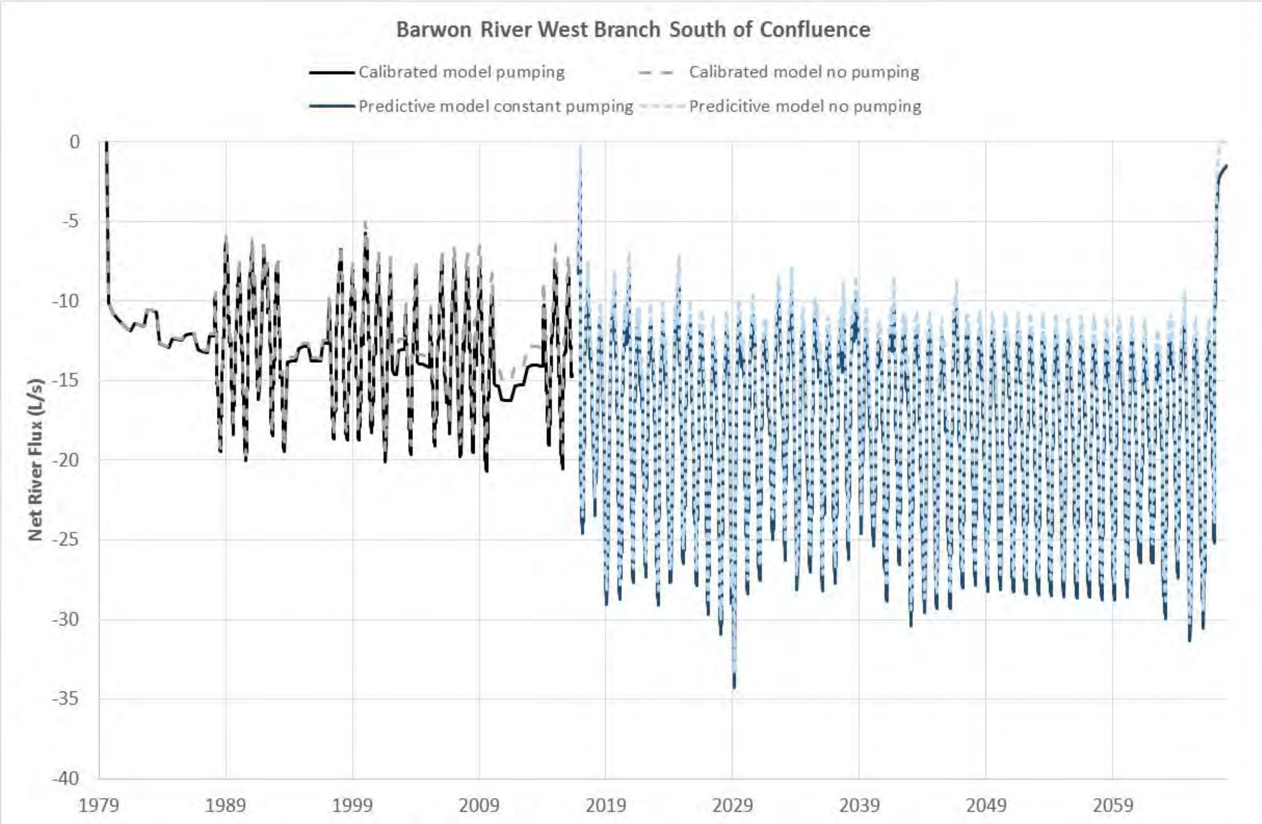


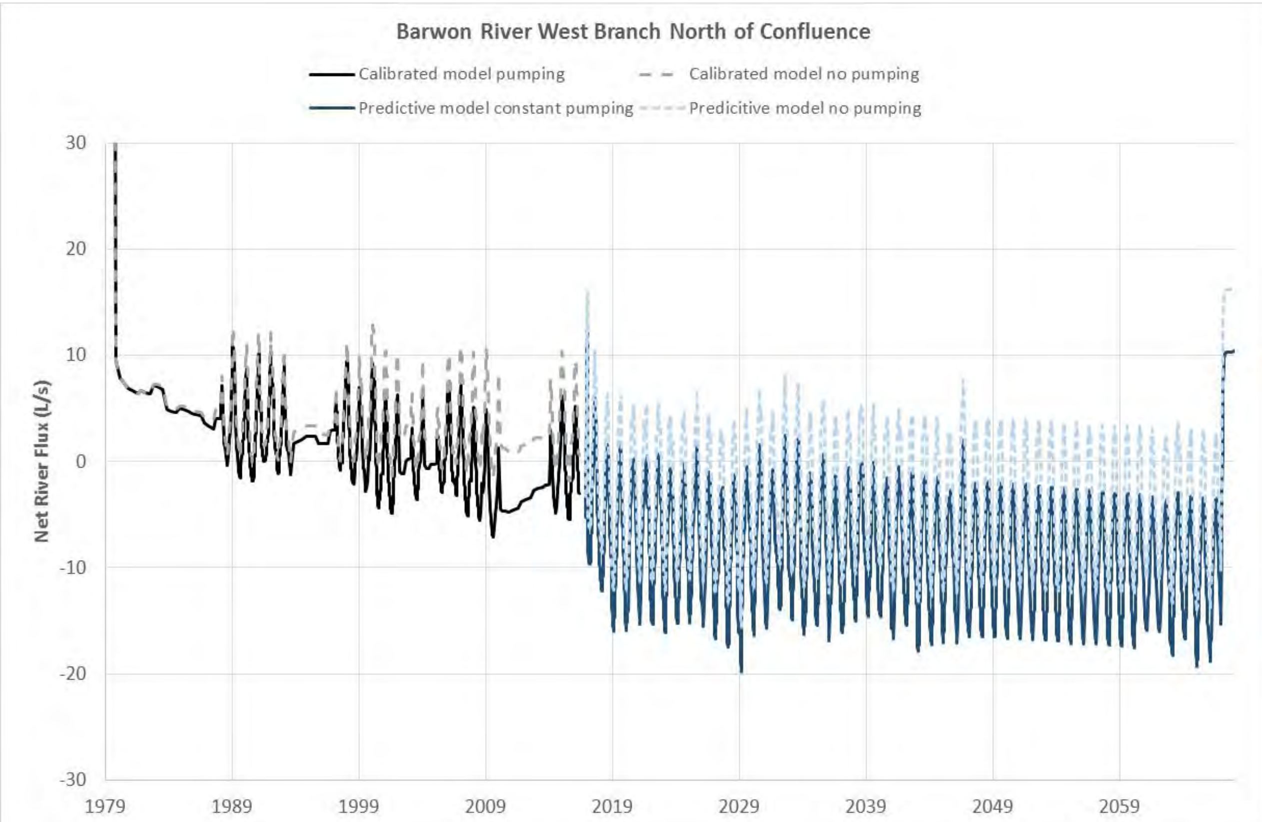


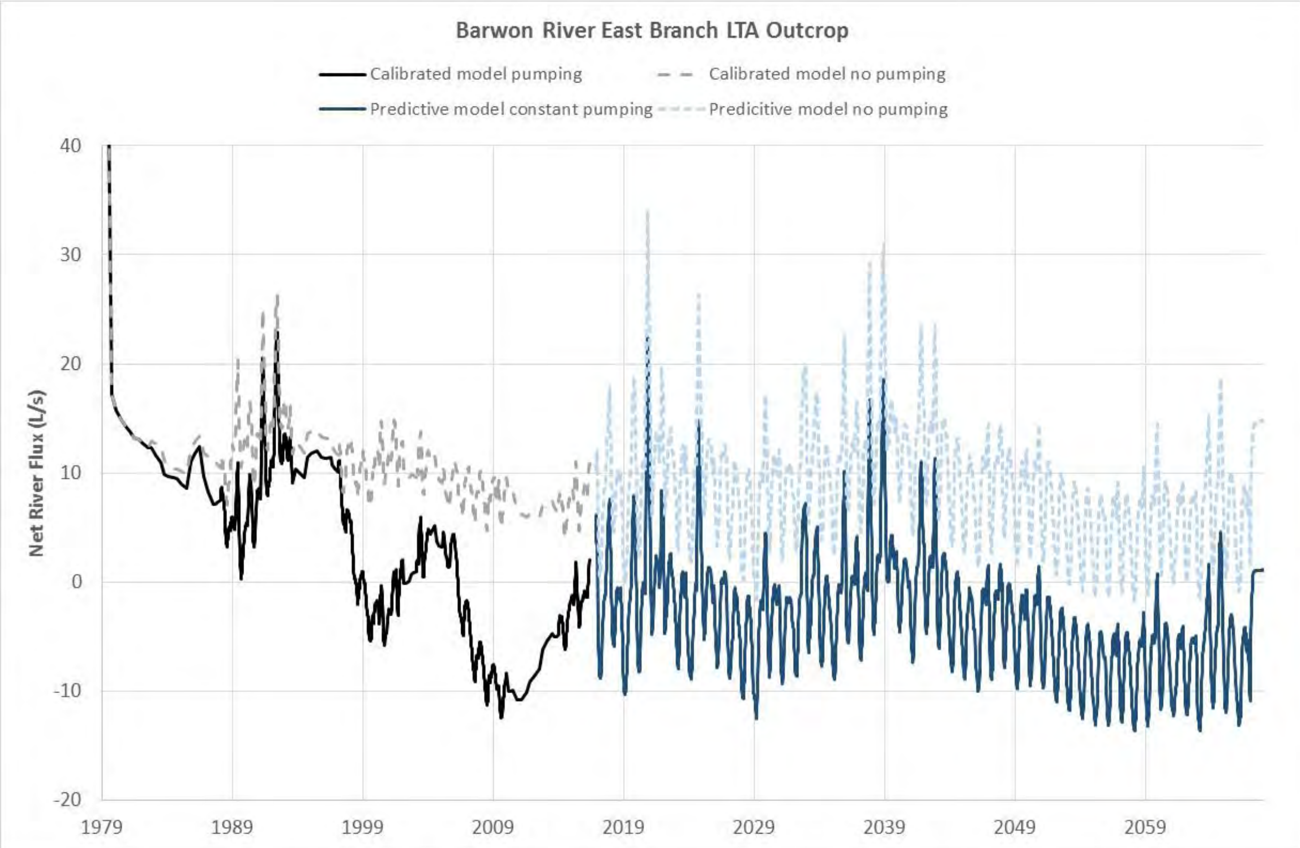


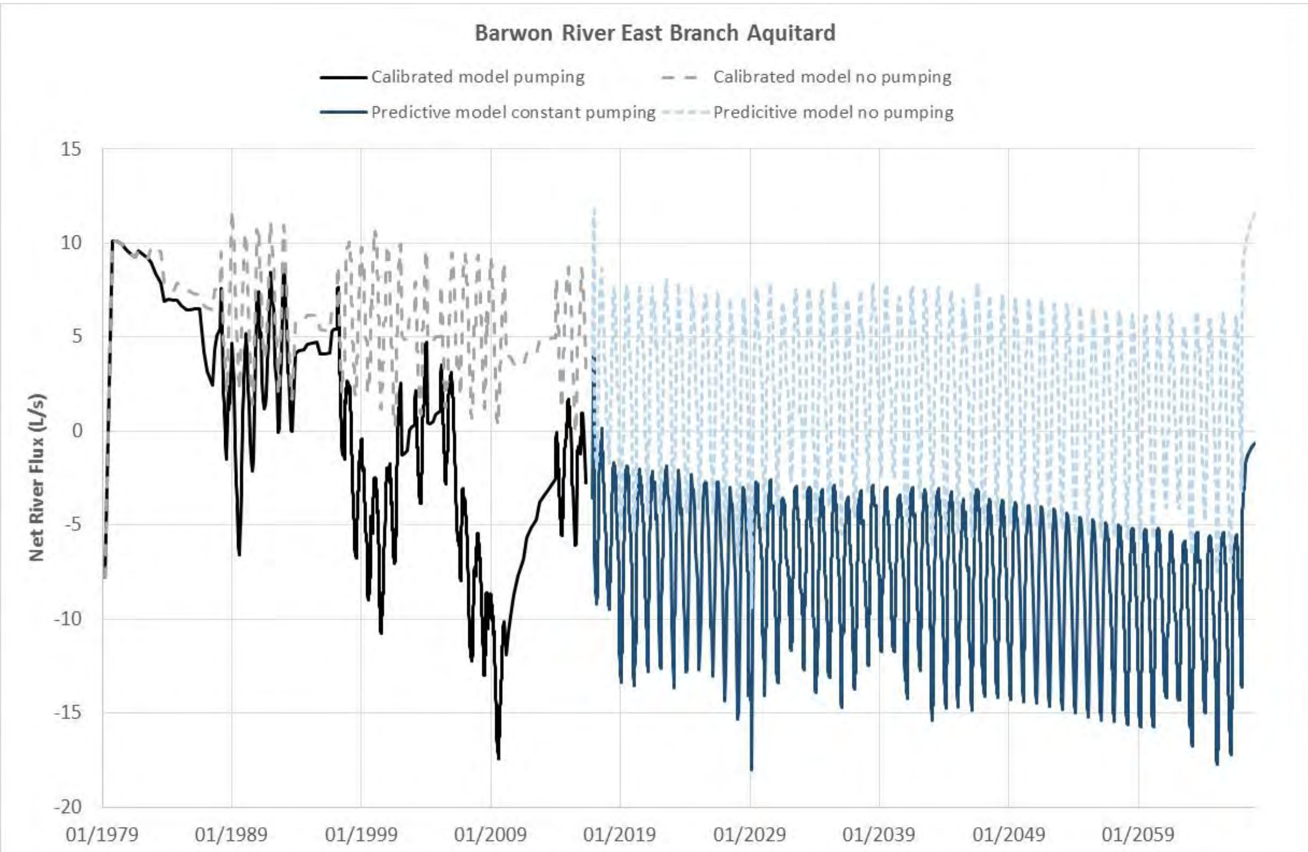
A.2 Barwon River



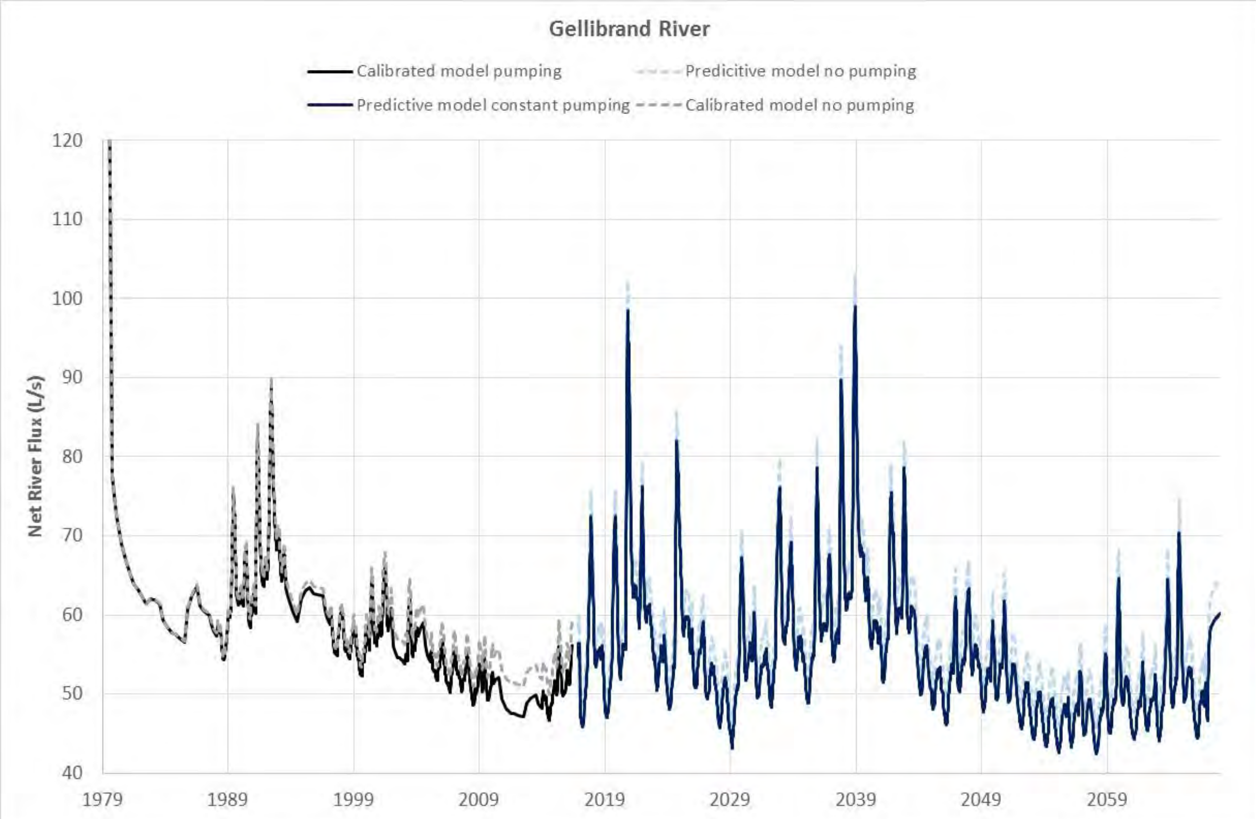

Barwon River West Branch South of Confluence
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
0
-5
-10
-15
-20
-25
-30
-35
-40
1979
1989
1999
2009
2019
2029
2039
2049
2059

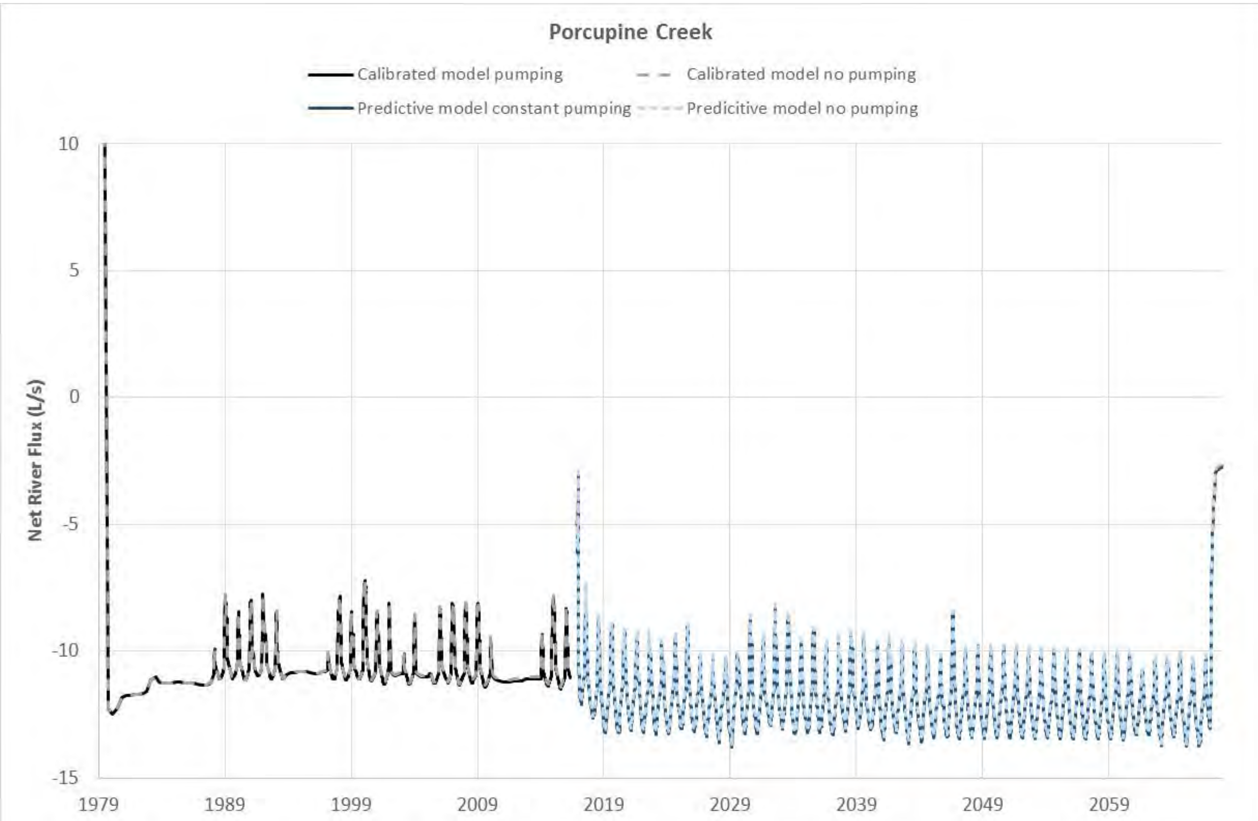

Barwon River West Branch North of Confluence
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
30
20
10
0
-10
-20
-30
1979
1989
1999
2009
2019
2029
2039
2049
2059

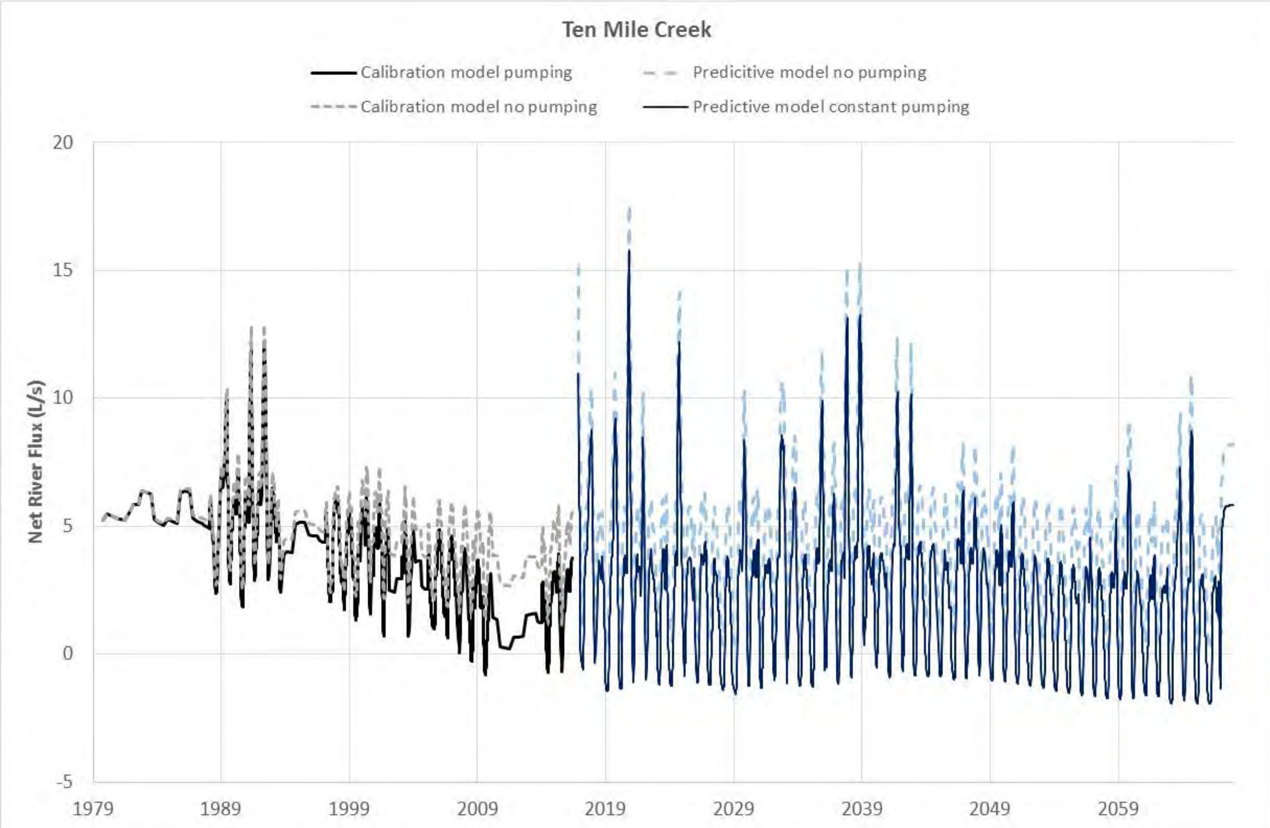

Barwon River East Branch LTA Outcrop
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
40
30
20
10
0
-10
-20
1979
1989
1999
2009
2019
2029
2039
2049
2059

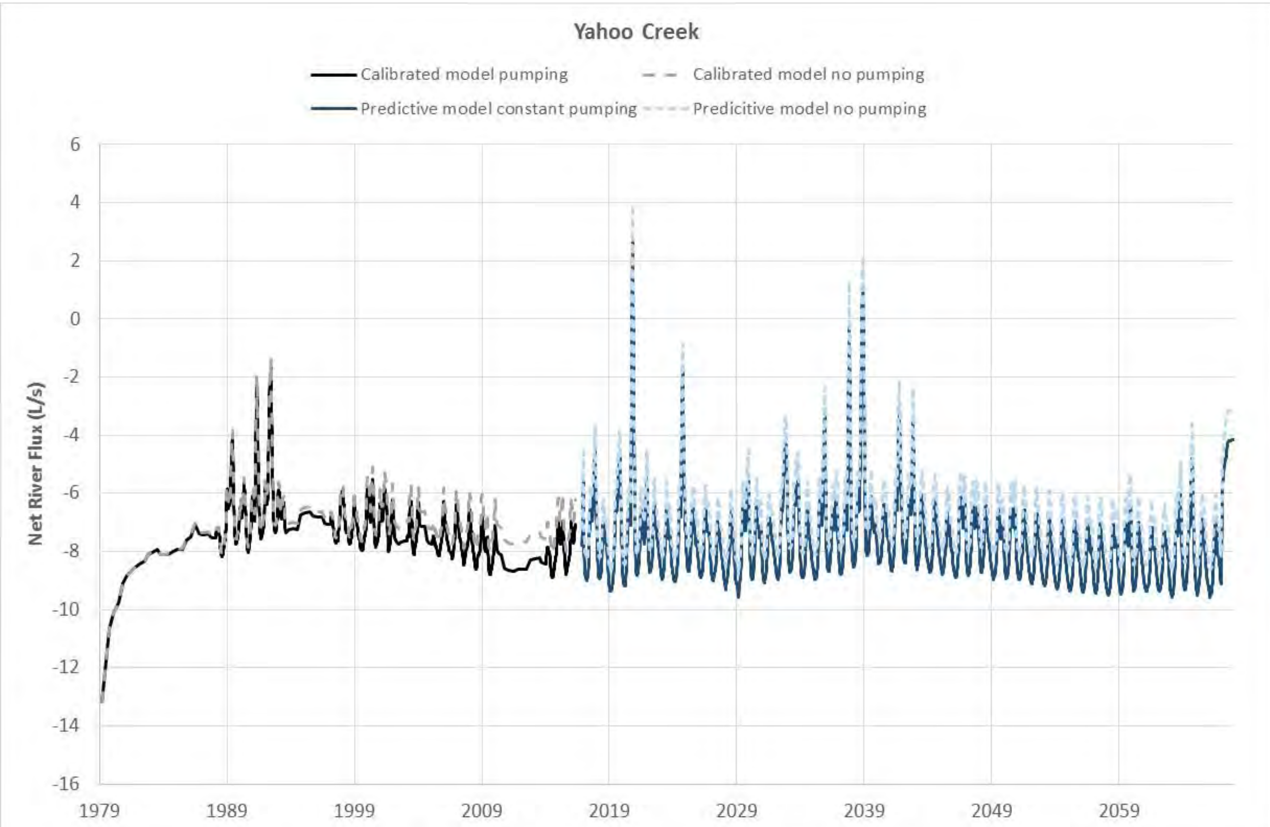

Barwon River East Branch Aquitard
Calibrated model pumping
Calibrated model no pumping
Predictive model constant pumping
Predicitive model no pumping
Net River Flux (L/s)
15
10
5
0
-5
-10
-15
-20
01/1979
01/1989
01/1999
01/2009
01/2019
01/2029
01/2039
01/2049
01/2059

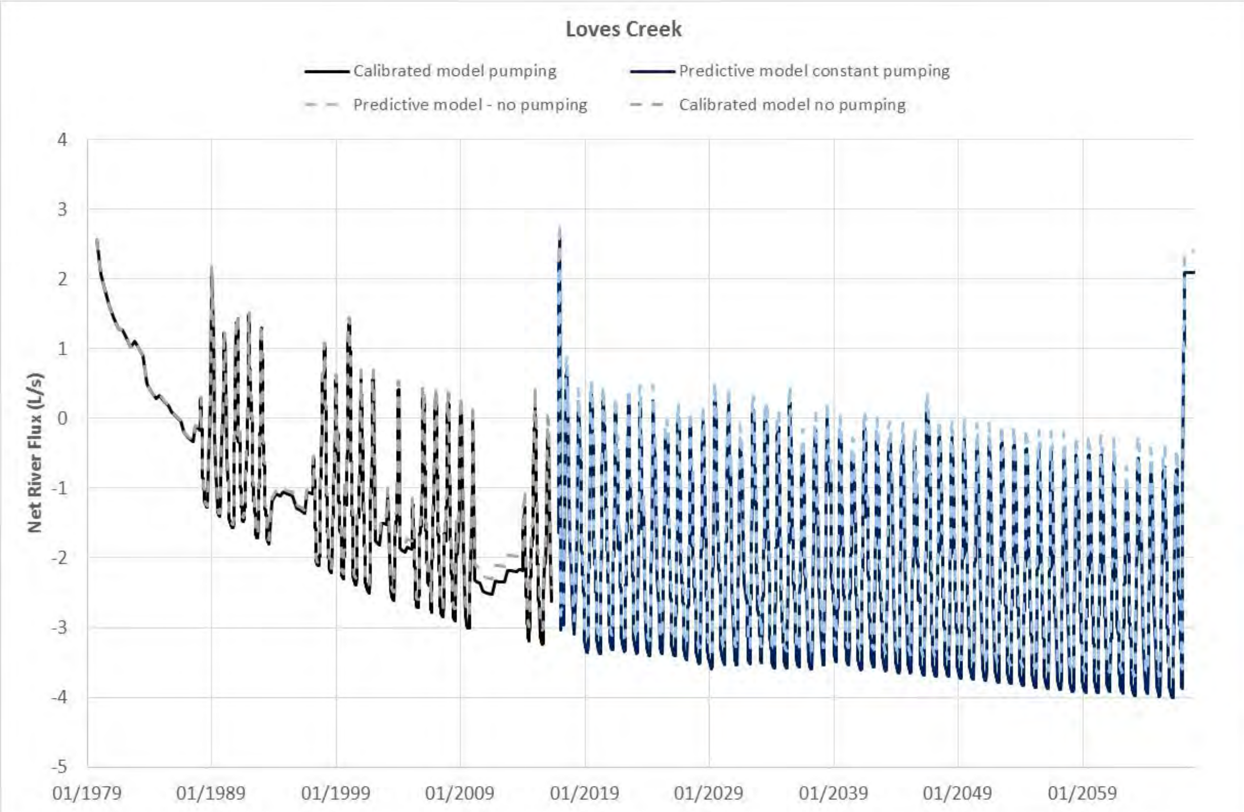
A.3 Gellibrand River and tributaries



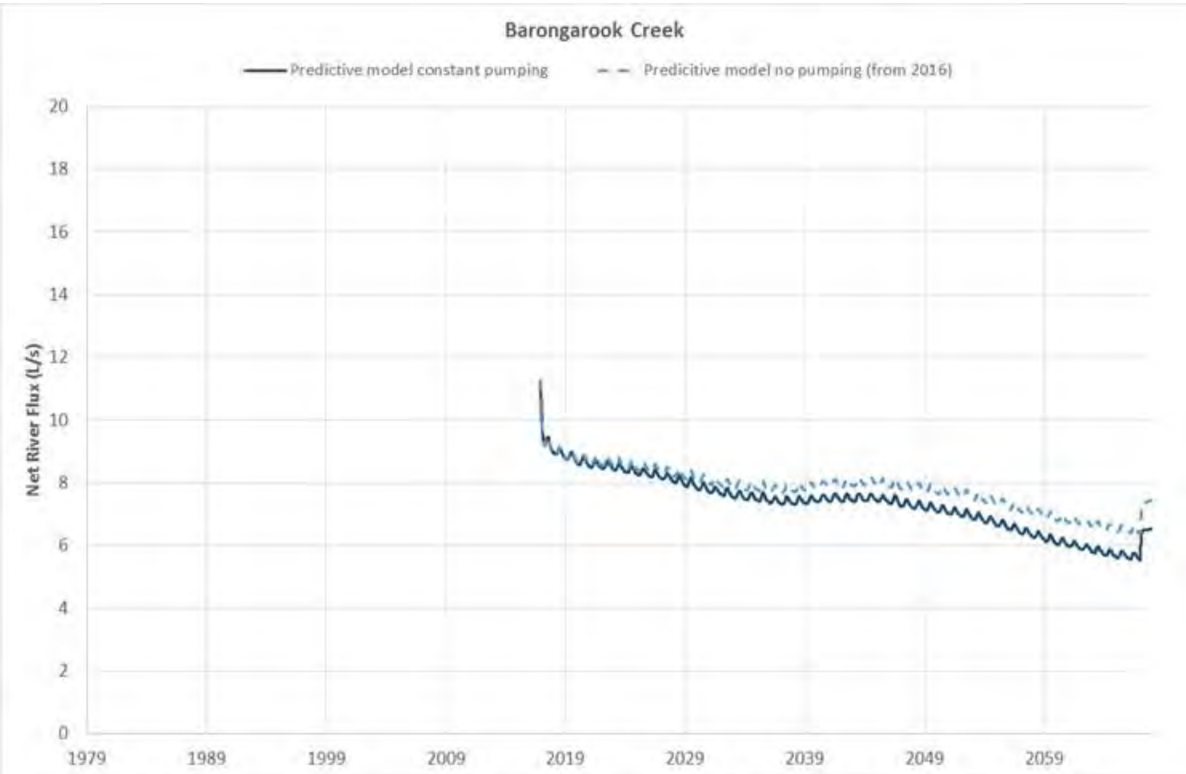



Ten Mile Creek
Calibration model pumping
Predicitive model no pumping
Calibration model no pumping
Predictive model constant pumping
Net River Flux (L/s)
20
15
10
5
0
-5
1979
1989
1999
2009
2019
2029
2039
2049
2059


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 10-1 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 10-2 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 10-3 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 10-4 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

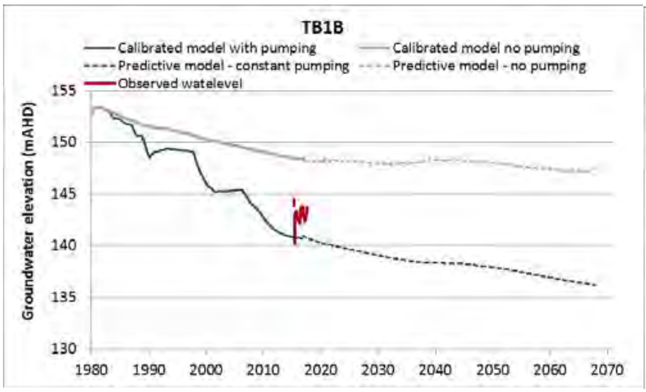
Vegetation monitoring site	Impact/ Reference site	Local Hydrogeology	Vegetation dependent on regional aquifer	Likelihood of connection to regional aquifer	Consequence (drawdown predicted in regional aquitard/aquifer)			Unmitigated Potential Risk	Mitigated potential risk (presence of alluvial aquifer)
					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**

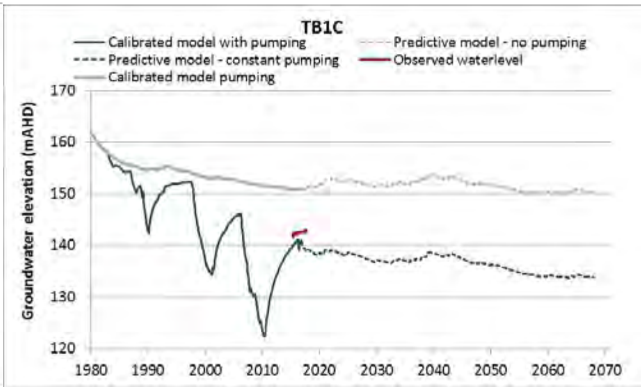
C.1 Impact sites

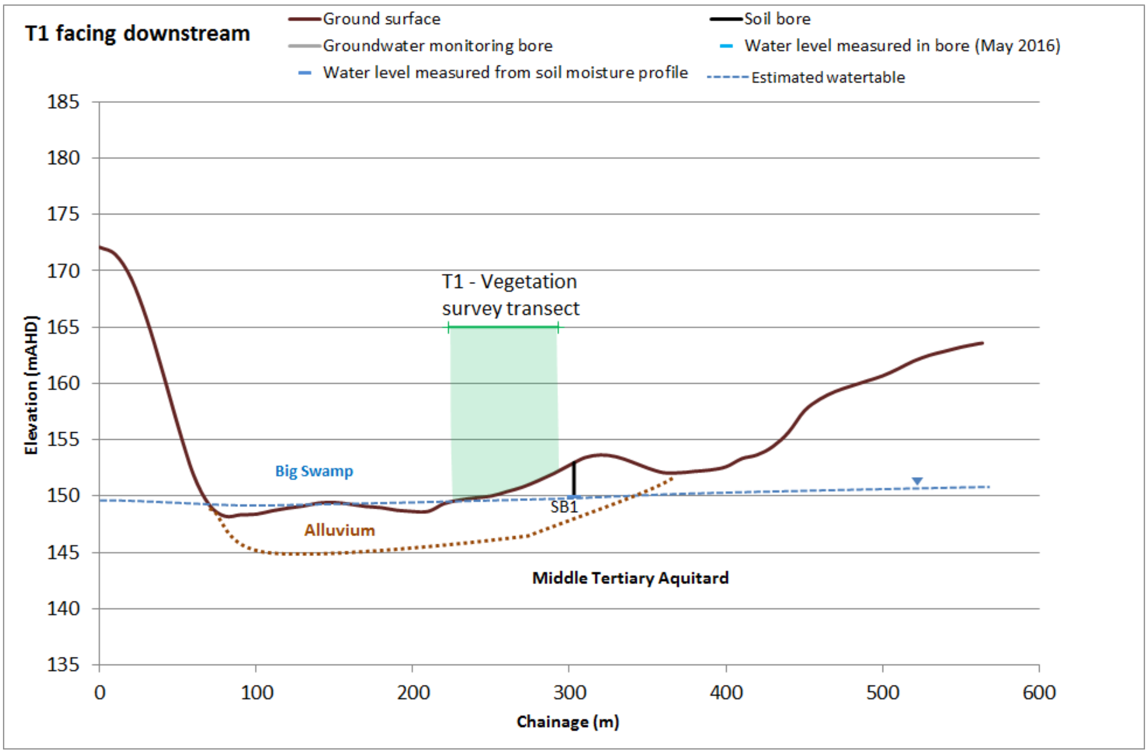
Impact sites

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.



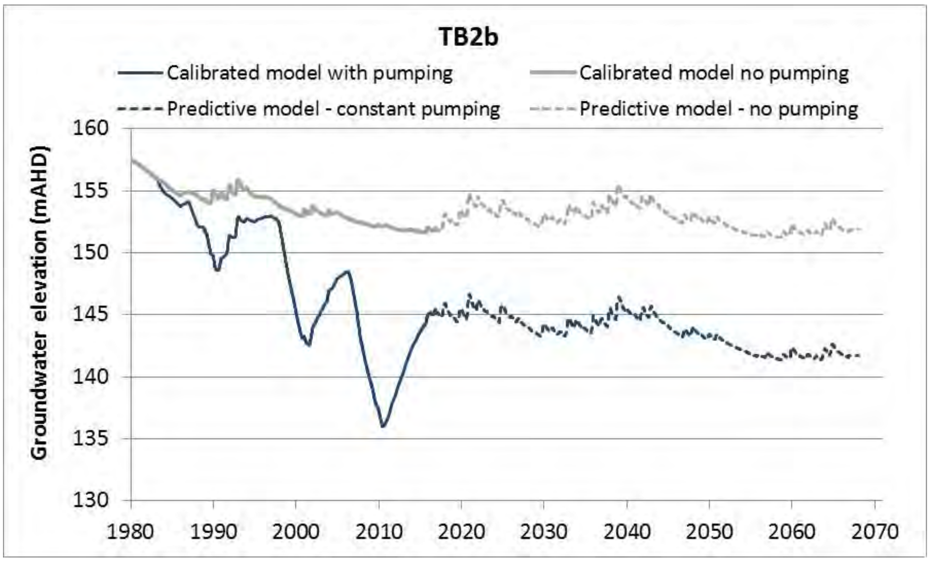


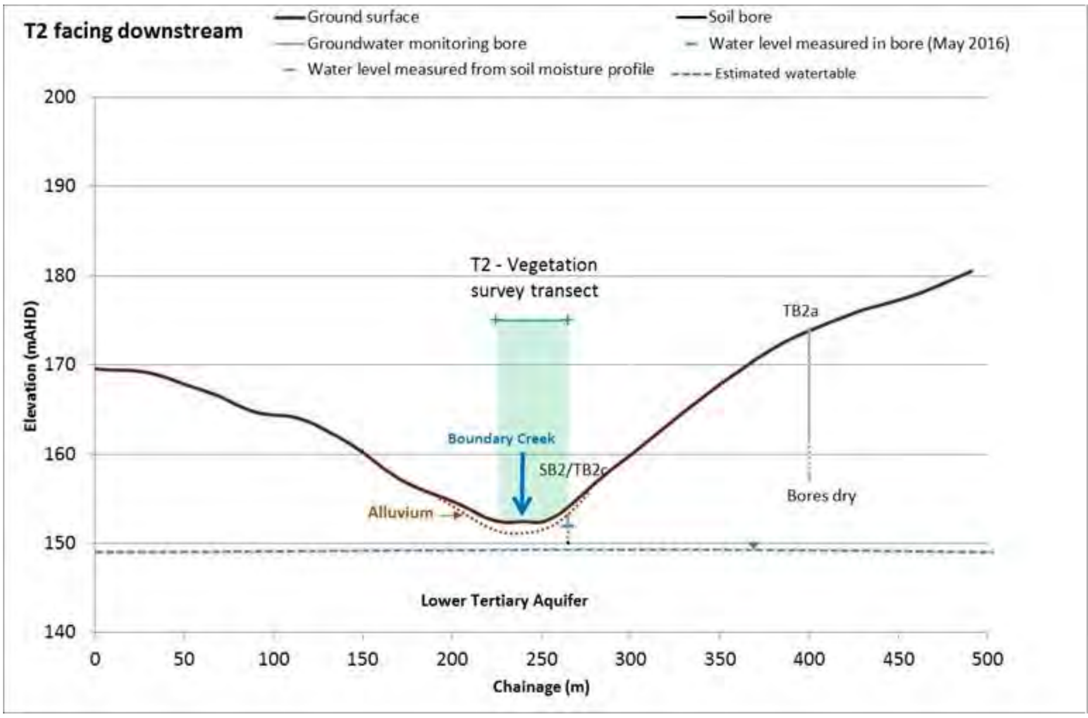


Impact sites

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.

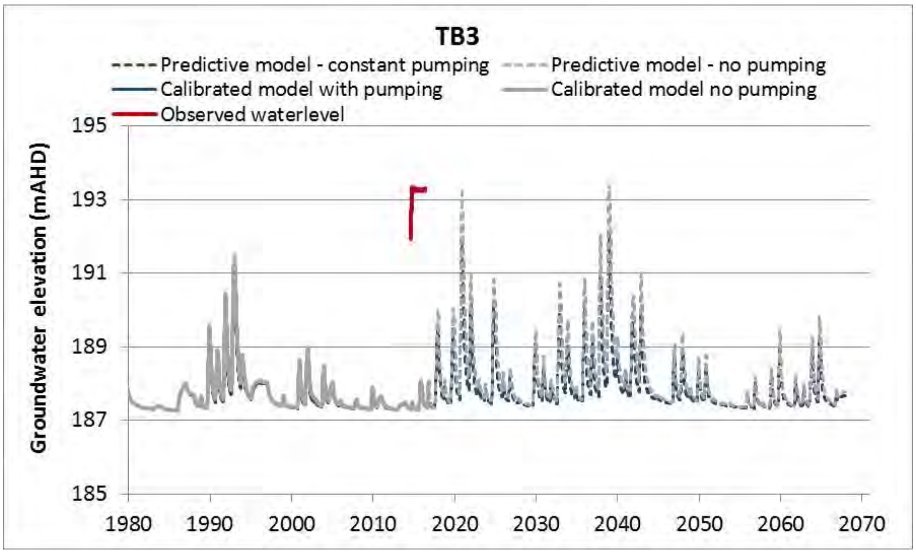


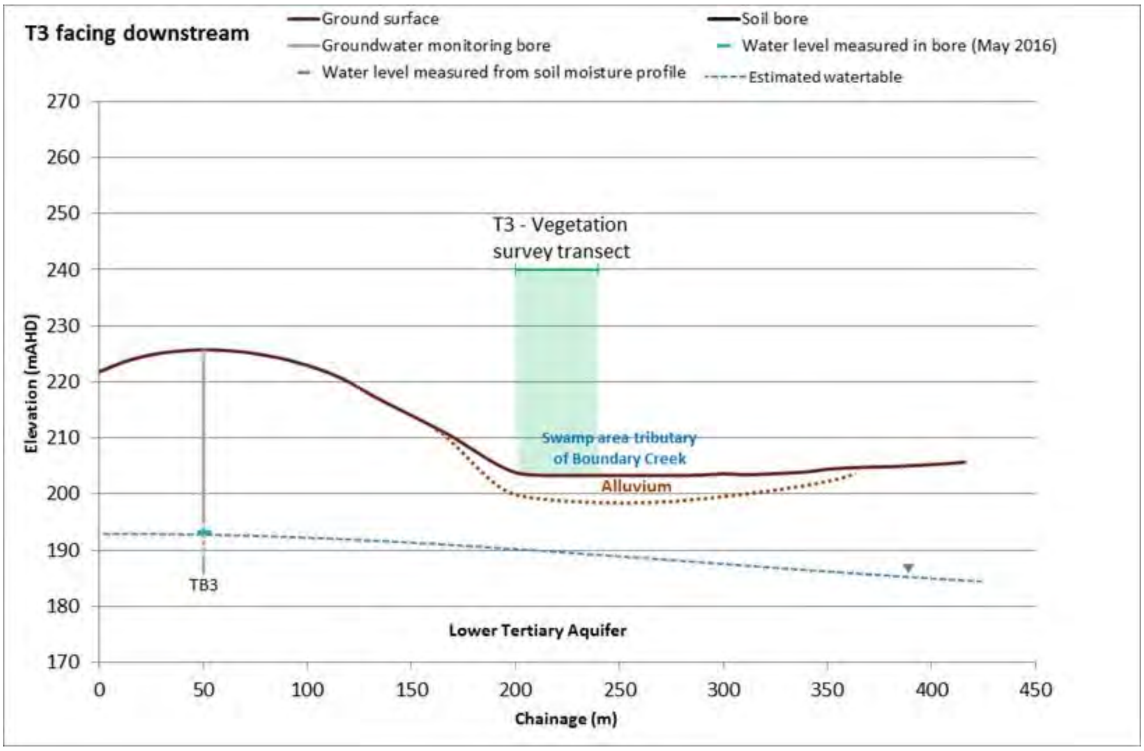


Impact sites

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.

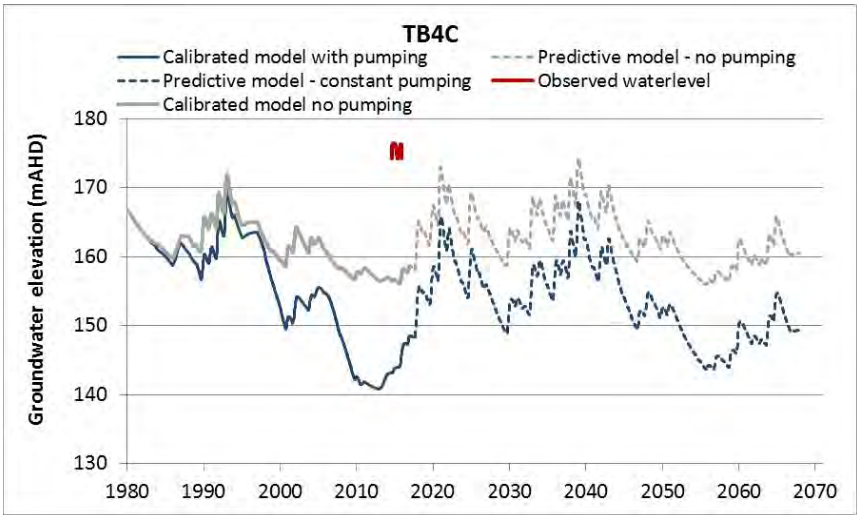


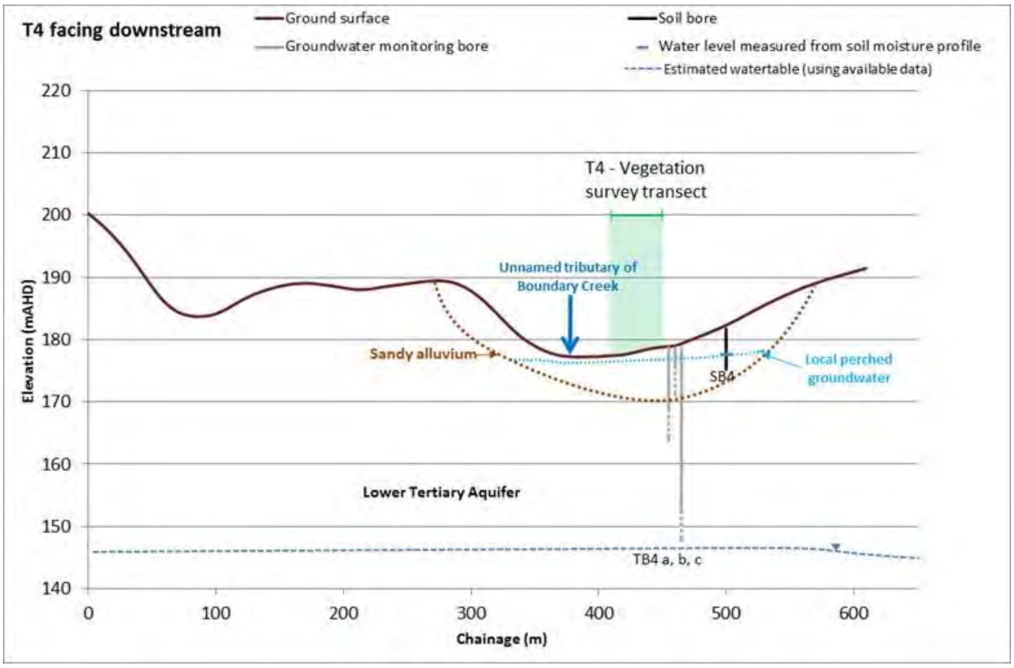


Impact sites

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.

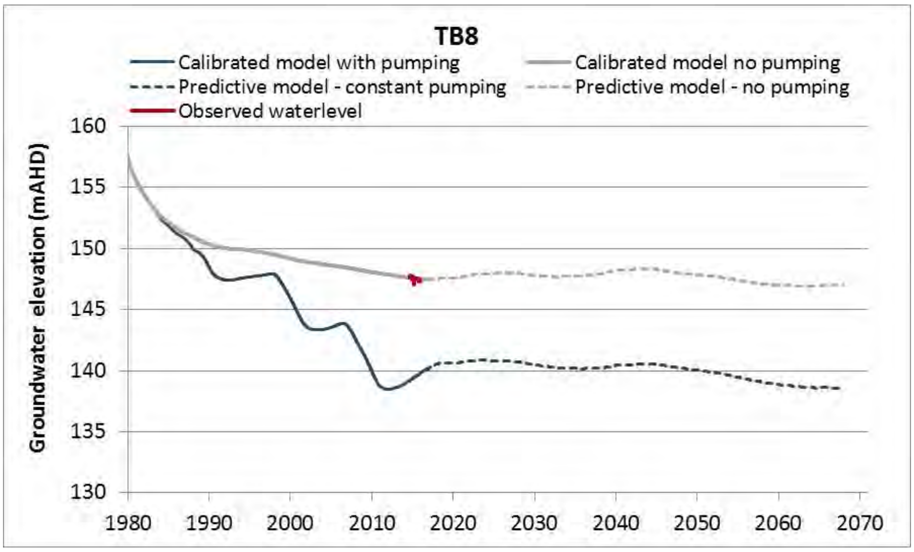


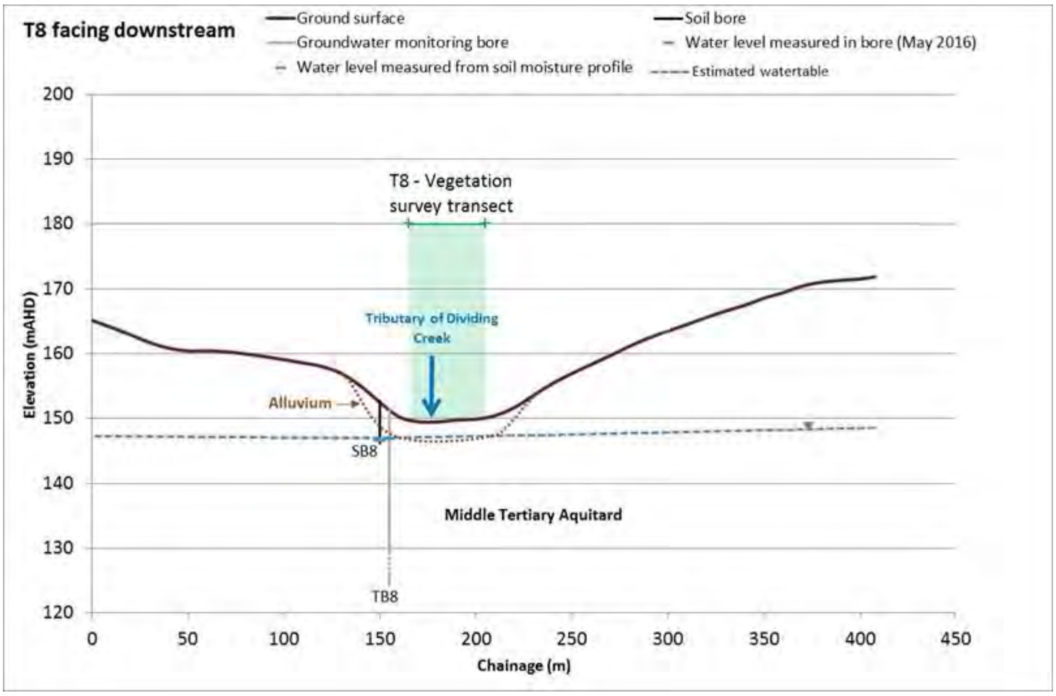


Impact sites

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.

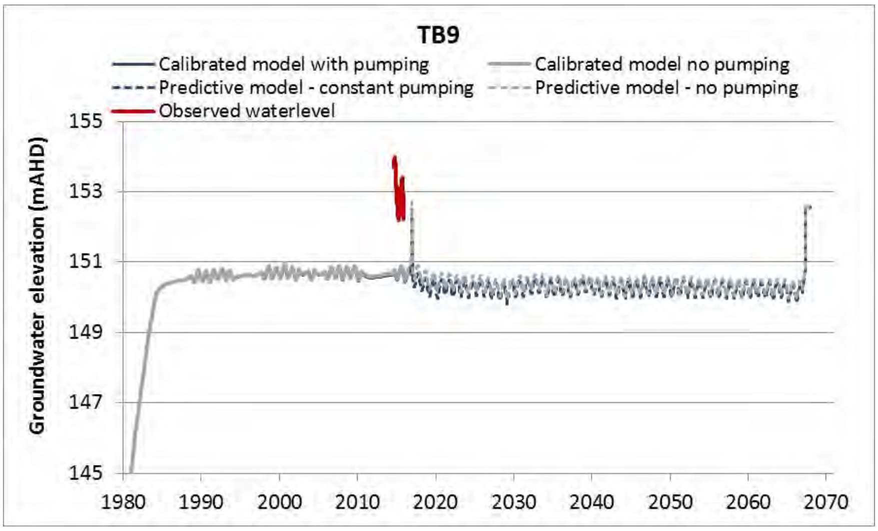


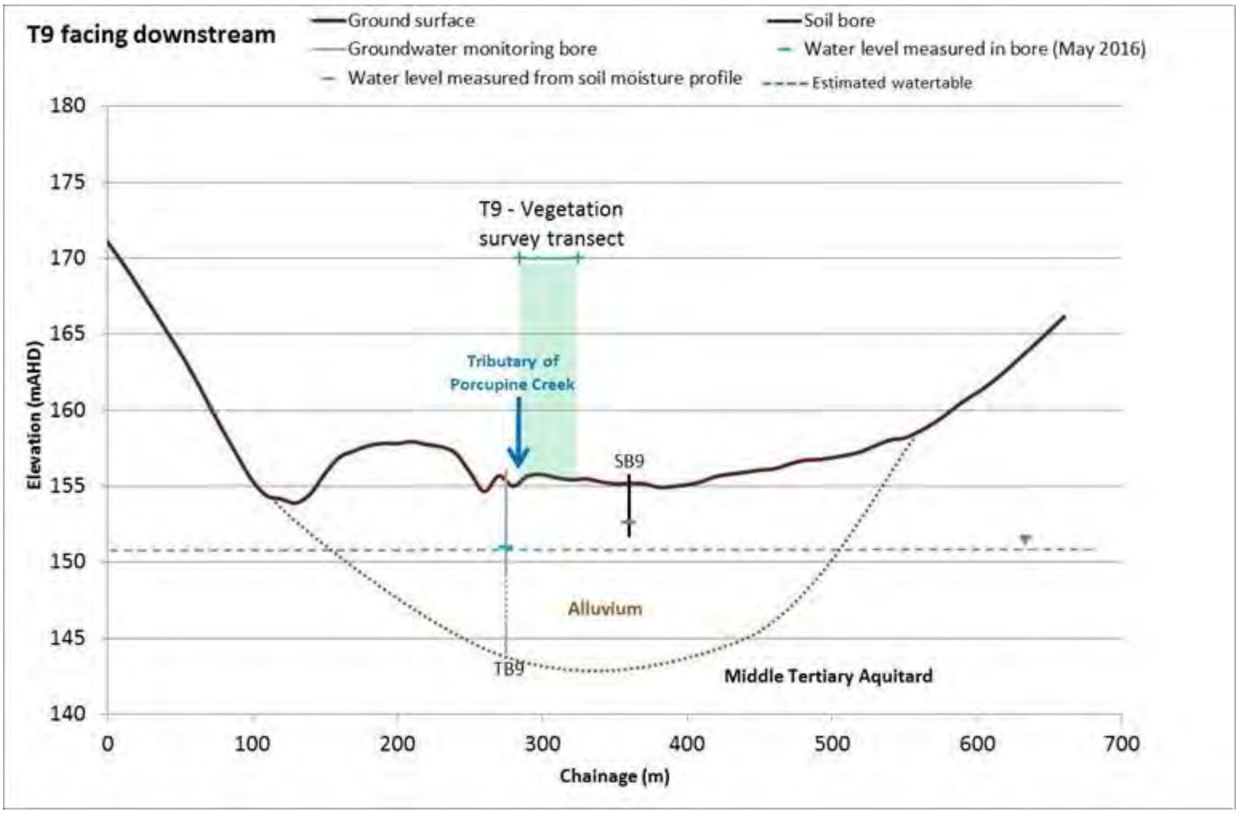


Impact sites

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.

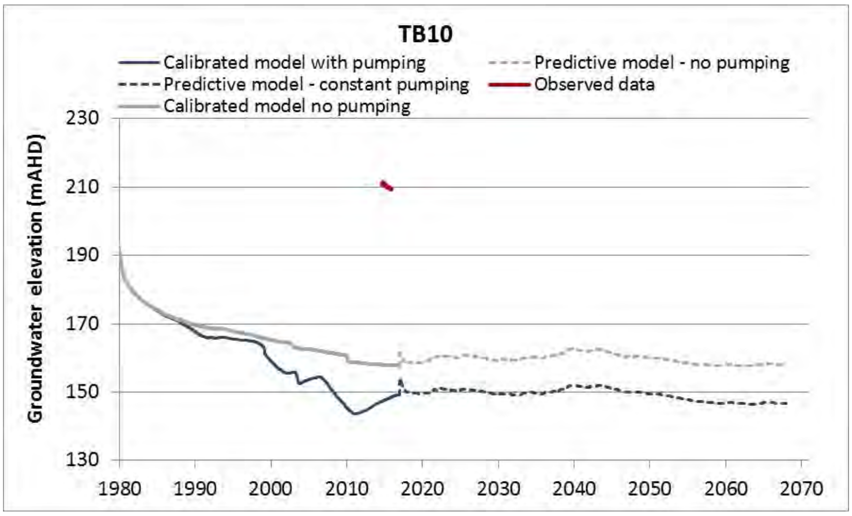


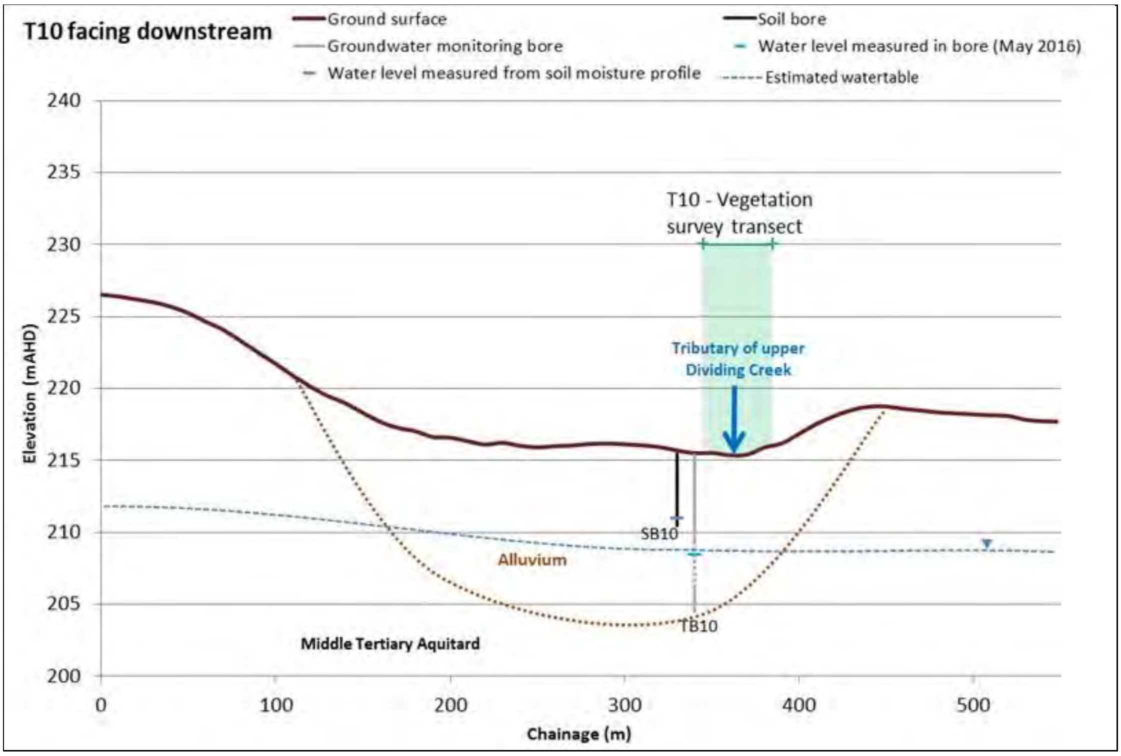


Impact sites

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.



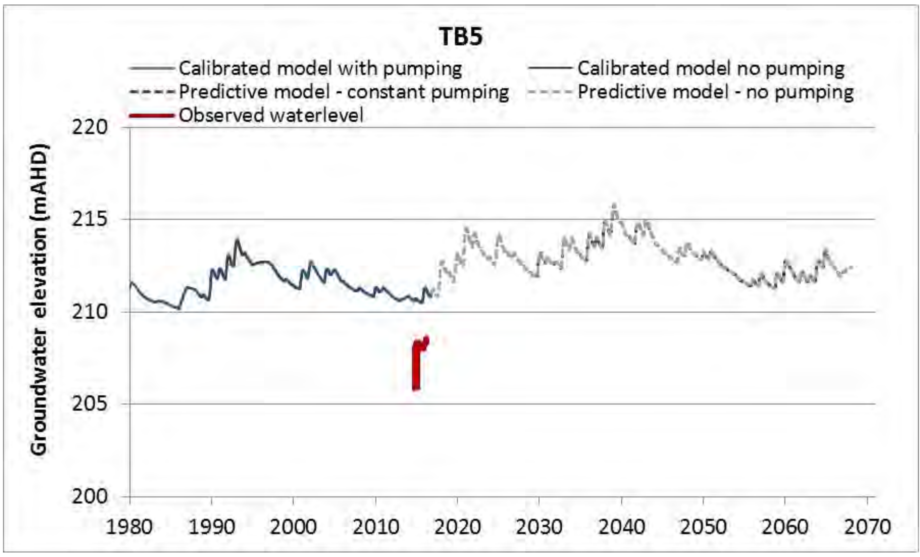


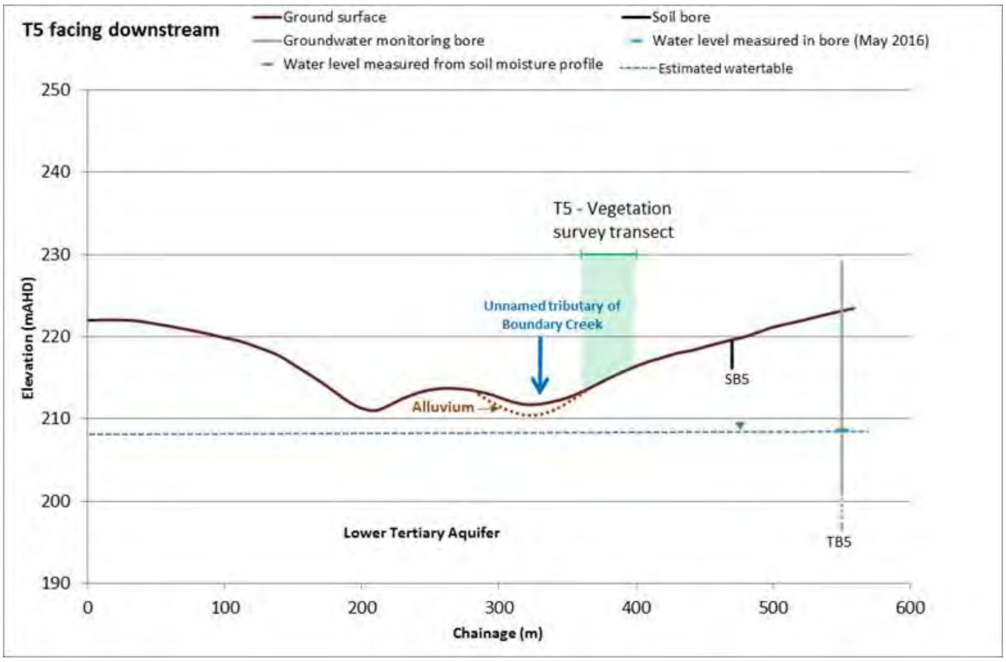
C.2 Reference vegetation monitoring sites

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.

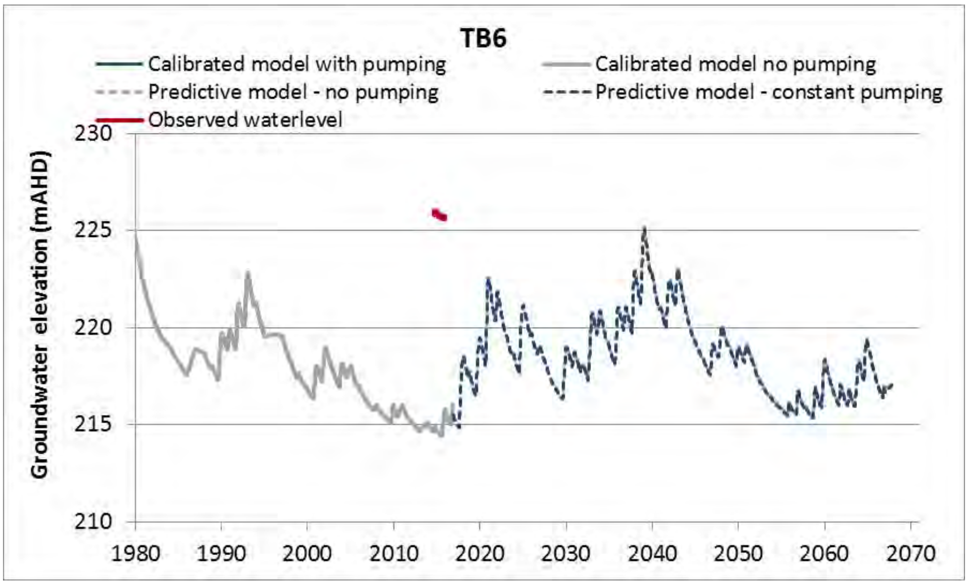


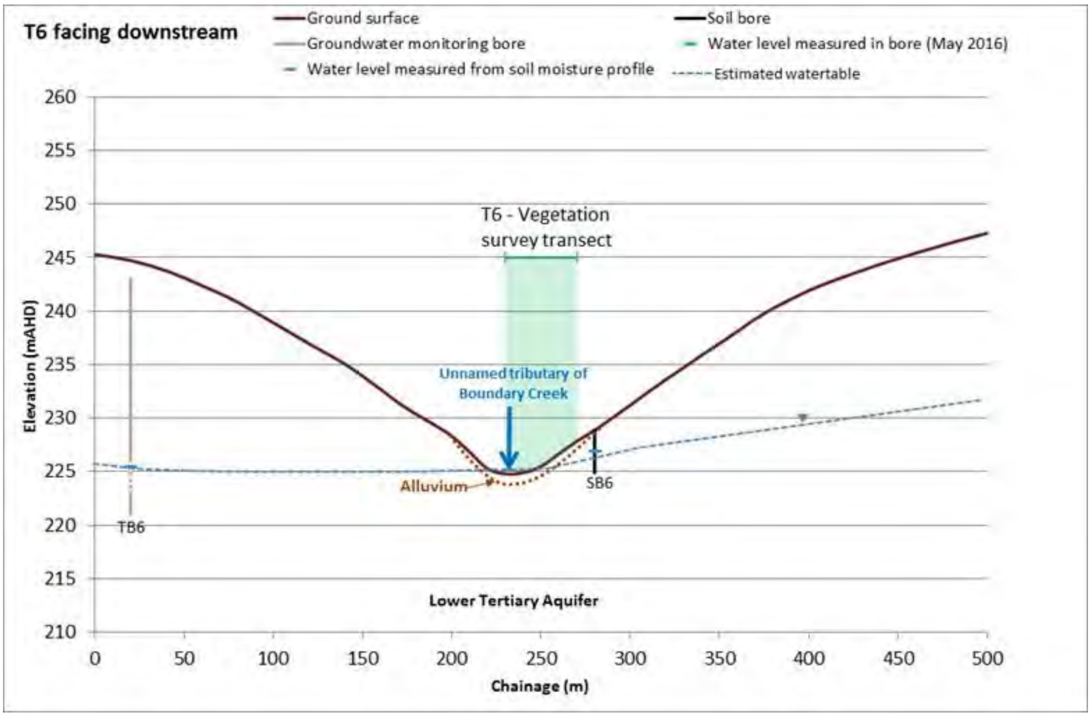


Reference sites

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.

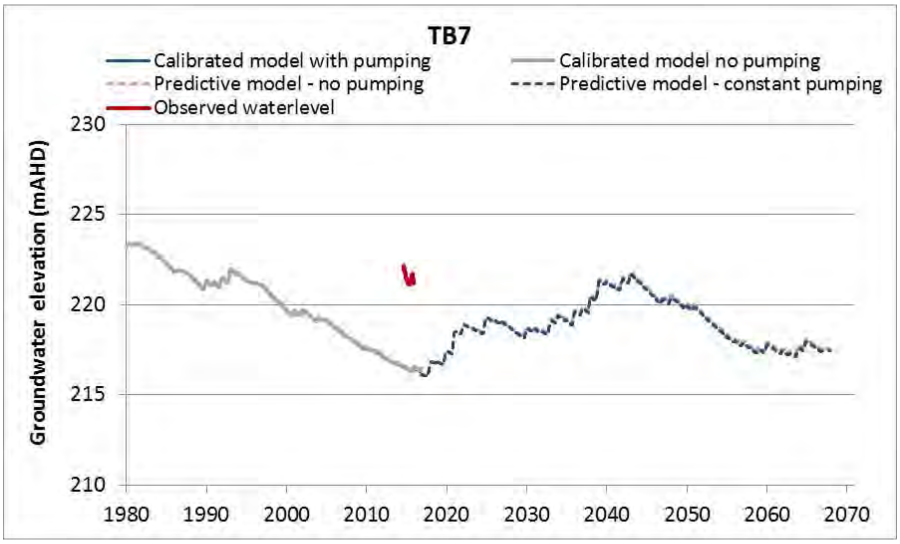


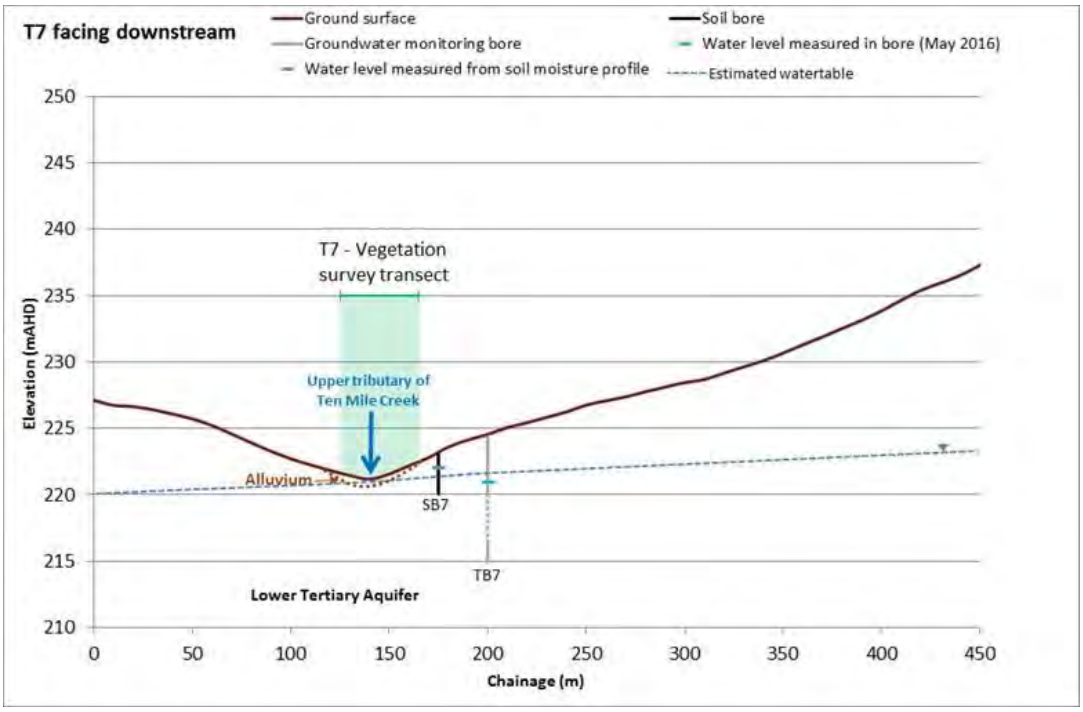


Reference sites

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.

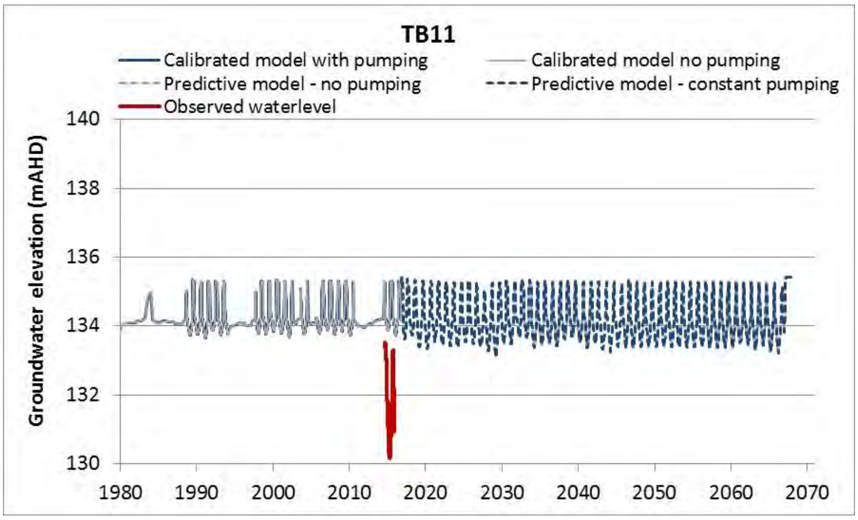


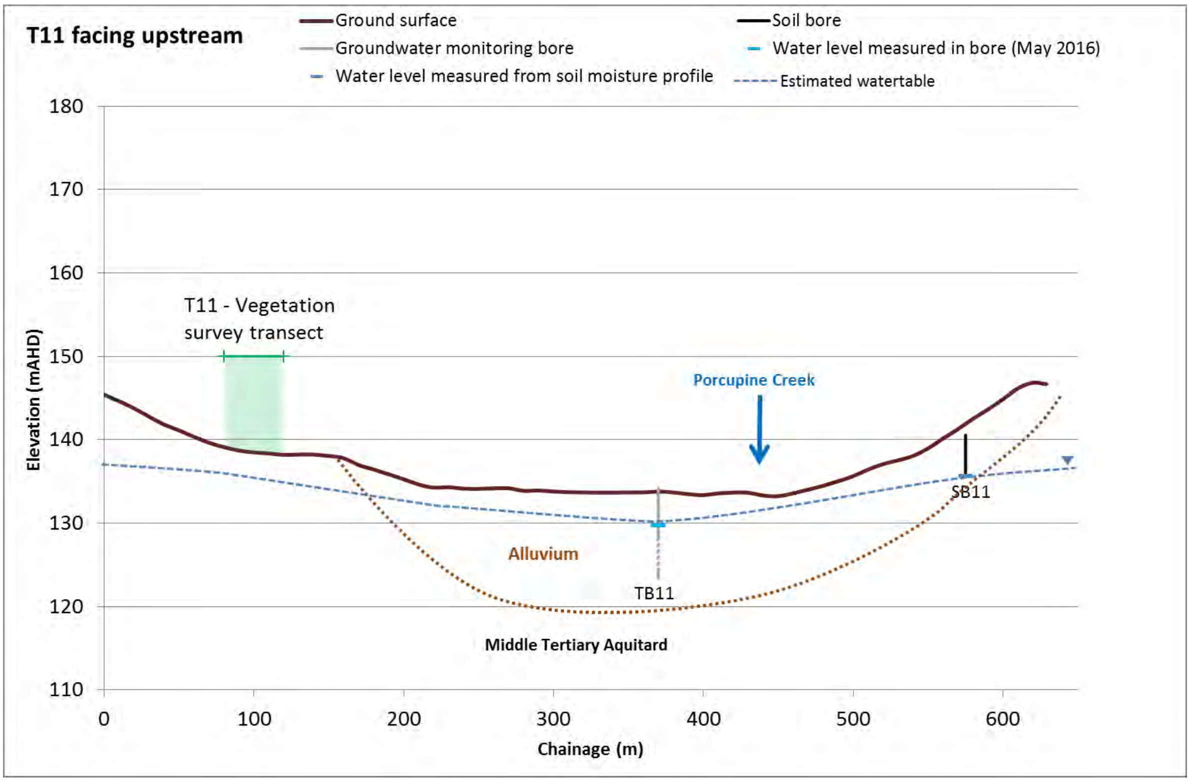


Reference sites

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.

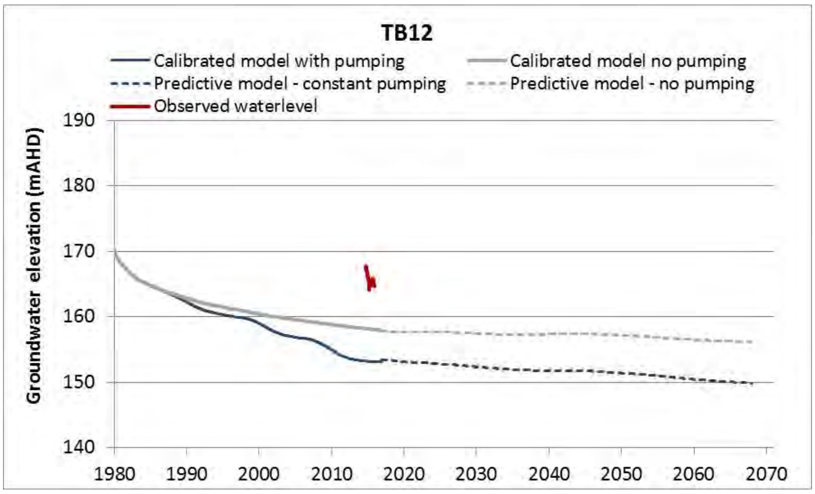


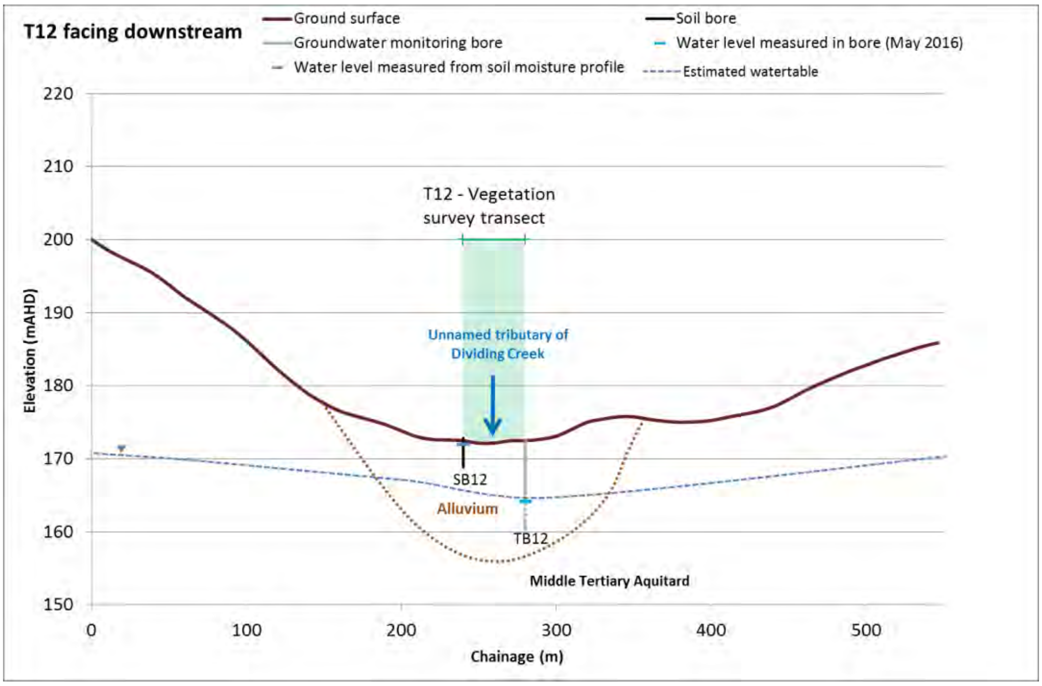


Reference sites

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.

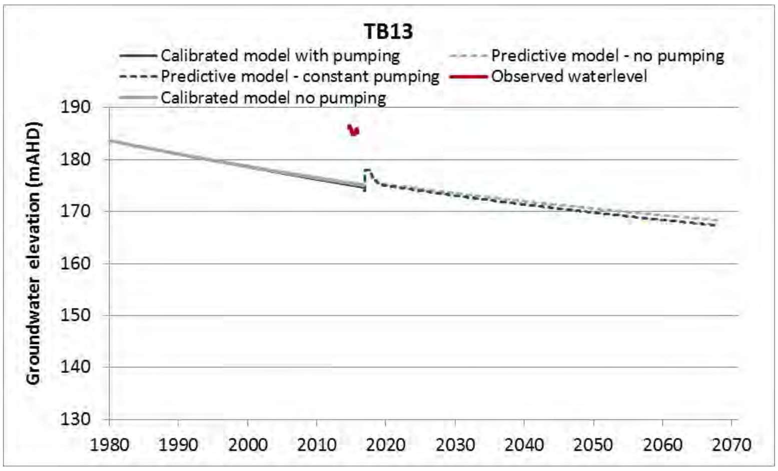


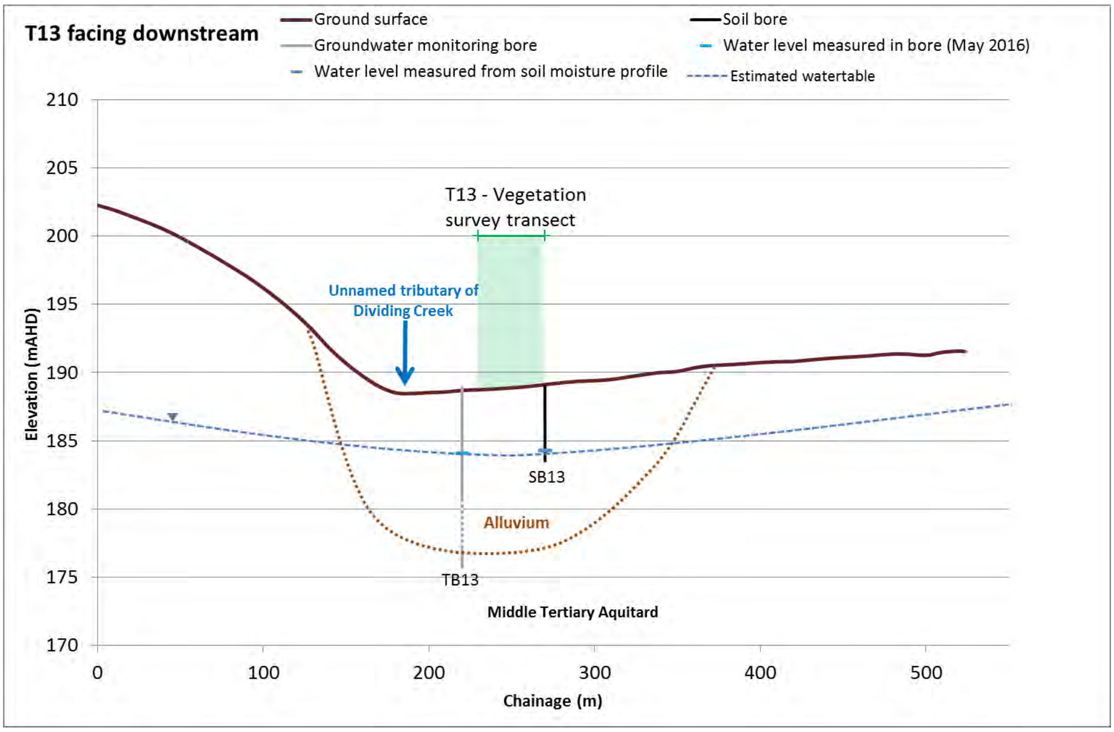


Reference sites

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.

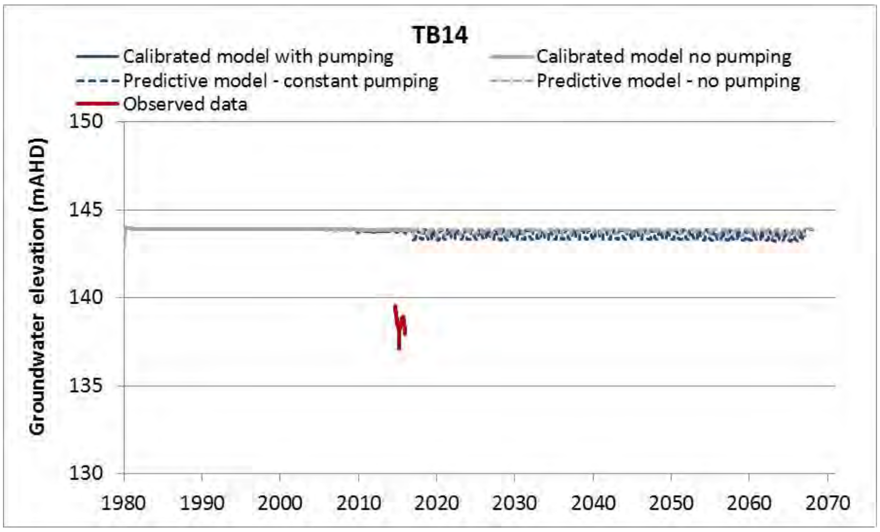


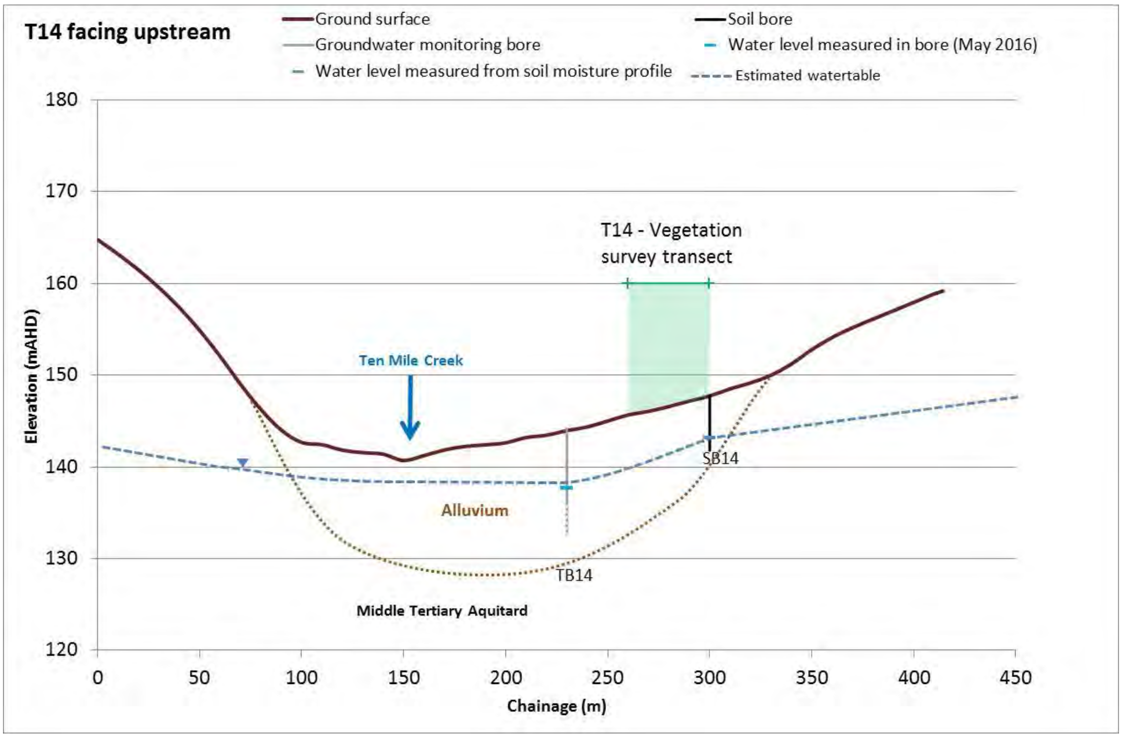


Reference sites

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.





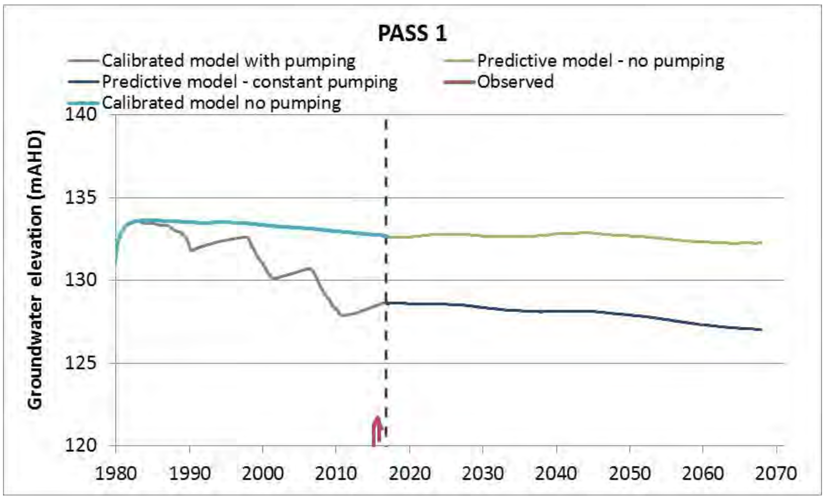
Appendix D. PASS monitoring sites

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

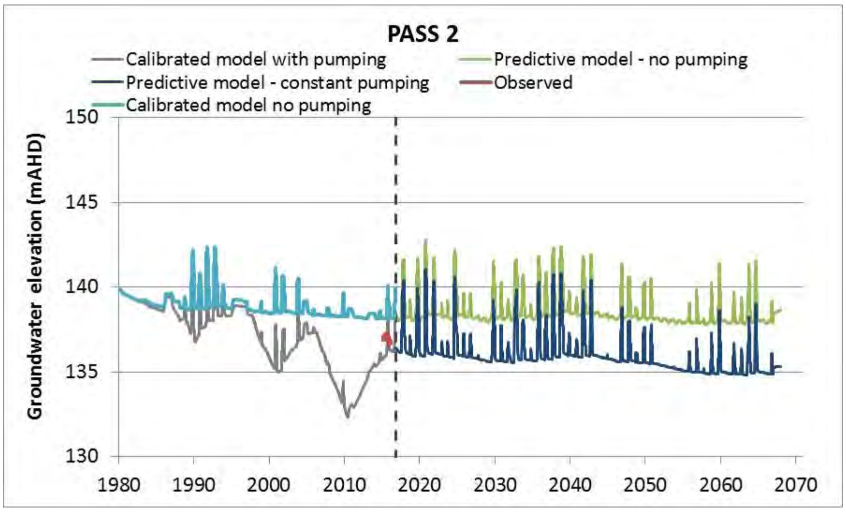
PASS 1

- 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

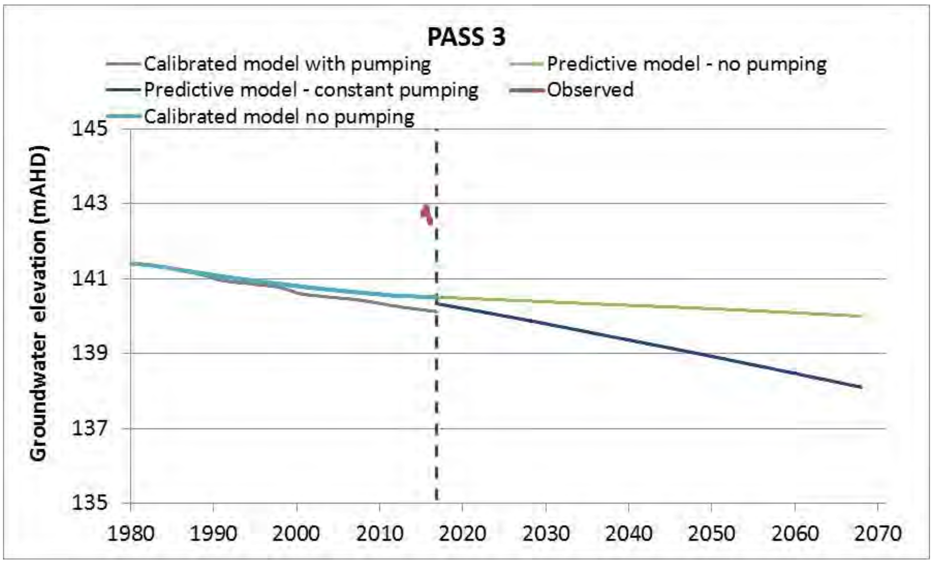
- Located to the east of the Barwon River East Branch approximately 7 km upstream of its confluence with the Barwon River West Branch
- Groundwater levels are weakly artesian (above ground level) for much of the year and decline below the ground level during the summer months. The surface water is supported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