Barwon Downs Technical Works Program

Barwon Water

Integration Report

FINAL REPORT

22 March 2017

Barwon Downs Technical Works Program

Project No: IS129200
Document Title: Integration Report
Document No.: IS129200-100
Revision: FINAL REPORT
Date: 22 March 2017
Client Name: Barwon Water
Client No:
Project Manager: Louise Lennon
Author: Louise Lennon
File Name: J:\IE\Projects\03_Southern\IS129200\21 Deliverables\Integration report\Final report\Barwon Downs Integration Report FINAL REPORT.docx

Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

Document history and status

Revision	Date	Description	By	Review	Approved
DRAFT		Preliminary draft report	NU ,FD, LL	LL	LL
DRAFT v2	13/09/2016	Draft report	LL	GH	GH
FINAL	25/11/2016	Final draft report	LL	SP	SP
FINAL	22/03/2017	Final report	LL	GH	GH

Contents

An important note about your report

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

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

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

Executive Summary

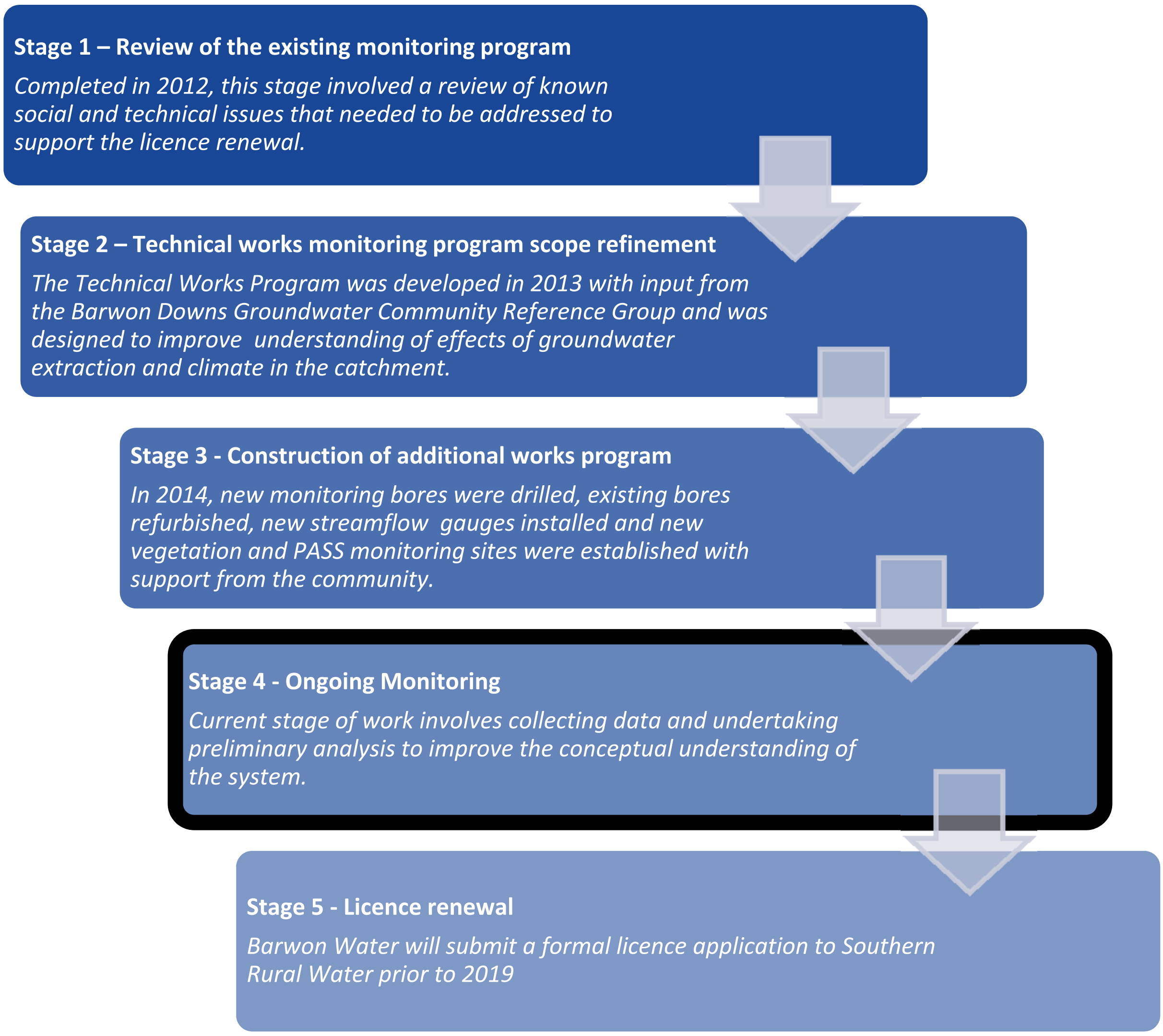
Background

Barwon Water uses the Barwon Downs borefield to augment Geelong's surface water supplies during dry times. The groundwater extraction licence for Barwon Downs is due for renewal in mid 2019 and in preparation for this, Barwon Water has commissioned a range of studies under the Technical Works Monitoring Program. This report is a compilation of the results of the Technical Work Monitoring Program to date.

The Technical Works Monitoring Program is broken into five stages of work as illustrated in Figure 0-1. The Technical Works Monitoring Program is a complex multi-disciplinary program with many interrelated components and has been designed to address knowledge gaps on the potential impacts caused by groundwater extraction.

The program involves collecting data on receptors that could potentially be impacted by the Barwon Downs borefield. This information will help improve understanding of how receptors respond to changes in climate and the availability of surface water and groundwater in the catchment. The results have been integrated to present a strengthened conceptual understanding of how the Barwon Downs system operates.

Figure 0-1 Overview of the Technical Works Monitoring Program



The key findings from the Technical Works Monitoring Program are presented below under the following headings:

- Land (ground) subsidence
- Groundwater levels
- Surface water flows
- Aquatic groundwater dependent ecosystems
- Terrestrial groundwater dependent ecosystems
- Potential acid sulphate soilsYeodene (Big) Swamp

Objective of the Integration Report

The objective of this report is to integrate the findings of all the studies – over multiple disciplines – completed under the Technical Works Monitoring Program. Individual studies have been completed since 2012 to advance the understanding in five key areas groundwater, surface water, aquatic groundwater dependent ecosystems, terrestrial groundwater dependent ecosystems and potential acid sulphate soils.

The intent of bringing together this work is to improve the conceptual understanding of the hydrogeology in the Barwon Downs region, particularly to improve the knowledge of the relationship between groundwater pumping and how pumping may impact groundwater receptors in the catchment.

This report documents a summary of the work completed and the key findings. An overview of the Technical Works Monitoring Program is presented in Table 0-1 and more detail is provided below.

This report will also support the upcoming licence renewal application.

Table 0-1 Key findings of the Technical Works Monitoring Program and implications for the licence renewal

ASS = Actual Acid Sulphate Soils, GDE = Groundwater Dependent Ecosystem, LTA = Lower Tertiary Aquifer, MTD: Mid Tertiary Aquitard, PASS = Potential Acid Sulphate Soils

Activity	Objective	Key findings to date	Implications for the licence renewal	Additional work required
Groundwater	New groundwater monitoring bores installed to address knowledge gaps on groundwater level responses in the aquitard, the watertable at the vegetation monitoring sites and groundwater surface water interactions around the catchment.	• Appropriate monitoring is in place with the addition of 34 monitoring bores (including replacement of one bore) and refurbishment of three existing bores. • Groundwater levels in shallow aquifers and MTD have declined over the last 18 months, consistent with the below-average rainfall conditions. Groundwater levels in the shallow aquifers did not respond to a short pumping period in 2016. • Rising groundwater levels recorded in bores monitoring the LTA and the lower MTD are consistent with groundwater levels recovering after pumping ceased in 2010. • Local perched alluvial aquifers in some parts of the catchment are recharged from rainfall and surface water and are independent of the LTA. • Drawdown from pumping at Barwon Downs borefield is more pronounced in the lower LTA compared to the upper LTA. Drawdown is buffered through the unit due to layering in the aquifer which protects the upper LTA and alluvial aquifers from groundwater level declines caused by pumping.	• Sound baseline monitoring network established to assess changes in groundwater levels which can influence groundwater-surface water interactions and streamflow, aquatic GDEs, terrestrial GDEs and PASS. • Strong evidence base is now available on which to understand past effects and to predict future impacts to receptors associated with groundwater pumping. This should place the renewal application on a sound technical basis.	• Replacement of loggers in A6a, TB1c, and 109136 (loggers ceased working). • Ongoing monitoring of existing bores with interpretation as required.
Surface water Boundary Creek Catchment	New stream flow gauges and existing gauges were reinstated to ensure there was sufficient monitoring data to inform a conceptualisation of groundwater surface water interactions in the Boundary Creek catchment.	• Appropriate monitoring is in place with one new gauge installed and two existing gauges replaced to collect data on streamflow at various sections along Boundary Creek. • Supplementary flow makes up a significant portion of the flow in the upper reaches of the creek during summer and autumn. • Throughout the summer months, there is flow upstream of Yeodene (Big) Swamp, but rarely downstream of the swamp (at the Yeodene gauge on Colac-Forrest Road), making the effect of the swamp on flow hard to determine. • Boundary Creek rarely stopped flowing during summer months prior to 1999, but since then has stopped flowing for varying periods each summer. Various factors contributing to these ongoing cease of flows events have yet to be untangled and will be the focus of more technical works in 2017. • Water downstream of Yeodene (Big) Swamp is highly acidic.	• Sound baseline monitoring network to assess fluctuation in stream-flow. • There is some community perception that pumping from Barwon Downs has caused drying of Yeodene (Big) Swamp which has subsequently caused changes to hydrology and water quality downstream (Reach 3). Further technical work will improve the understanding of the functions of the swamp which will assist with understanding the contribution of pumping to issues in Reach 3. • Need to improve understanding of relative contribution of climate conditions and pumping to declining stream flow to inform future operating regimes and licence conditions (for example, timing and volumes pumped). • Need to improve understanding of the role of Yeodene (Big) Swamp in the hydrology and water quality of Reach 3 in Boundary Creek to inform licence conditions relating to supplementary flow.	• Improve calibration of the numerical model around Boundary Creek to better investigate base flow changes. • Use the calibrated groundwater model to quantify stream flow reduction to untangle the relative contribution of climate and pumping from Barwon Downs borefield. • Quantify supplementary flow requirements to maintain current ecological values of Boundary Creek. • Determine supplementary flow requirements to provide stock and domestic flow in the downstream reaches of Boundary Creek. • Use the calibrated groundwater model to assess future groundwater development scenarios and their potential impact on Boundary Creek stream flow.
Surface water Gellibrand River Catchment	To determine if additional stream flow gauges are required in the Gellibrand River catchment.	• Gellibrand River is connected to the LTA and is a key discharge area for the aquifer. • Most of the tributaries flow over the MTD, and springs from the MTD provide baseflow to some of the creeks. The MTD protects (buffers) the tributaries from drawdown in the LTA. • Drawdown from pumping at the Barwon Downs borefield does not appear to have affected the Gellibrand River to date due to the effect of a hydraulic restriction (geological barrier) within the aquifer between the Barwon and Gellibrand catchments	• Additional stream-flow gauges are recommended on Ten Mile and Porcupine Creeks as a precautionary measure to ensure there is sufficient baseline information to assess potential future impacts although these are expected to be small. • Need to quantify potential impacts to Gellibrand River and tributaries (through the groundwater model). Current indications suggest that these are inconsequential to small but this needs to be confirmed.	• Install additional stream flow gauges on Ten Mile and Porcupine Creeks. • Use the calibrated groundwater model to assess potential stream-flow reduction to Gellibrand River and its tributaries.
Aquatic GDEs	To identify the ecological values of Boundary Creek and recommend an appropriate flow regime to support both environmental and social receptors.	• Reach 1 (upstream of McDonalds Dam) has been artificially enhanced by the supplementary flow and current ecological values are good. Macro invertebrate communities are in excellent condition and the channel supports Short-finned Eels, Flathead Gudgeon, and Mountain Galaxias. Arange of common and widespread frog species is likely to be supported. • Reach 2 includes the 'dampland' area downstream of McDonalds Dam and upstream of Yeodene (Big) Swamp and Yeodene (Big) Swamp itself. The water in the channel is usually shallow and unlikely to be suitable for fish. The macro invertebrate	• Sound understanding established of existing ecological values in Boundary Creek and qualitative flow requirements. • Need to quantify flow requirements of current ecological values. • Need to improve understanding of the role of the supplementary flow in maintaining current ecological values and consider alternative	• Develop a detailed conceptualisation of the surface water groundwater interactions that influence Boundary Creek. • Use the calibrated groundwater model to help quantify baseflow contributions to Boundary Creek. • Develop hydraulic models at representative sites in the creek to link depth of water in the

Activity	Objective	Key findings to date	Implications for the licence renewal	Additional work required
		communities are significantly impaired (AUSRIVAS Band B) but the reach likely supports the Otway Bush Yabby and the assemblage of common frogs. • Reach 3 (downstream of Yeodene (Big) Swamp) dries frequently in summer, has highly acidic water when it is flowing and has limited aquatic habitat. The macro invertebrate community is in poor condition (AUSRIVAS Band C). • Note that fish, frogs and Platypus surveys were not conducted because direct surveys were unlikely to yield statistically representative results due to the small size of the creek which is likely to support only a low number of aquatic fauna.	scenarios for the supplementary flow that would deliver greater benefits.	channel with flow volume. • Determine the quantitative flow needs of the identified aquatic values in Boundary Creek. • Develop recommendations to improve the effectiveness of the supplementary flow.
Terrestrial GDEs (vegetation)	• Monitor the vegetation condition at the 14 monitoring sites to ensure there is adequate baseline information prior to future extraction from the Barwon Downs borefield. • To determine whether terrestrial vegetation at the monitoring sites is using groundwater and if there has been an impact from historical groundwater pumping on the condition of groundwater dependent vegetation.	• Baseline monitoring network established including 14 sites to monitor the relationship between vegetation health and groundwater pumping. Monitoring was undertaken in 2014/15 and 2016. • 2016 vegetation survey showed declines in vegetation health, in response to below average rainfall conditions. Given the borefield had not operated between 2010 and mid 2016 the results of this survey highlight vegetation's response to natural climate variability. • Groundwater monitoring bores are located at all the vegetation monitoring sites and although the link between groundwater and vegetation present was concluded to be highly variable and localised, all sites are considered to be groundwater dependent to some extent. • Additional work was completed to determine if deep rooted vegetation species, like trees, use groundwater. • Results showed that deep rooted vegetation at most sites was found to rely on a groundwater during times of drought and where the watertable is shallow. • No evidence was found that declining groundwater levels caused by groundwater extraction at Barwon Downs had a negative impact on vegetation health in the catchment.	• Sound baseline monitoring network established to assess potential changes to terrestrial GDEs, although no changes due to operation of the borefield detected to date. • No vegetation health issues were identified that would influence the upcoming licence renewal.	Ongoing monitoring involving: • Vegetation surveys to be conducted every two years, whilst the borefield is operating during mid to late autumn and every five years when borefield is not operational • Relocate transect at site T11 to better connect with the groundwater dependent ecosystems in the area. • Review remote sensing data after each period of borefield use to monitor potential changes in the regional vegetation condition that is not possible in the site by site assessment.
PASS	• To provide a baseline condition assessment of four monitoring sites that are known to contain acid sulphate soils so any changes to the sites can be monitored to understand key drivers.	• Natural PASS existing across the study area. • Review of potential ASS sites in the region was completed and a baseline monitoring network including 4 sites has been established. Monitoring was undertaken in 2015 and 2016. • Changes noted in ground conditions, surface water and groundwater were consistent with seasonal fluctuations • Groundwater quality did not change over the monitoring period. • Groundwater levels are typically shallow (within 1 m below the surface) and display seasonal fluctuations of around 0.5 m, rising during the winter months and declining during the summer months. • Changes in surface water salinity were consistent with seasonal fluctuations, e.g. higher salinity during summer months when evaporation is higher.	• Highest priority PASS sites are being monitored regularly. • Sound baseline monitoring network established to assess potential changes to PASS. • No ASS issues outside of Yeodene (Big) Swamp were identified that would influence the upcoming licence renewal. • Review the need for additional PASS site/s in the Porcupine Creek catchment for ongoing monitoring. Possible impacts linked to groundwater extraction are likely to be inconsequential to small but this needs to be confirmed.	• Ongoing monitoring bi-annually during summer and winter months whilst the borefield is operating and every three years when the borefield is not operating to monitor changes at the site and understand drivers. • Additional monitoring bore/s in Yeodene (Big) Swamp and downstream to monitor groundwater quality and improve understanding of impacts of the swamp on surface water and groundwater quality. • Establish a PASS monitoring site in the Porcupine Creek catchment and complete baseline monitoring on groundwater and surface water quality.
Land subsidence	• To monitor the changes in land subsidence in accordance with current licence conditions.	• Monitoring of land subsidence across the region is within licence conditions: o 200 mm subsidence permitted in licence conditions o Maximum recorded 76 mm (2010) o Some rebound has occurred since. Subsidence water 42 mm in June 2015.	• No issues were identified relating to land subsidence that would influence the upcoming licence renewal. • Recommendation to decrease monitoring frequency.	• Investigate the potential to reduce monitoring frequency and recommend alternate frequency.
Update the numerical groundwater model	• To create a new and updated model that builds on earlier model versions that can be used with confidence to assess future impacts associated with groundwater extraction from the Barwon	• The model includes features and characteristics of a Class 3 Confidence Level Classification model as defined by the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). This is the highest confidence level classification in the guidelines and reflects the amount and quality of groundwater data used to conceptualise and calibrate the model. • New model extended to include the Gellibrand River and Kawarren. New model also	• Need to improve the calibration of the model around Boundary Creek to ensure the model can reliably assess impacts in this catchment.	• Improve the calibration of the model around Boundary Creek. • Use the calibrated groundwater model to run predictive scenarios to understand potential impacts to environmental and social receptors under future development (pumping)

Activity	Objective	Key findings to date	Implications for the licence renewal	Additional work required
	Downs borefield	includes two additional model layers - Pember Mudstone is an aquitard present between the Dilwyn and Pebble Point Formations basement rock is considered to be a minor aquifer. • Recharge rates of 15% of rainfall to the area of the outcropping LTA and 5% of rainfall to the area of outcropping MTD were selected. These rates are consistent with upper estimates from recharge analysis but are lower than previous modelling estimates of up to 20%. • Model is reasonably well calibrated at a regional scale; however there is opportunity for improvement for the flanks of the Barongarook High where the aquifer transitions from confined to unconfined.		scenarios.

Community engagement

A Community Reference Group was established by Barwon Water to ensure, where possible, the Technical Works Monitoring Program would take into consideration community issues. These issues mostly centre on possible impacts to environmental receptors in the Barwon Downs catchment. Further detail can be found in section 1.4.2.

The Community Reference Group's contribution towards all components of the Technical Works Monitoring Program has raised confidence that the right monitoring data would be captured to specifically target key areas of community concern.

Groundwater level monitoring

The capital works program completed during Stage 3 of the Technical Works Monitoring Program involved the drilling and construction of 34 new groundwater monitoring bores (including one replacement bore) and the refurbishment of three existing bores. Data loggers were installed in most of the monitoring bores and aquifer testing was also undertaken to collect information on aquifer parameters.

The objective of the additional monitoring bores was to address key knowledge gaps and ensure there was sufficient baseline information to monitor potential impacts to groundwater levels and groundwater dependent ecosystems (GDEs).

A preliminary analysis of the monitoring data between 2014 and 2016 was undertaken to improve the understanding of groundwater level fluctuations across the catchment. Groundwater level trends across the region are generally consistent with the below-average rainfall conditions experienced over the monitoring period. Only four bores showed rising levels and these bores are monitoring the LTA aquifer where the aquifer is unconfined in the Boundary Creek catchment on the Barongarook High, or the MTD near Yeodene. Groundwater levels in the LTA in this area have been impacted from pumping and the rising trends are representative of the aquifer recovery after pumping ceased in 2010.

Additional groundwater monitoring bores also provided information on vertical gradients between units. There are three new nested sites and these show an upward vertical gradient from the LTA to the MTD. One nested site near the East Barwon River Branch showed a slight downward trend from the LTA to the MTD.

Two new bores installed in Boundary Creek catchment to provide information on groundwater surface water interactions show that there is a gradient towards the creek in the basement aquifer on the Barongarook High.

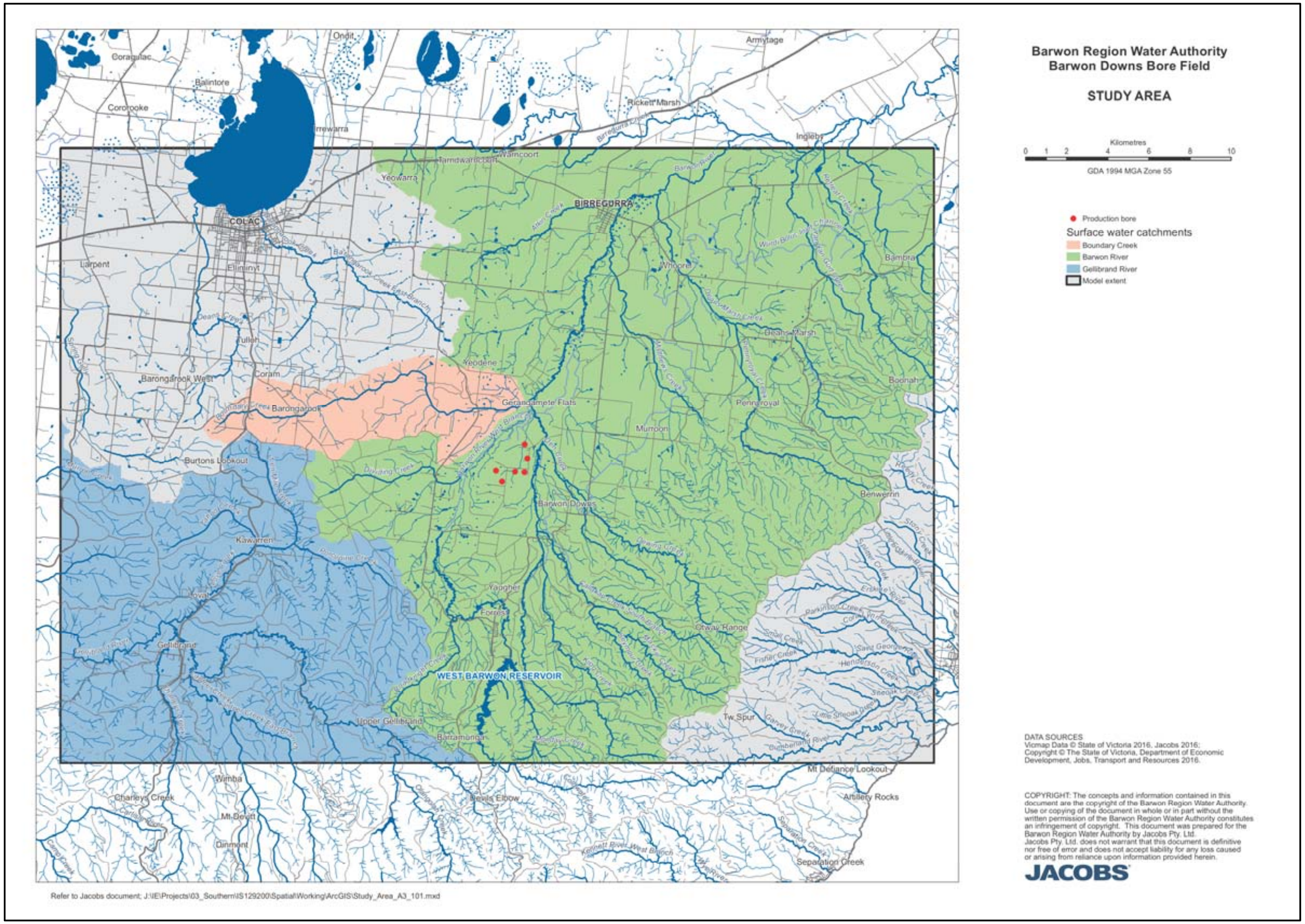
Local perched alluvials aquifers were found to exist in some parts of the catchment. These local perched systems were found to be recharged from rainfall and suface water and are independent of the groundwater levels in the LTA. Where the perched aquifers are not underlain by MTD, they are susceptible to climate conditions. Some of these aquifers dried during 2015 when rainfall conditions were below average.

Surface water monitoring

The regional groundwater system extends across two surface water catchments, the Barwon River and Gellibrand catchments. Interactions between groundwater and surface water are variable throughout the region. The main recharge area for the LTA lies in the Barwon River catchment near the Barongarook High. The Gellibrand River in the Otways Coast catchment is a key discharge area for the aquifer. Consequently studies have been undertaken on both rivers as part of the Technical Works Monitoring Program.

The location of the surface water catchments in shown in Figure 0-2.

Figure 0-2 : Location of surface water catchments



Barwon River Catchment

In the Barwon River catchment, the focus of the Technical Works Monitoring Program has been on Boundary Creek. The Boundary Creek catchment is highly modified and has experienced significant changes over the last century. These include:

- land use change from forest to agriculture and farming,
- the construction of large drains since the early 1900s to reclaim low lying land,
- the construction of the McDonalds Dam in 1979,
- groundwater extraction from the Barwon Downs borefield,
- climatic influences including extended dry periods, and
- a slow-burning peat fire at Yeodene (Big) Swamp.

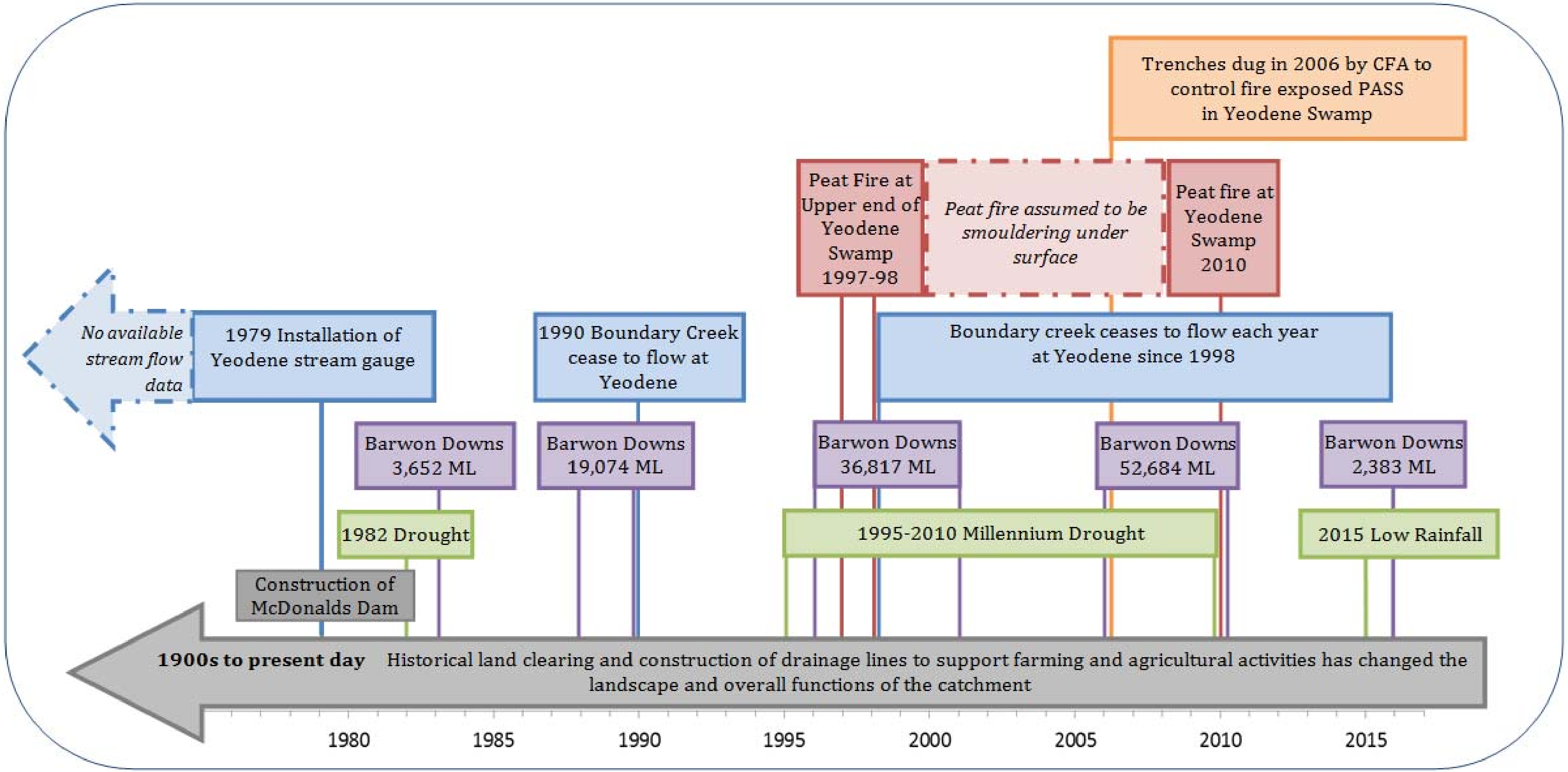
In accordance with the current groundwater extraction licence, Barwon Water releases a supplementary flow of 2 ML/day into the upper reach of Boundary Creek from its Colac water pipeline (when triggered by the licence). This condition was intended to provide supplementary water in Boundary Creek for stock and domestic users as a precautionary measure to mitigate any potential loss of flows related to groundwater extraction, A timeline illustrating when these changes occurred is shown in Figure 0-3.

The objective of the Technical Works Monitoring Program was to ensure there was sufficient monitoring to inform a conceptualisation of the groundwater surface water interactions in the catchment. As part of the capital works program completed in Stage 3, one new stream flow gauge was installed and two existing gauges were reinstated. There are now five active monitoring gauges along Boundary Creek.

The gauging stations show that the supplementary flow makes up a significant portion of the flow in upper reaches of the creek. Throughout the summer months, flow is recorded upstream of Yeodene (Big) Swamp, but rarely downstream of the swamp (at the Yeodene gauge). The stream flow gauges also show that Boundary Creek rarely stopped flow during summer months prior to 1999, but since then has stopped flowing during periods in each summer. The water quality downstream of the Yeodene (Big) Swamp is also highly acidic.

The reasons for the changes in stream flow volumes, cease to flow events and water quality issues are the subject of further investigation scheduled for 2017.

Figure 0-3 : Time of events in Boundary Creek catchment



Gellibrand River Catchment

The Gellibrand River catchment occupies the south western part of the study area and its tributaries originate in the Otway Ranges and the Barongarook High. Given the Gellibrand River is a key discharge zone for the aquifer, a review of the conceptual understanding of the Gellibrand catchment, including surface water monitoring in the upper part of the catchment, was completed as part of the Technical Works Monitoring Program.

The objective of the review was to investigate whether additional stream gauges were required in the Upper Gellibrand catchment.

The existing stream flow monitoring was found to be adequate from a technical perspective and additional monitoring gauges were not recommended by Jacobs (2015a) for the following reasons:

- The drawdown in the watertable in the aquitard is expected to be small, particularly along Porcupine Creek and

- Ten Mile Creek and Yahoo Creek flow over areas of outcropping Lower Tertiary Aquifer, however drawdown from the bore field is not significant in the area.

The Community Reference Group raised that community interest in potential impacts to the Gellibrand catchment was considerable. Given this, additional stream flow gauges for monitoring on an ongoing basis are recommended on Ten Mile Creek and Yahoo Creek as a precautionary measure to ensure there is no impact from groundwater extraction.

Aquatic groundwater dependent ecosystems

The aquatic groundwater dependent ecosystems (GDEs) with the most potential to be impacted by the Barwon Downs borefield are in the Boundary Creek catchment. This study was completed to understand at a high level the ecological condition of Boundary Creek and the ecological values the creek currently supports taking into account the changes within the catchment.

It should be noted that the study was preliminary in nature and had a number of limitations and assumptions. For example, the study did not explore groundwater-surface water interactions nor did it involve direct survey for fish, frogs, Platypus and vegetation. The presence of these ecological values was inferred using a combination of direct survey and indirect assessment techniques. The rationale for this approach is that the creek is unlikely to support large numbers of aquatic animals, so if a species is not recorded in the field assessment does not necessarily mean that it is not present and it would take extensive field studies to confirm the presences of some species.

In light of the current hydrological regime, the key findings of the study are outlined below:

- Reach 1 – upstream of McDonalds Dam – is likely to support some fish (e.g. Short-finned Eels, Flathead Gudgeon and Mountain Galaxias) and a range of common frog species. The macro invertebrate communities are in excellent condition.

- Reach 2 - McDonalds Dam outlet to the downstream end of Yeodene (Big) Swamp, includes a ‘dampland’ and shallow water channels that are unlikely to be suitable for fish. The macro invertebrate communities are significantly impaired but the reach is likely to support the Otway Bush Yabby and common frogs.

- Yeodene (Big) Swamp is located at the downstream end of Reach 2. The peat swamp has experienced significant change over the last 30 years, including drying, fire and excavation of a trench to control the fire. This combination has resulted in acidification leading to poor water quality in the creek downstream.

- Reach 3 - Downstream of Yeodene (Big) Swamp to confluence with Barwon River – dries frequently in summer, has highly acidic water when it is flowing and has limited aquatic habitat. It is unlikely to support many fish or frog species. The macro invertebrate community is in poor condition.

Terrestrial groundwater dependent ecosystems

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

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

The Technical Works Monitoring Program included three separate vegetation studies to date. Two studies involved collecting baseline information and another study was complete to understand the dependency of deep rooted vegetation on groundwater throughout the catchment. The overall objective of the vegetation studies is to two-fold:

- Monitor the vegetation condition at the 14 monitoring sites to ensure there is adequate baseline information prior the Barwon Downs borefield being turned on.

- To determine whether terrestrial vegetation at the monitoring sites is using groundwater and if there has been an impact from historical groundwater pumping on the condition of groundwater dependent vegetation.

Baseline Monitoring Results

The 14 vegetation monitoring sites have been monitored on three occasions - late 2014, early 2015 and early 2016. Vegetation surveys were completed at each site to determine the cover of each species. Species were categorised according to their dependence on groundwater.

In 2014 and 2015, the baseline results highlighted that all vegetation was in good condition, with the exception of T1 which is located at Yeodene Swamp, which was impacted by recent burning and acidic soil. No significant difference was detected between impact and reference sites.

In 2016, the vegetation survey was completed after a period of below average rainfall conditions and the vegetation condition across the catchment showed signs of decline. Given the borefield had not operated since 2010 the results of this survey highlight vegetation’s response to natural climate variability. Decline in vegetation condition was consistent across the monitored sites and similar to 2014/15, there were no noticeable differences between impact/reference sites and confined/unconfined sites.

Groundwater monitoring bores are located at all the vegetation monitoring sites and although the link between groundwater and vegetation present is highly variable and localised, all sites are considered to be groundwater dependent to some extent.

Assessing Groundwater Dependency

In addition to the baseline monitoring, additional work was undertaken to determine if deep rooted vegetation species, like trees, use groundwater. Remote sensing analysis using satellite imagery was used to assess vegetation health over the years, and field investigations were also completed at each of the vegetation monitoring sites. A field sampling program involved measurement of water potential and analysis of stable isotopes from vegetation, soils and groundwater which were used to determine the likely source of water for the vegetation at the time of sampling.

The results from the field investigation and the remote sensing analysis were consistent and demonstrated that deep rooted vegetation at most sites was found to rely on a groundwater during times of drought and where the watertable is shallow. No evidence was found that declining groundwater levels caused by groundwater extraction at Barwon Downs had a negative impact on vegetation health in the catchment.

Potential acid sulphate soils

Acid sulphate soils (ASS) are naturally present within the Barwon River catchment. ASS refers to soils that contain pyrite. Pyrite forms under waterlogged conditions where there is little or no oxygen available. These soils remain stable under these conditions and are referred to as potential acid sulfate soils (PASS). They pose little environmental concern while they remain saturated. If the 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 sulphate soils (ASS).

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

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

The four PASS monitoring sites were monitored three times between late 2015 and mid-2016. Monitoring involved inspection of ground conditions, surface water quality, groundwater quality and groundwater levels. The borefield was turned on in April 2016, but was not operational for the monitoring rounds in November 2015 and March 2016. The key findings of the PASS baseline assessment are:

- Changes noted in ground conditions, surface water and groundwater were consistent with seasonal fluctuations.
- Groundwater quality did not change over the monitoring period.
- Groundwater levels are typically shallow (within 1 m below the surface) and display seasonal fluctuations of around 0.5 m, rising during the winter months and declining during the summer months.
- Changes in surface water salinity were consistent with seasonal fluctuations e.g. higher salinity during summer months when evaporation is higher.
- The pH of surface water and groundwater generally remained constant over the monitoring period:
    - At two sites (PASS2 and PASS4), the pH of the surface water and groundwater quality is neutral.
    - At PASS1 located on Boundary Creek, the surface water is acidic as a result of ASS at Yeodene (Big) Swamp, and the groundwater is neutral.
    - On a tributary of Boundary Creek (PASS3), both the surface water and groundwater are slightly acidic.

A summary of how the Technical Works Monitoring Program has improved the conceptual understanding of the hydrogeology in the area is provided below and outlined in more detail in the main report.

Revised Hydrogeological Conceptual Model

While the hydrogeological conceptual model of the Barwon Downs Graben is reasonably well understood, information gaps were identified that led to the Technical Works Monitoring Program. These information gaps had meant that the understanding of how the groundwater system responds in some areas and potential impacts have been limited. Additional work completed as part of the Technical Works Monitoring Program was undertaken to refine the conceptual understanding which feeds into the update and recalibration of the groundwater numerical model. The existing groundwater numerical model has been revised and recalibrated so that it can be used with confidence to assess future impacts associated with groundwater extraction from the Barwon Downs borefield.

Key focus areas in the hydrogeological conceptual model are as follows:

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

A description of the work undertaken to improve our understanding in these areas for both the conceptual model and the numerical model is provided below.

Extent and thickness of key formations

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

Groundwater flow across faults

There are two key faults in the region – the Colac Fault and the Bambra Fault. The Bambra Fault is shown in Figure 4-2 which highlights that the LTA is uplifted across the fault and not continuous, which has a significant influence on groundwater flow across the fault. The Bambra Fault forms the south eastern boundary of the numerical model and understanding flow across the fault is important to understand how much water can get into the groundwater system.

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

Recharge to groundwater

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

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

Recharge rates of 15% of rainfall to the area where the LTA outcrops and 5% of rainfall to the area where the MTD outcrops were selected based on the results of the field methods.

The information on recharge rates was incorporated into the revised numerical groundwater model.

Understanding drawdown in the Lower Tertiary Aquifer (LTA)

Groundwater levels fluctuate in response to climate conditions and groundwater extraction. Groundwater level decline in response to pumping is referred to as drawdown and a sound understanding of the drawdown is important to understand where impacts may occur and to help calibrate the numerical model.

When the Barwon Downs borefield is operational, the drawdown cone in the aquifer spreads in a north east – south west direction within the Graben. Typical of most aquifers the drawdown also spreads unevenly throughout the region. For example, monitoring data indicates that drawdown extends to Kawarren, however some bores located near Kawarren, but closer to the borefield, have less drawdown. Additional work was completed under the Technical Works Monitoring Program to investigate if there are other potential causes of impact of the drawdown around Kawarren other than the borefield. This work concluded that the drawdown from the borefield extends to Kawarren and that bores located closer to the borefield with less drawdown are likely to be influenced by differences in the local hydrogeology.

Drawdown also varies between the different hydrogeological units and at different depths within the same hydrogeological unit. For example, bores monitoring the lower part of the LTA show more drawdown than bores monitoring the top half. Similarly, bores monitoring the lower MTD show greater response than bores monitoring the top half. The reason for this is that drawdown in an aquifer take more time to move vertically, so the drawdown responses in formation overlying the LTA will be more subdued.

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

Groundwater surface water interactions along Boundary Creek

Groundwater surface water interactions exist throughout the catchment. Given the significant changes that have occurred to Boundary Creek and Yeodene (Big) Swamp, there has been a significant effort under the Technical Work Program to improve the understanding of groundwater-surface water interactions in Boundary Creek. The overall objective of the work is to understand the potential impacts of groundwater extraction on the creek.

Boundary Creek flows across the Barongarook High over a mixture of LTA, Basement and Quaternary Alluvium. As previously mentioned the Creek is divided into three reaches:

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

A long section of the hydrogeology changes along Boundary Creek is shown in Figure 0-4.

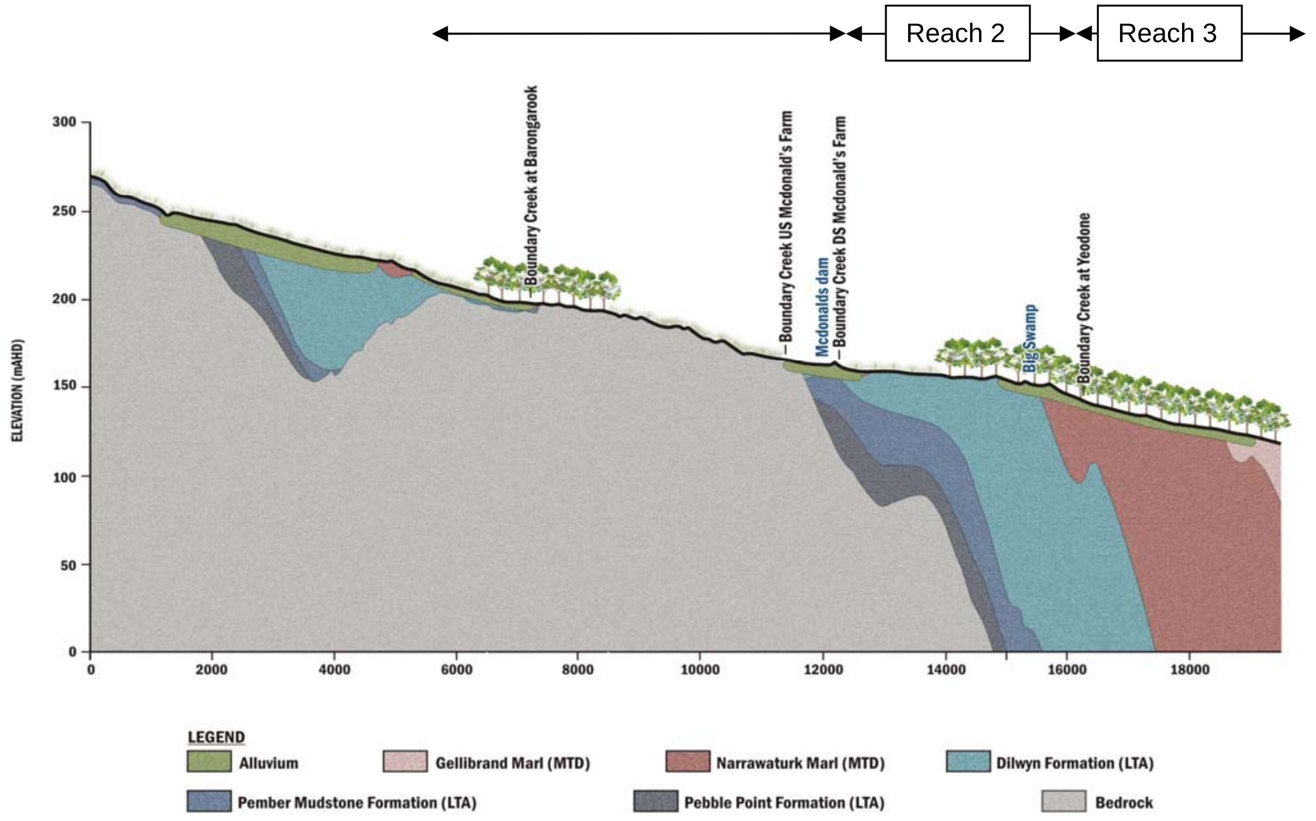
In Reach 1 hydrogeology is locally varible and groundwater levels in this part of the catchment have not experienced any drawdown in response to the operation of Barwon Downs. Monitoring bores in this part of the catchment indicate the creek is gaining along this reach.

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

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

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

Figure 0-4 Hydrogeological long section along Boundary Creek



Implications for the Numerical Model

A regional three dimension groundwater numerical model of the Barwon Downs Graben was developed in 2001 and since this time has been updated to incorporate additional findings as information became available. The model was last updated in 2011, when it was used to illustrate predicted impacts under different climate change scenarios.

In 2016, the existing numerical model was expanded, re-built and recalibrated. The model includes new features and conceptual understanding that has arisen from related work undertaken as part of the Technical Works Monitoring Program. The model includes a significant extension to the west to incorporate the Kawarren area and two additional model layers - the Pember Mudstone and the upper part of the basement rocks.

The overall objective of revised model is to create a new and updated model that can be used with confidence to assess future impacts associated with groundwater extraction from the Barwon Downs borefield. The key findings from the Technical Works Monitoring Program were taken into account during the recalibration process.

The revised model is well calibrated as a regional model. The model includes features and characteristics of a Class 3 Confidence Level Classification model as defined by the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). This is the highest confidence level classification in the guidelines and reflects the amount and quality of groundwater data used to conceptualise and calibrate the model. It also reflects the fact that there is a long history of groundwater extraction and associated monitoring data that provides a good illustration of how the aquifer system responds to large scale borefield extraction.

However some areas within the model are not well calibrated at a local scale. The key area of concern is the flanks of the Barongarook High where the LTA dips below the MTD (see Figure 4-2). Additional work is recommended to improve the calibration of the model around Boundary Creek as this is an area where there has been significant community interest.

Conclusions

The key conclusions from the Technical Works Monitoring Program are outlined below:

- A sound **groundwater** baseline monitoring network will provide strong evidence base to assess past effects and to predict future effects, which provide sound technical basis for the licence renewal.
- While there is a sound **surface water** baseline monitoring network, there is a perception amongst some community members that the Barwon Downs borefield has caused the drying of Yeodene (Big) Swamp. Further work is required to understand the causes of declining stream flow in Boundary Creek and the role of Yeodene (Big) Swamp in the hydrology of the catchment.
- In the Gellibrand Catchment, further work is required to quantify the potential impacts to the Gellibrand River using the calibrated numerical model. Additional stream-flow gauges are recommended on Ten Mile and Porcupine Creeks as a precautionary measure to ensure there is sufficient baseline information to assess future impacts although these are expected to be inconsequential to small.
- The existing **ecological values** in Boundary Creek and qualitative flow requirements have been defined, and further work is required to quantify the flow requirements and understand the role of the supplementary flow in maintaining the current ecological values.
- Investigations to assess **groundwater use by vegetation** and surveying of the vegetation monitoring network has highlighted that there have been no changes due to operation of the borefield detected to date. No vegetation health issues have been identified that would influence licence renewal.
- Baseline monitoring network comprising highest priority **PASS** sites has been established and no acid sulphate soil issues outside of Yeodene (Big) Swamp were identified that would influence licence renewal. Further work is required to establish a PASS monitoring site in the Porcupine Creek catchment as a precautionary measure to demonstrate impacts that are likely to be inconsequential to small.
- No issues identified relating to **land subsidence** have been identified that would influence the licence renewal. Further work required to recommenda decrease in monitoring frequency.
- **Numerical groundwater model** has been updated and recalibrated. The model is reasonably well calibrated at the regional scale, however further work is required to improve the calibration around Boundary Creek where the LTA transitions from confined to unconfined.

Recommendations

Ongoing monitoring of all existing assets is recommended to continue. Recommendations from individual studies completed during the Technical Works Monitoring Program are outlined in the table below.

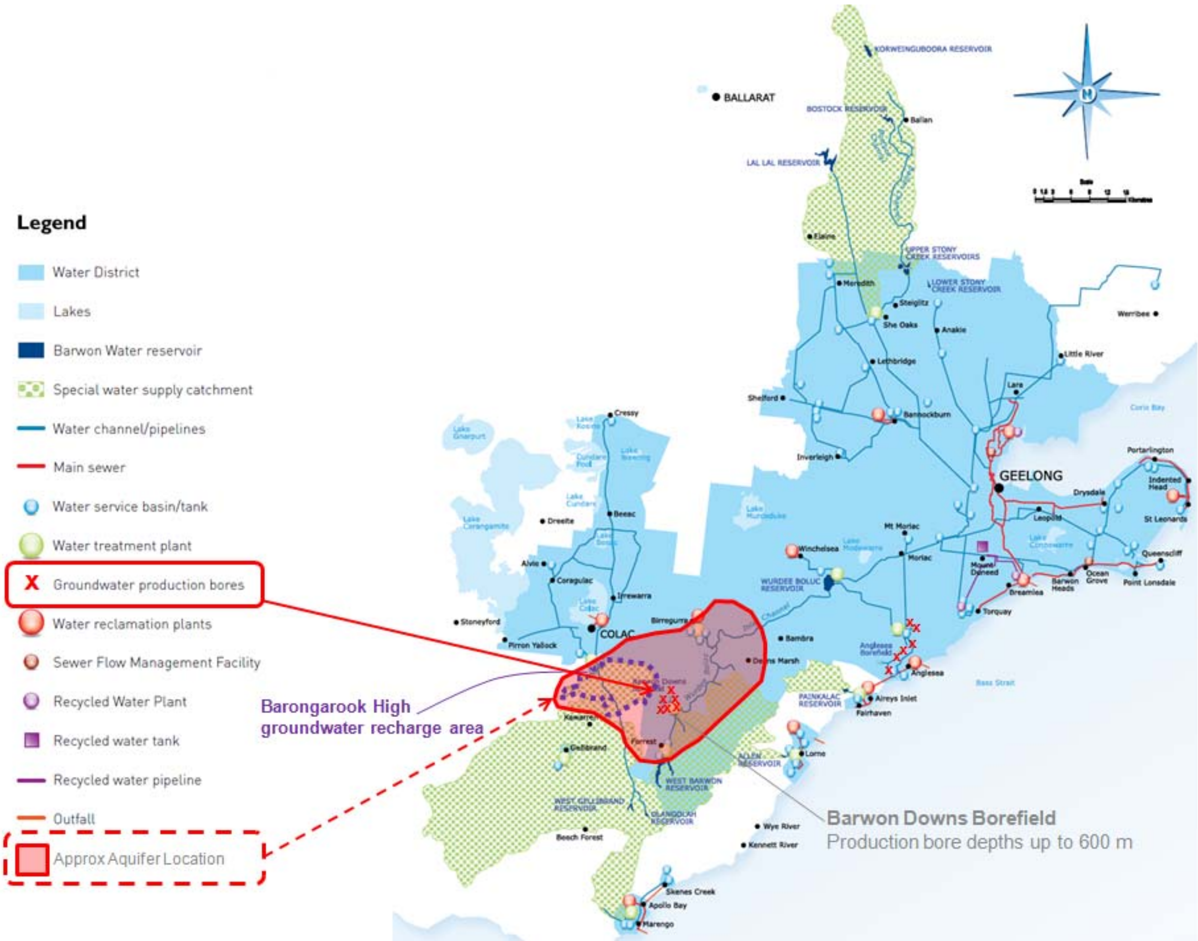
Technical Works Monitoring Program	Recommendation
Groundwater	1. Installation of loggers in A6a, TB1c, and 109136 (loggers ceased working) 2. Ongoing monitoring of existing bores with interpretation.
Surface water	3. Improve calibration of the numerical model around Boundary Creek to better investigate base flow changes 4. Use the calibrated numerical model to quantify stream-flow reduction due to climate and pumping from Barwon Downs borefield. 5. Quantify supplementary flow requirements to maintain current ecological values of Boundary Creek. 6. Determine supplementary flow requirements to provide stock and domestic flow in the downstream reaches of Boundary Creek and prevent inundation events to properties upstream near the current release point. 7. Use the calibrated numerical model to assess future groundwater development scenarios and their potential impact on Boundary Creek stream-flow. 8. Install additional stream flow gauges on Ten Mile and Porcupine Creeks. 9. Use the calibrated numerical model to assess potential stream-flow reduction to Gellibrand River and its tributaries
Aquatic ecology	10. Develop a detailed conceptualisation of the surface water-groundwater interactions that influence Boundary Creek. 11. Use the numerical groundwater model to help quantify baseflow contributions to Boundary Creek. 12. Develop hydraulic models at representative sites in the creek to the link depth of water in the channel with flow volume. 13. Determine the quantitative flow needs of the identified aquatic values in Boundary Creek 14. Develop recommendations to improve the effectiveness of the supplementary flow
Terrestrial GDEs (Vegetation)	15. Vegetation surveys to be conducted every 2 years, whilst the borefield is operating during mid to late autumn and every 5 years when borefield not operational 16. Relocate transect at site T11 to better connect with the groundwater dependent ecosystems in the area. 17. Review of remote sensing data after each period of borefield use to monitor potential changes in the regional vegetation condition that is not possible in the site by site assessment.
PASS	18. Establish a PASS monitoring site in the Porcupine Creek catchment and complete baseline monitoring on groundwater and surface water quality to demonstrate no impact.
Land subsidence	19. Ongoing monitoring as part of existing licence conditions 20. Investigate the potential to reduce monitoring frequency and recommend
Groundwater modelling	21. Improve the calibration of the model around Boundary Creek 22. Use the calibrated model to run predictive scenarios to quantify potential impact under future development (pumping) scenarios

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



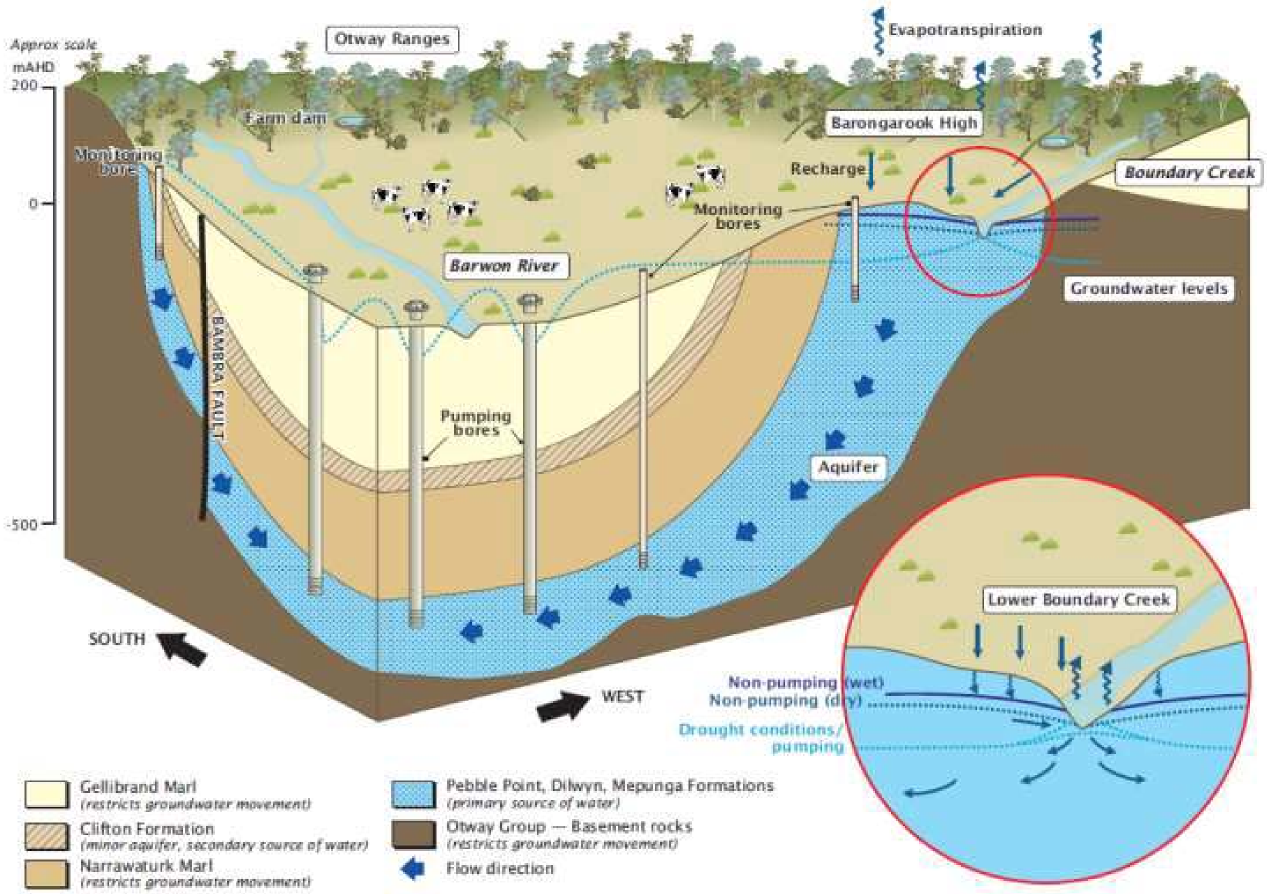
The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment.

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, with depths of up to 600 metres at the borefield. 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
- 2,383 ML in 2016 to boost storages after a very dry summer.

Groundwater extraction has supplemented surface water supply by a total of 114,610 ML, equating to approximately 10 per cent of total water consumed over a 30 year period.

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 rate of 80,000 ML; and
- Periods of licence renewal of 15 years (1975 – 1990).

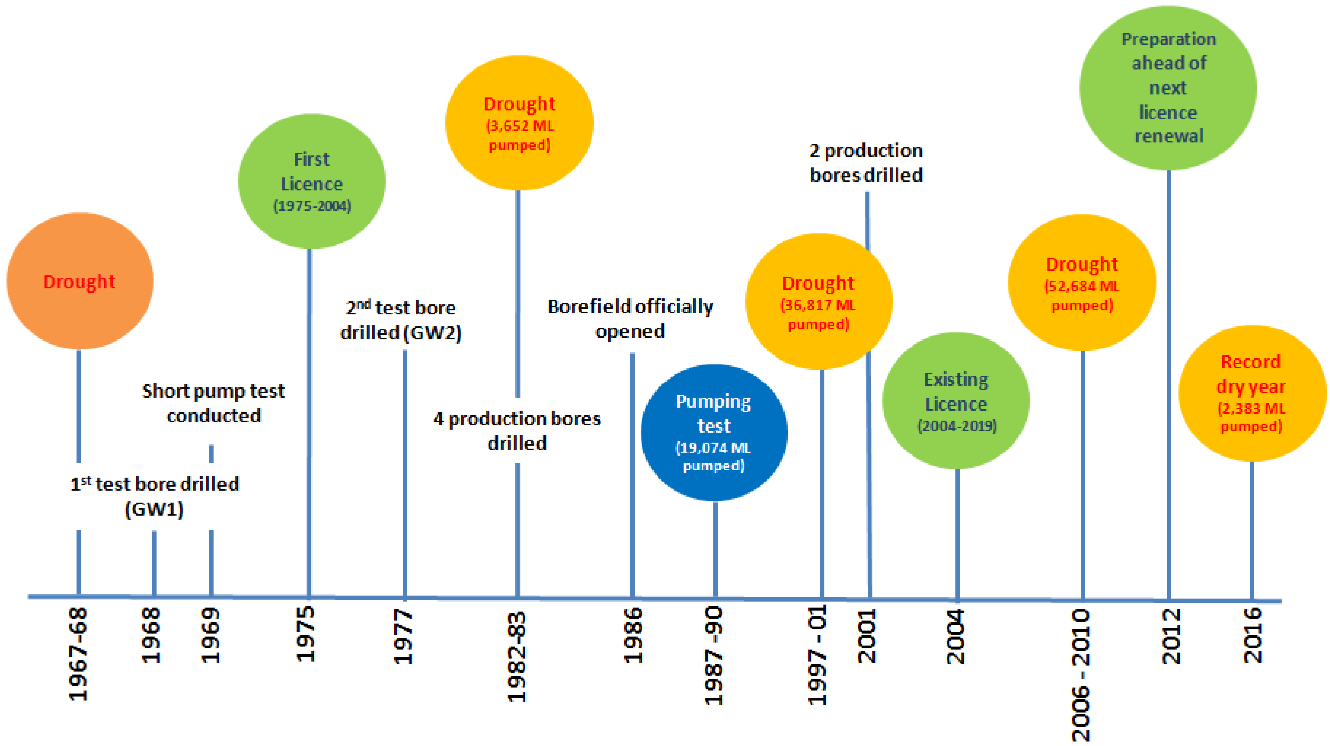
The licence was subsequently renewed for two periods of five years up to 2000. From 2000, the licence was temporarily extended three times for a total of four years to allow the licence renewal to take place through to 31 August 2004.

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;
- 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.

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



[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.*

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 centered 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,
- potential to increase existing acid sulphate soil risks in the Yeodene peat swamp,
- potential to increase the existing fire risk at the Yeodene peat swamp, 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 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.

<u>Stage 1: Review of the existing monitoring program</u>

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 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 sulphate 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 compensatory 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 sulphate 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

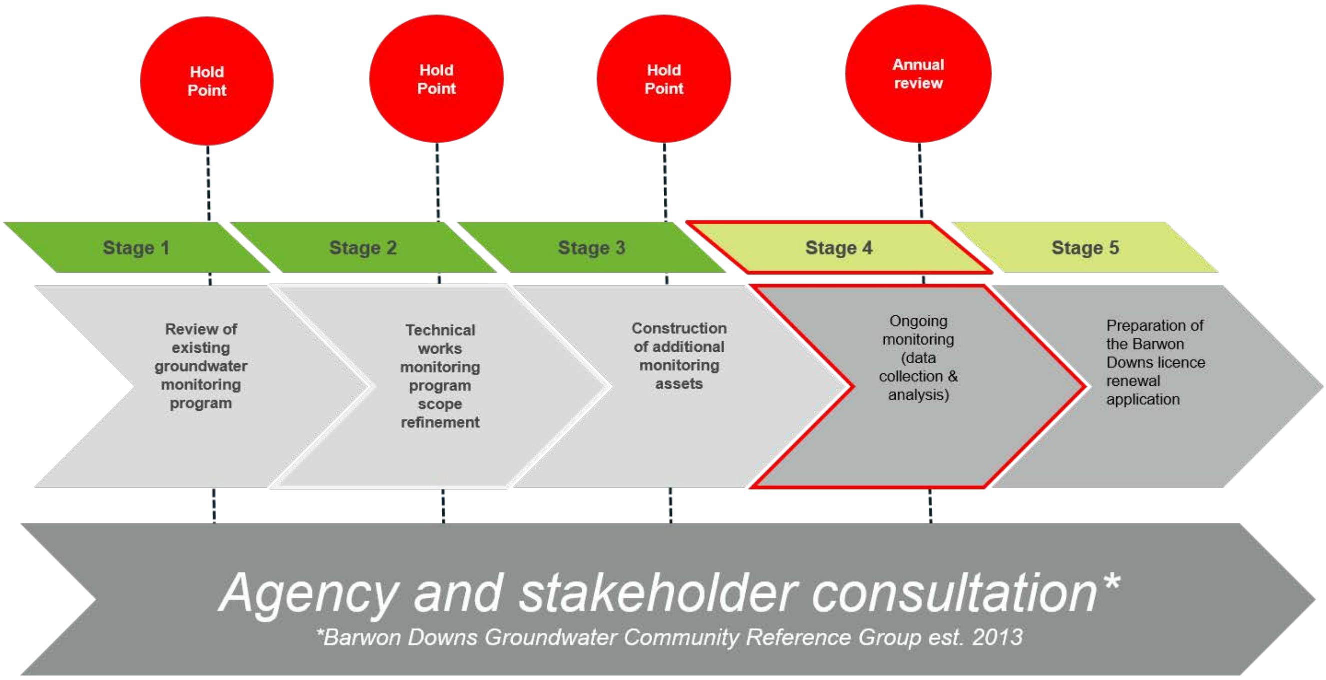
The technical works monitoring program is now in a phase of data collection and preliminary analysis. The intention of this stage is to update the conceptual understanding of the hydrogeology in the Barwon Downs region. This will be based on data collected from additional and existing monitoring assets 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

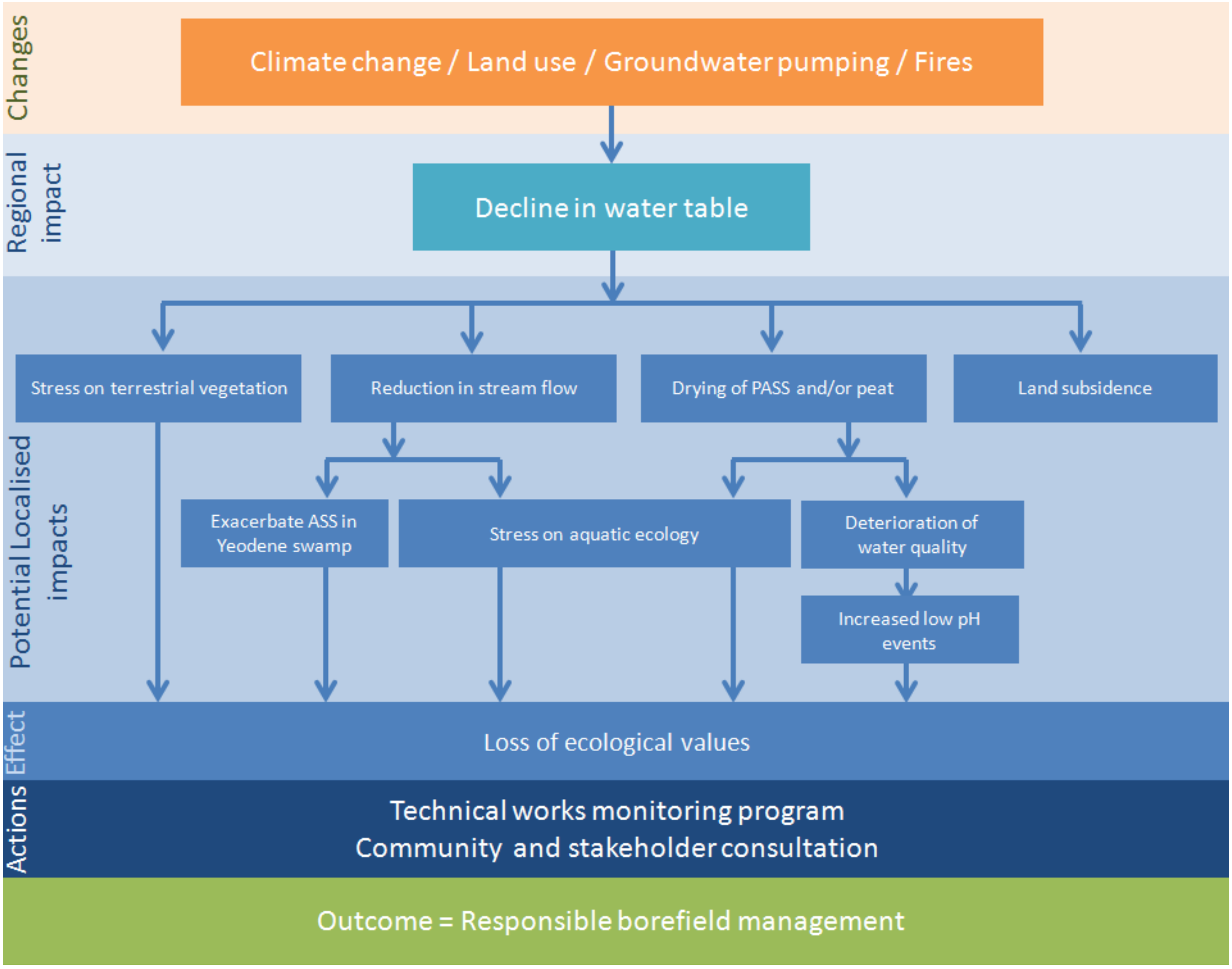
The technical works monitoring program is a complex, multi-disciplinary project due to the overlapping nature of the various components of the program as shown in Figure 1-5.

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



2. Barwon Downs Study Area

The Barwon Downs borefield is located in the Otways in southwest Victoria, approximately 100 km southwest of Melbourne, between the town of Colac to the north and the Otway Ranges to the south. The borefield extracts groundwater from aquifers that are very deep (500 m) where the borefield is situated. However the same aquifer rises to surface in other parts of the catchment. Figure 1-2 shows a conceptual diagram of the Barwon Downs borefield and how the aquifer is connected to other areas in the catchment.

Surface elevation is highest in the west of the study area known as the Barongarook High. The Barongarook High is centred on a region of basement outcrop near the settlement of Barongarook (refer to Figure 2-1). The topographic high is a key area of groundwater recharge for the aquifers of the Barwon Downs area and also contains the headwaters of a number of creeks and streams that drain radially to the north, south, east and west (e.g. Boundary Creek). Similar to surface water flow, groundwater flow is also often driven by the shape of the topography and flows away from the Barongarook High towards the Barwon Downs area.

2.1 Surface water catchments

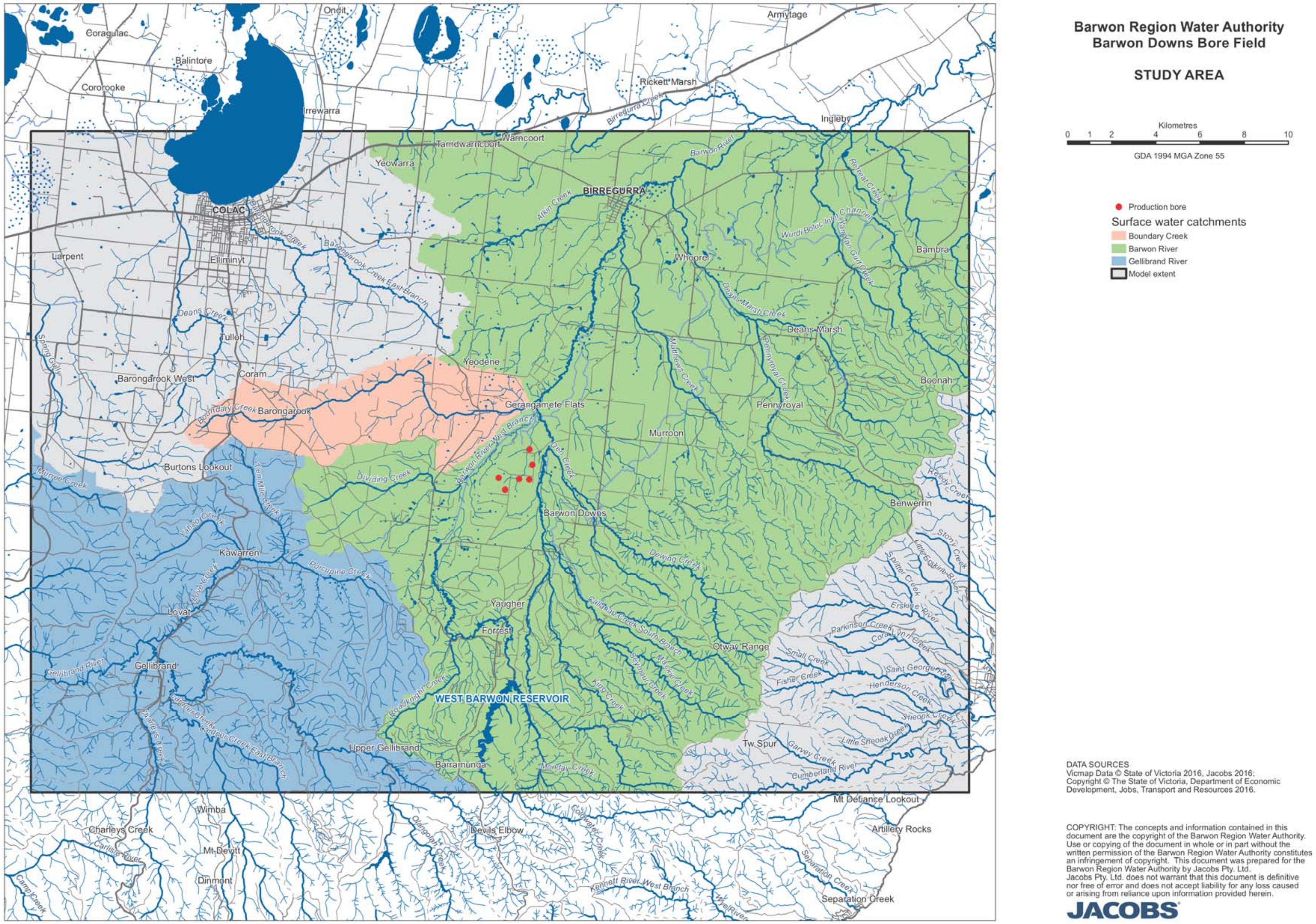
The borefield is located in the Barwon River catchment. The majority of the Barwon River's tributaries rise in the Otway Ranges to the south east of the borefield and flow north towards Birregurra. The remaining tributaries, including Boundary Creek, rise in the west of the catchment and flows across the Barongarook High before joining the Barwon River at the Gerangamete Flats. Figure 2-1 shows the location of the borefield in relation to these features.

The Gellibrand River is located to the south west of the borefield with tributaries rising in the Otway Ranges and the Barongarook High. This includes Porcupine Creek and Ten Mile Creek which converge and become Love Creek just upstream of the township of Kawarren (see Figure 2-1).

Boundary Creek is a tributary of the Barwon River that flows across the Barongarook High. The catchment has been highly modified over the last century. Changes to the catchment, some of which are permanent and irreversible, have significantly altered the natural hydrological flow regime of Boundary Creek (Jacobs, 2016c). These changes include a range of natural and human factors including:

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

Figure 2-1 Location of the Barwon Downs borefield and surface water catchments



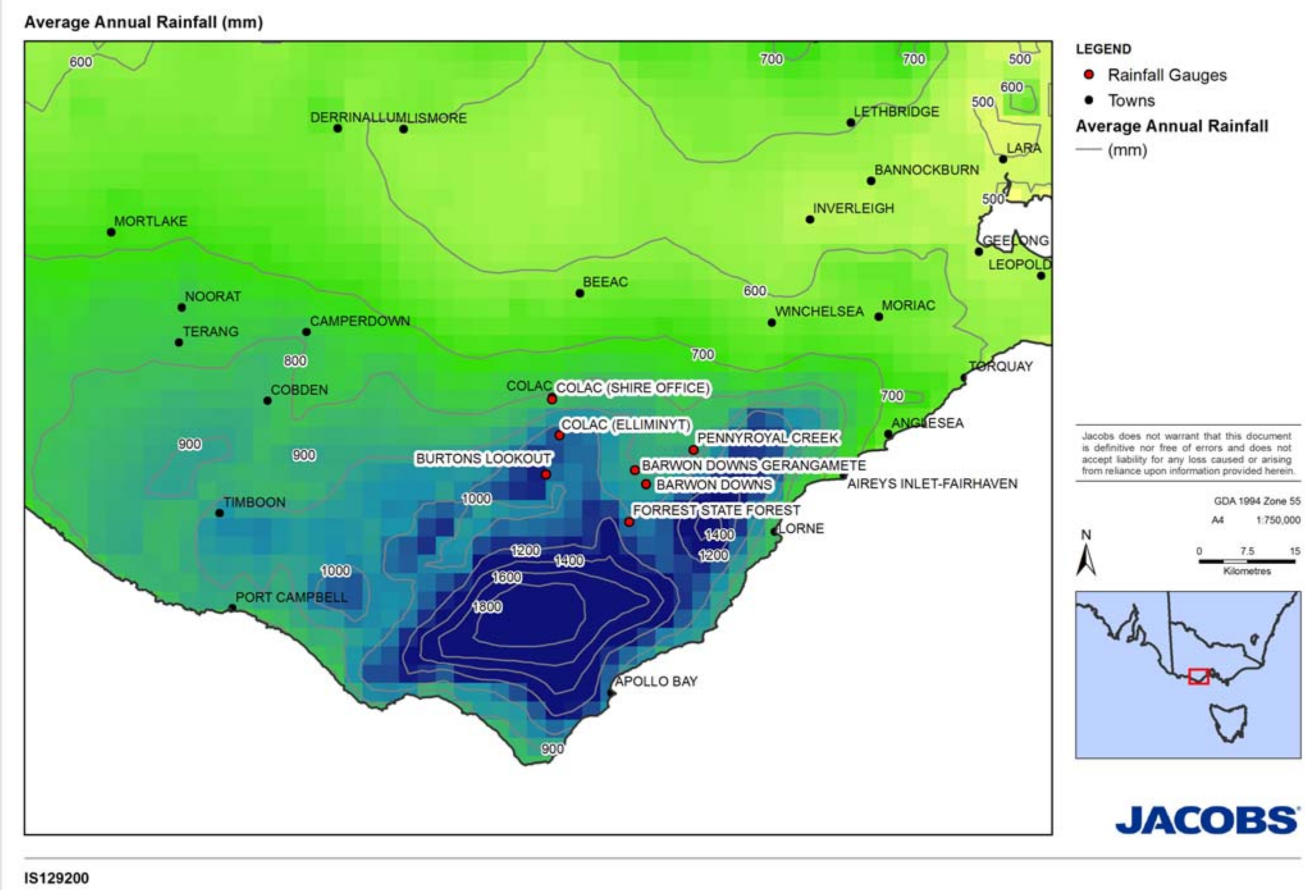
Refer to Jacobs document; J:\IE\Projects\03_Southern\IS129200\Spatial\Working\ArcGIS\Study_Area_A3_101.mxd

2.2 Rainfall

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

Figure 2-2 also shows the distribution of rainfall across the region. The Otway Ranges are one of the wettest places in Victoria with rainfall reaching greater than 1,500 mm per year in the highest parts of the ranges. There is a steep rainfall gradient across the Otways and the average annual rainfall varies from 800 to 1,200 mm across the study area, as shown in Figure 2-2. Rainfall across the study area is higher in the south and lower in the north.

Figure 2-2 : Rainfall distribution across the study area



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

Figure 2-3 shows the cumulative deviation from the mean monthly rainfall at the Forrest State Forest rainfall gauge over the last 116 years. This plot is used to highlight periods of above and below average rainfall conditions (e.g. drought). Periods of above average rainfall are represented by rising trends and periods of below average rainfall are shown as declining trends.

Figure 2-3 shows a significant period of below average rainfall conditions was experienced between 1915 and 1945. Rainfall was generally above average between 1945 and 1995 with two periods of drought in the late 1960s and early 1980s. Since 1995 rainfall has fluctuated between periods of below average and average conditions.

Figure 2-4 shows the same rainfall pattern between 1970 and 2000. A significant period of drought was experienced across Victorian between 1997 and 2000, 2005 and 2010 and more recently in 2014 to 2015. These dry periods had a significant impact on surface water flows and groundwater levels across the State, and the Barwon Downs region was no exception to this.

Figure 2-3 : Rainfall cumulative deviation from mean for the Forrest State Forest gauge (090040) 1900 - 2016

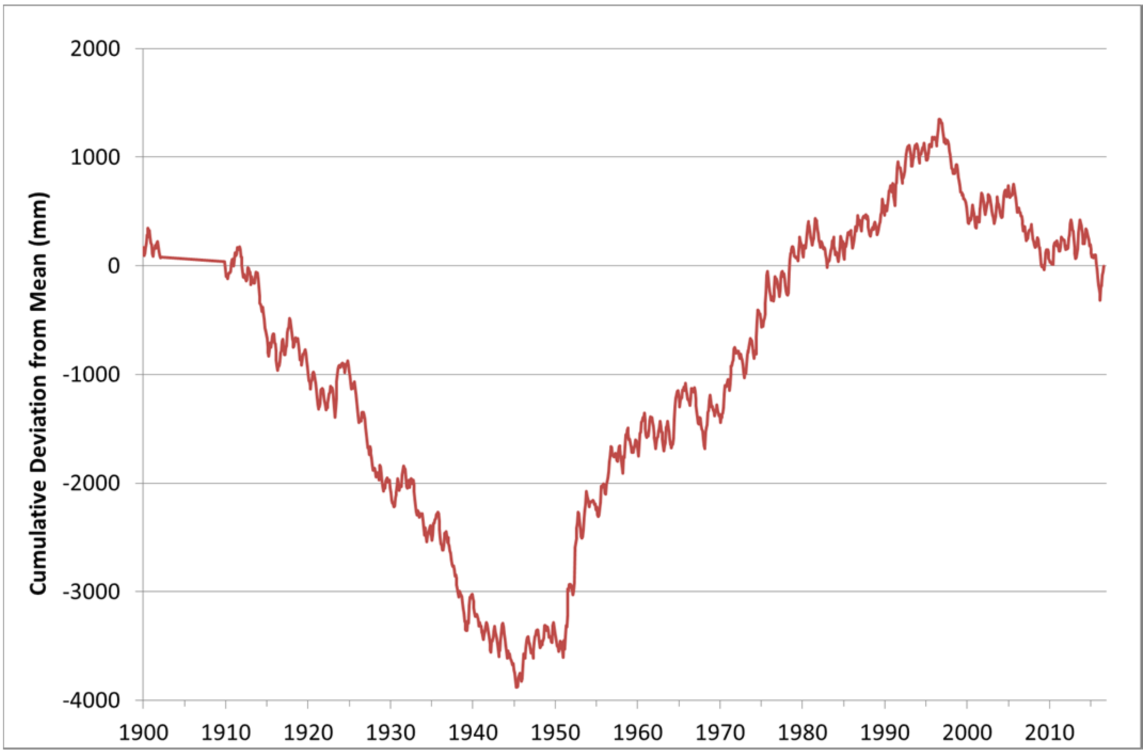
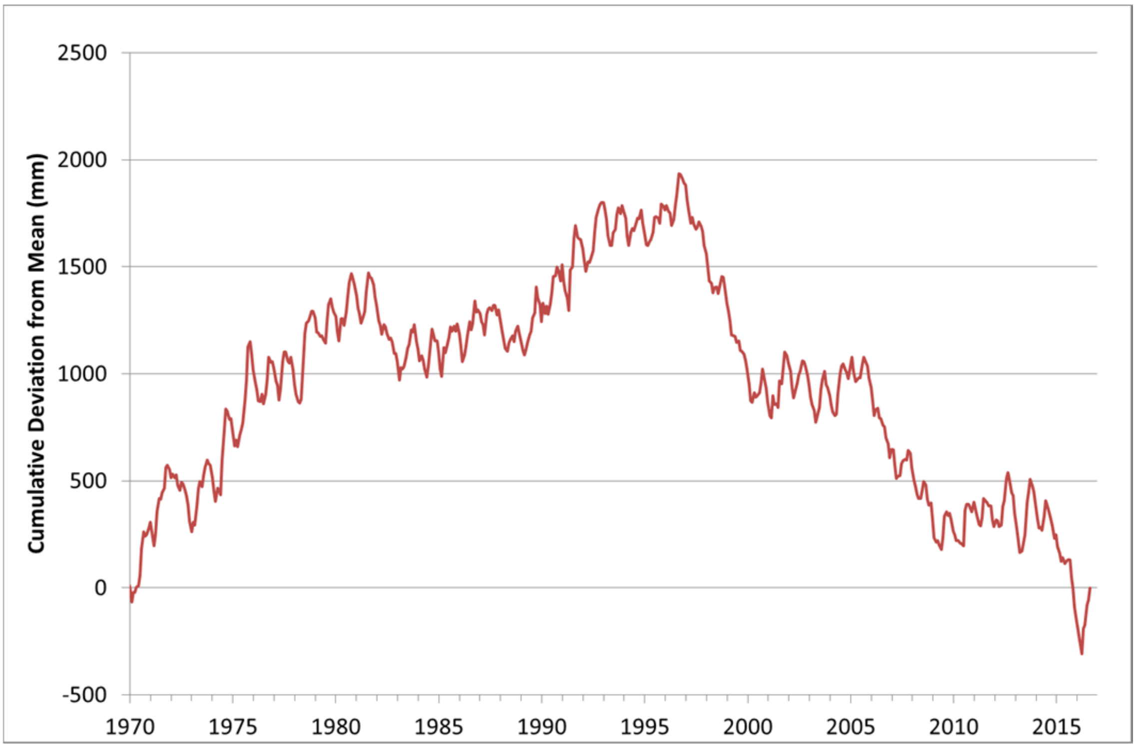


Figure 2-4 : Rainfall cumulative deviation from mean for the Forrest State Forest gauge (090040) 1970 - 2016



3. Technical Works Monitoring Program

The objective of the Technical Works Monitoring Program is to address the known information gaps that will help improve the technical understanding of the Barwon Downs study area. To this end, many studies have been undertaken and completed that were focussed on:

- Improving the hydrogeological understanding of the system and
- Understanding the potential impact that changes in the catchment (e.g. climate and groundwater extraction) might have on receptors in the catchment.

The following sections discuss the range of work undertaken in recent years to understand the potential impacts on the following:

- Groundwater levels
- Surface water flows and quality
- Aquatic groundwater dependent ecosystems (GDEs)
- Terrestrial groundwater dependent ecosystems (GDEs) and
- Potential acid sulphate soils (PASS).

Chapter 4 discusses the range of work completed under the Technical Works Monitoring Program to improve the hydrogeological conceptual understanding.

3.1 Groundwater levels

The key driver behind the majority of potential impacts from Barwon Downs borefield is declining groundwater levels in the water table aquifer. Barwon Water operates an extensive monitoring network around the Barwon Downs bore field for the purpose of assessing impacts of pumping on all the aquifers, including the water table aquifer, stream flow and other water dependent ecosystems.

Following a review of the surface and groundwater monitoring network, SKM (2013) recommended additional monitoring locations to strengthen the Barwon Downs monitoring network to improve the capacity to assess impacts of groundwater extraction from the bore field. New groundwater monitoring bores and stream flow gauges were installed and in some cases old sites were reinstated. Additional groundwater monitoring bores were recommended at priority sites for potential acid sulphate soils, vegetation monitoring sites and other areas where information gaps had been identified.

Based on the recommendations in SKM (2013), a capital works program was completed in 2014/15 that involved the installation or reinstatement of the following monitoring assets:

- 33 new groundwater monitoring bores drilled, including the replacement of one existing bore,
- Four new potential acid sulphate soils monitoring bores were installed,
- Three bores were reinstated by airlifting and fixing bore head works (109130, 109139 and 109143),
- Dataloggers were installed to monitor groundwater levels in all bores with the exception of bores that were dry or not considered to add significant value (e.g. TB2a, TB2b, TB4a and TB4c),
- Gamma logging was undertaken on bores where practical, as well as an additional 12 existing bores to collect information on the presence of confining clay layers in the hydrogeological profile,

- Hydraulic testing, in the form of slug tests, was undertaken on 30 bores to understand the range of aquifer parameters in each formation,.
- Groundwater samples were analysed for salinity and pH and some aquitard bores were analysed for major ions,and
- One surface water stream gauge was installed and two were reinstated.

The outcomes of the capital works program are documented in the Field Investigations Report (Jacobs, 2016b).

3.1.1 Objective

The objective of the new groundwater monitoring bores is to address knowledge gaps on groundwater level responses in the aquitard, the watertable at the vegetation monitoring sites and groundwater surface water interactions around the catchment.

The new and upgraded sites have been monitored since August 2014 (along with the existing monitoring sites). This section discusses the groundwater monitoring data collected for those new sites only. The new surface water monitoring sites are discussed in Section 3.2. The hydrographs for the monitoring bores are shown in Appendix A and discussed below. This does not review the monitoring data for the entire monitoring network, only the new information collected at new/upgraded sites since 2015.

3.1.2 Approach

The dataloggers in the “TB series” monitoring bores at the vegetation monitoring sites were downloaded in April 2016. The dataloggers in the remaining bores were downloaded in December 2015. The approach used to review the water levels included:

- Correcting the water levels for barometric changes
- Hydrograph data analysis.

More detail on these processes and a brief comment on the general trend in groundwater levels at each of the monitored sites are provided in Appendix A. The bores have been separated into their monitoring objective (i.e. aquitard, terrestrial vegetation sites or surface water interaction). It should be noted that although some seasonality in the groundwater levels has been identified, the data only covers around 16 months and thus any analysis of medium to long term trends cannot be determined at this stage.

3.1.3 Key Findings

The location of the new monitoring bores is shown Figure 3-1. This section provides a brief description of the groundwater trends, vertical gradients and groundwater surface water interactions. All bore hydrographs are provided in Appendix A.

Groundwater trends across the catchment

Most of the shallow monitoring bores (<15 m deep) show declining groundwater trends with seasonal fluctuations, consistent with the below average rainfall conditions over the monitoring period. However monitoring bores that are deeper than 20 m, generally show more stable groundwater trends, with smaller declines and very limited seasonality.

Four bores showed rising trends – Bore TB1c, 109130, 109143 and A2. Bores TB1c, 109130 and 109143 are all screened in the LTA aquifer where the aquifer is unconfined in the Boundary Creek catchment (between McDonalds Dam and Yeodene Swamp). Groundwater levels in the LTA have been impacted from pumping and the rising trends are representative of the aquifer recovery (since 2010).

Bore A2 is screened at 40 m depth in the MTD downstream of Yeodene Swamp. This rising trend is the result of the bore intersecting very low permeability aquitard material and because the groundwater moves so slowly, the water level has taken a long time to equilibrate after development at the end of bore construction. The steady trend observed in more recent months is considered to be representative of the regional groundwater level in the MTD at this location. Bore A3 is a shallower bore in the MTD located nearby and groundwater levels at this depth in the MTD display seasonal trends consistent with seasonal fluctuation in rainfall recharge.

Vertical gradients within and between hydrogeological units

There are several sites where multiple bores monitor water levels in either the same unit at different depths or different units. These nested bores provide information on the vertical gradients driving vertical groundwater flow.

There are three nested sites monitoring different depths in the MTD. Two of these sites, located to the west of the Barwon River, show there is an upward gradient driving groundwater flow towards the surface. One site (bores A5a and A5b) located near the bore field and on the Barwon River East Branch show there is a slight downward gradient in the upper part of the MTD at this location.

TB1a, TB1b and TB1c are located downstream of Yeodene (Big) Swamp. TB1b is screened in the alluvial aquifer, TB1a is screened in the MTD and Tb1c is screened in the LTA. This nested site shows that there is an upward gradient from the MTD to the alluvial aquifer and a downward gradient from the MTD to the LTA. The LTA at this location has been impacted by groundwater extraction from Barwon Downs and is recovering after pumping ceased in 2010. Historically it is likely that before pumping commenced at Barwon Downs the vertical gradient was upwards from the LTA to the MTD. However the change in the vertical gradients at this location has not propagated through the MTD, which means the water table aquifer in the alluvium, is buffered from changes in groundwater levels in the LTA.

Groundwater Surface Water Interactions

UBCk1 and UBCk2 are located on the Barongarook High and were installed to understand groundwater flow directions towards Boundary Creek. UBCk1 is located furthest from the creek and is screened in the LTA. UBCk2 is located close to the creek and is screened in basement where it outcrops at the surface. The groundwater levels in these bores show a slightly declining trend with seasonal fluctuations, consistent with rainfall conditions at the time of monitoring. The groundwater flow direction is towards the creek (i.e. the creek is gaining along this reach).

Bores 109140, 109130 and 109143 are all located on Boundary Creek, either adjacent to McDonalds Dam (109140) or downstream. All bores screen the LTA at reasonably shallow depths. These bores can be used to understand groundwater surface water interaction along the reach in combination with stream bed elevation data. Bore 109136 is also located some distance from Boundary Creek (0.5 – 1km) and can be used to understand groundwater flow gradients towards the river.

Local perched alluvial aquifers

Local perched alluvials aquifers were found to exist in some parts of the catchment, for example, TB1, TB2, TB3 and TB4. These local perched systems were found to be recharged from rainfall and suface water and are independent of the groundwater levels in the LTA.

TB1 is located downstream of Yeodene (Big) Swamp and three nested bores show there is an alluvial aquifer overlying the MTD which in turn overlies the LTA. Groundwater levels are rising in the LTA at this location, however waterlevel trends were steady in the MTD and fluctuate with climate conditions in the alluvial aquifer. Watelevels in the alluvial aquifer are not significantly influence by waterlevels in the LTA at this location.

Local perched alluvial aquifers are also present at sites TB2, TB3 and TB4. The perched aquifers exist in the alluvial sediments which overly the LTA and the depth to water level in the LTA ranges between 3 and 20 m. The water levels in these perched aquifers declined below the base of the monitoring bore during 2015 in response to the climate conditions. Where the perched aquifers are not underlain by MTD, they appear to be more susceptible to climate conditions.

3.1.4 Recommendations

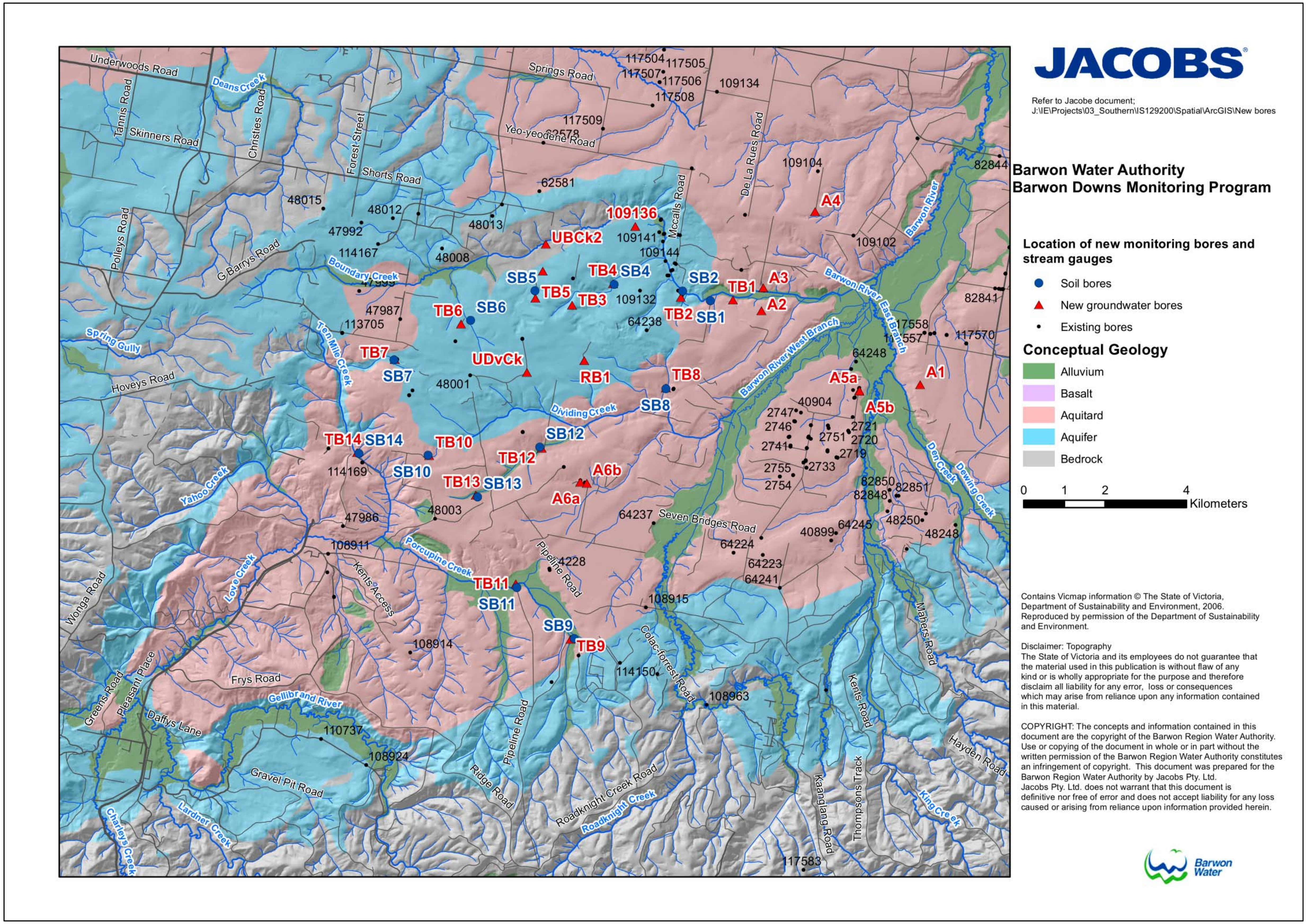
The current groundwater monitoring network is a sound baseline monitoring network to assess changes to groundwater levels which can influence groundwater-surface water interactions and streamflow, aquatic GDEs, terrestrial GDEs and PASS.

The groundwater monitoring information provides strong evidence to assess past effects and predict future effects and will be used to improve the calibration of the numerical groundwater model. The model will be used to support the licence renewal and help quantify predicted effects of different borefield operating regimes and under different climate scenarios. This will improve the technical basis that will support Barwon Water's licence renewal application.

Ongoing monitoring of the full network (as currently configured) is recommended, as well as:

- Ongoing quarterly monitoring of bores without dataloggers
- Downloading data loggers in bores at least twice a year
- Installation of loggers in A6a, TB1c, and 109136 as loggers in these bores ceased working

Figure 3-1 Location of new monitoring bores and surface water gauges compared with the location of existing bores



3.2 Surface water flow

There are two main river catchments in the study area as shown in Figure 3-3, the Barwon River which includes Boundary Creek, and the Gellibrand River. The work completed as part of the Technical Works Monitoring Program in each catchment is described below.

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.

3.2.1 Boundary Creek (Barwon River Catchment)

In the Barwon River catchment, Boundary Creek has been the focus of the Technical Works Monitoring Program. Boundary Creek is an important tributary in the Barwon River catchment in relation to the Barwon Downs borefield, as it flows over the Barongarook High which is the primary recharge area for the LTA. The creek is in direct hydraulic connection to the Lower Tertiary Aquifer across parts of the upper catchment.

There has also been ongoing community interest in the Boundary Creek catchment. Key areas of community interest recently have included the:

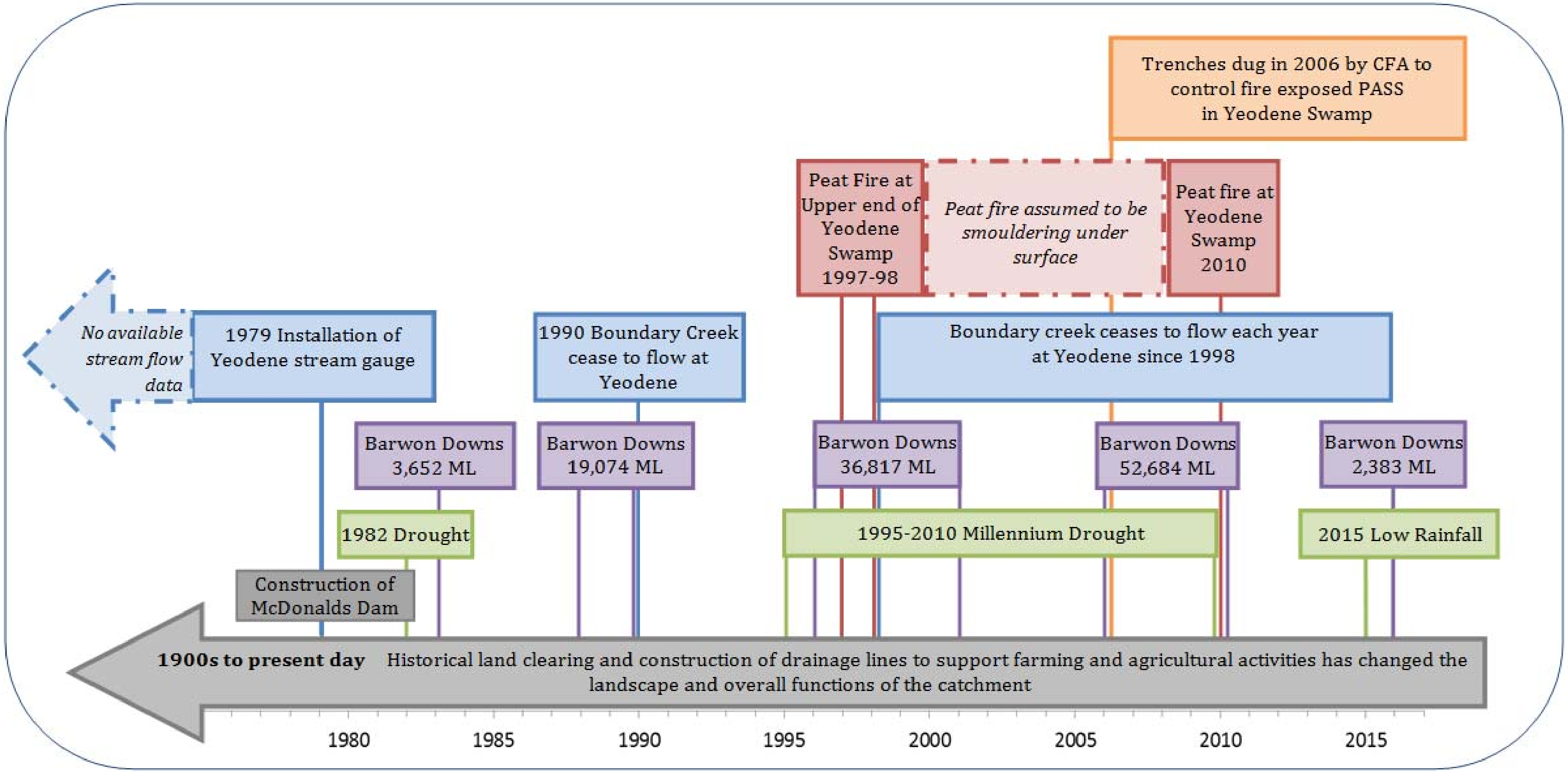
- extent of stream flow reduction and any ecological impacts at various points along Boundary Creek,
- potential to increase existing acid sulphate soil risks in the Yeodene peat swamp,
- potential to increase the existing fire risk at the Yeodene peat swamp, and
- extraction limits and whether they are sustainable under climate change projections.

The Boundary Creek sub-catchment is shown in Figure 3-4. The catchment is highly modified and has experienced significant hydrological and non-hydrological changes over the last century. These modifications include land use change, construction of drains to facilitate agriculture, construction of McDonalds Dam, groundwater extraction from the Barwon Downs bore field, climatic influences including drought and a slow burning peat fire at Yeodene Swamp and subsequent fire management involving the construction of a cut-off trench to prevent the spread of fire. It is unknown how the fire management response in 2006 altered the key functions of the swamp.

In accordance with the groundwater extraction licence, Barwon Water releases a supplementary flow of 2 ML/day into Boundary Creek from its Colac water pipeline (when triggered by licence conditions). This condition was intended to provide supplementary water in Boundary Creek for stock and domestic users who may have been impacted by groundwater extraction from the Barwon Downs bore field. The supplementary flow is delivered to a tributary of Boundary Creek near Bushby Road, and the tributary joins Boundary Creek approximately 1 km downstream of Barongarook Road.

There are four stream gauges in the Boundary Creek catchment along Boundary Creek, between Barongarook and Yeodene (see Figure 3-4). Another stream flow gauge is located on a tributary of Boundary Creek, which measures flow released from McDonalds dam. Two of the gauges on Boundary Creek were recently installed following recommendations from SKM (2013) (Jacobs, 2016b).

Figure 3-2 Timeline of changes in Boundary Creek catchment



3.2.1.1 Objective

The overall objective of the work completed in the Technical Works Monitoring Program regarding the hydrology of Boundary Creek was to ensure there was sufficient monitoring data to inform a conceptualisation of the groundwater surface water interactions in the catchment. Boundary Creek is now heavily gauged, however, historically, that was not the case and there is limited long term hydrologic data for the creek (Jacobs, 2016c) making it difficult to hind cast potential impacts and their likely contribution.

This section provides an overview of the surface water monitoring and hydrology in Boundary Creek.

3.2.1.2 Approach

For the purpose of the Technical Works Monitoring Program, Boundary Creek has been divided in three reaches as shown in Figure 3-4. The three reaches are (Jacobs, 2016c):

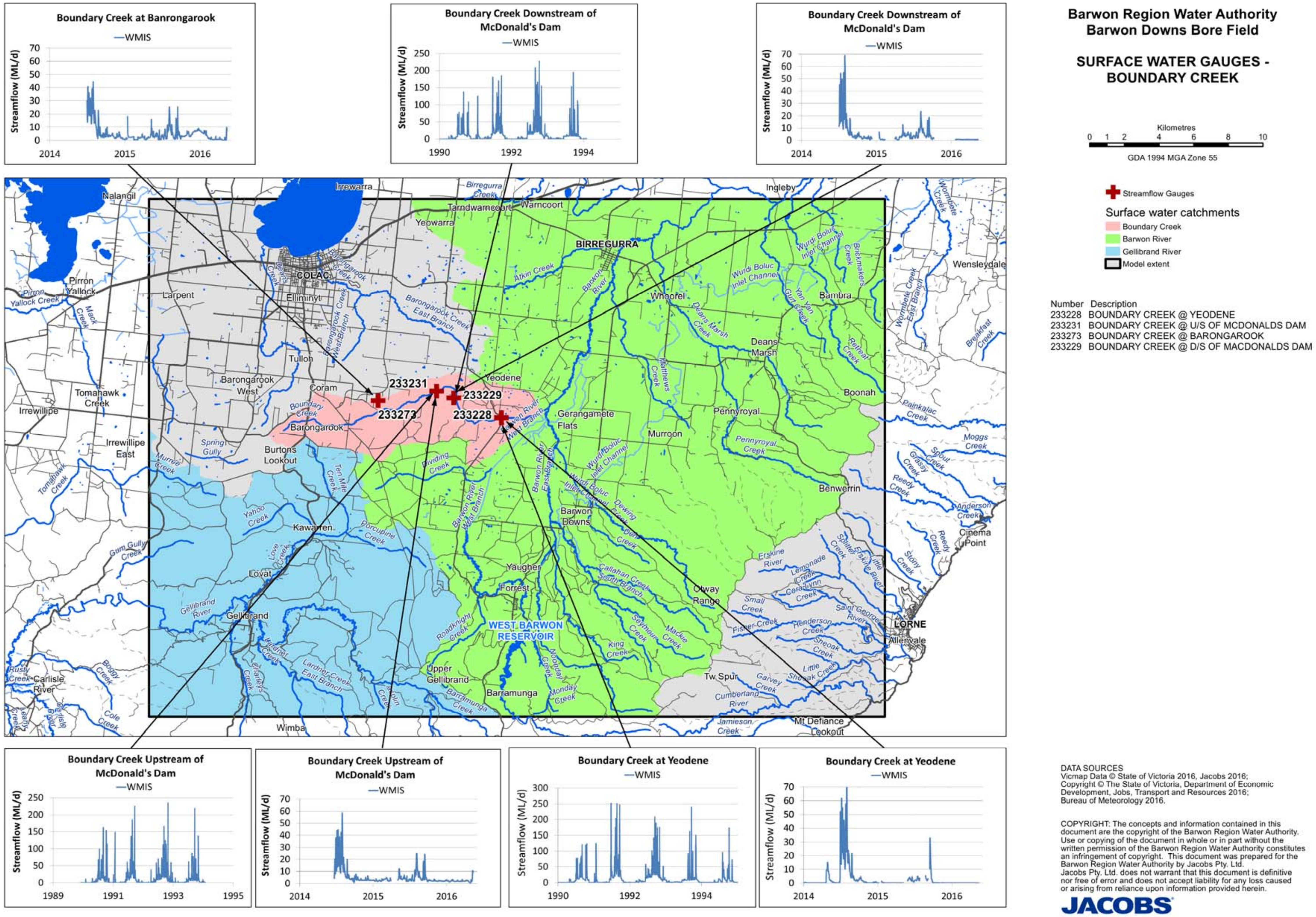
1. Upstream of McDonalds Dam
2. McDonalds Dam outlet to the downstream end of Yeodene (Big) Swamp
3. Downstream of Yeodene (Big) Swamp to confluence with Barwon River.

The surface water flow and quality in each reach is discussed below. Table 3-1 lists the stream flow gauges along Boundary Creek.

Table 3-1 Streamflow gauges in the Boundary Creek catchment

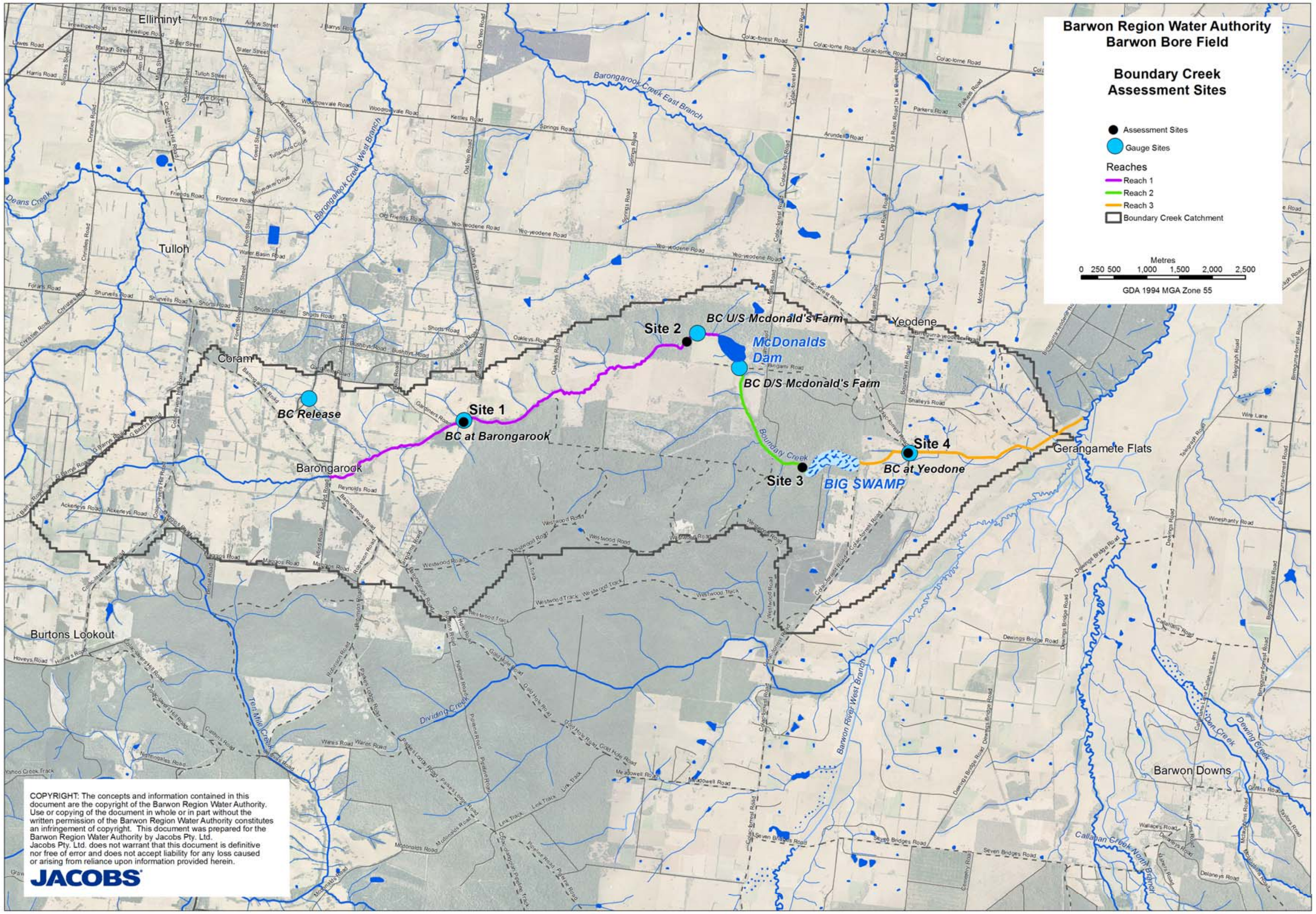
Gauge	Description	Record length	Confidence rating
bw763	Boundary Creek Release flow meter	Monitored since March 2015	High
233273A	Boundary Creek at Barongarook	Monitored since June 2014	Low (data prior to Aug 2016) Moderate (data after Aug 2016)
233231A	Boundary Creek Upstream Macdonald's Dam	Monitored since June 2014 (previously operated Dec 1989 to Feb 1994)	High
233229A	Boundary Creek Downstream Macdonald's Dam	Monitored since June 2014 (previously operated Dec 1989 to Feb 1994)	High
233228A	Boundary Creek at Yeodene	Monitored since June 1979	High

Figure 3-3 Location of Boundary Creek flow gauges



Refer to Jacobs document; \\Jacobs.com\ANZ\IE\Projects\03_Southern\IS129200\Spatial\ArcGIS\Stream_gauges_graphs_Boundary_Creek_A3_V2.mxd

Figure 3-4 Boundary Creek Catchment



Refer to Jacobs document; I:\VWES\Projects\VW07575\Technical\Spatial\Working\ArcGIS\Boundary_creek_stream_sites_A3.mxd

3.2.1.3 Key Findings

The hydrology of Boundary Creek has been significantly modified by changes in the catchment (refer to section 2.1). Key features of the hydrology of the creek are (Jacobs, 2016c):

- The supplementary flow makes up a significant portion of the flow in Reach 1 (and possibly Reach 2) in the summer months.
- The flow in Boundary Creek is passed through McDonalds Dam reliably in the winter months, but there is variability in the inflow and outflow in the summer months.
- Flow is recorded throughout the summer upstream of Yeodene (Big) Swamp, but rarely downstream of the Swamp (at Yeodene).
- Streamflow gauge data shows that Boundary Creek rarely stopped flowing at any time of year between 1979 and 1999, but since then has stopped flowing for long periods each summer.
- The water in Reach 3 of Boundary Creek (measured at the Yeodene gauge on the Colac-Forrest Road) is highly acidic.

The stream gauge readings were reviewed and the majority of gauges along Boundary Creek were generally found to be consistent and satisfactory with minimal periods of missing data. The hydrographs are presented in Appendix B.

An issue was discovered with the Barongarook gauge rating, as grass had grown up near the gauge and increases the water height relative to the flow rate, skewing the data record. This influence is apparent from August 2015 onwards, and suspected to affect the full record up to that point, which affects the confidence in the data from that of the gauge prior to August 2015.

Figure 3-5 shows the flow record in Reach 3 which is the longest flow record in the catchment (1979 to present). This shows that flow has declined notably since the late 1990s. Figure 3-6 shows the periods where flow is less than 0.1 ML/day, which effectively represents periods of no flow. This highlights that Reach 3 ceased to flow on one occasion in 1990 and then for periods in every year since 1999.

Figure 3-5 Stream flow record in Boundary Creek at Yeodene (233228A) in Reach 3.

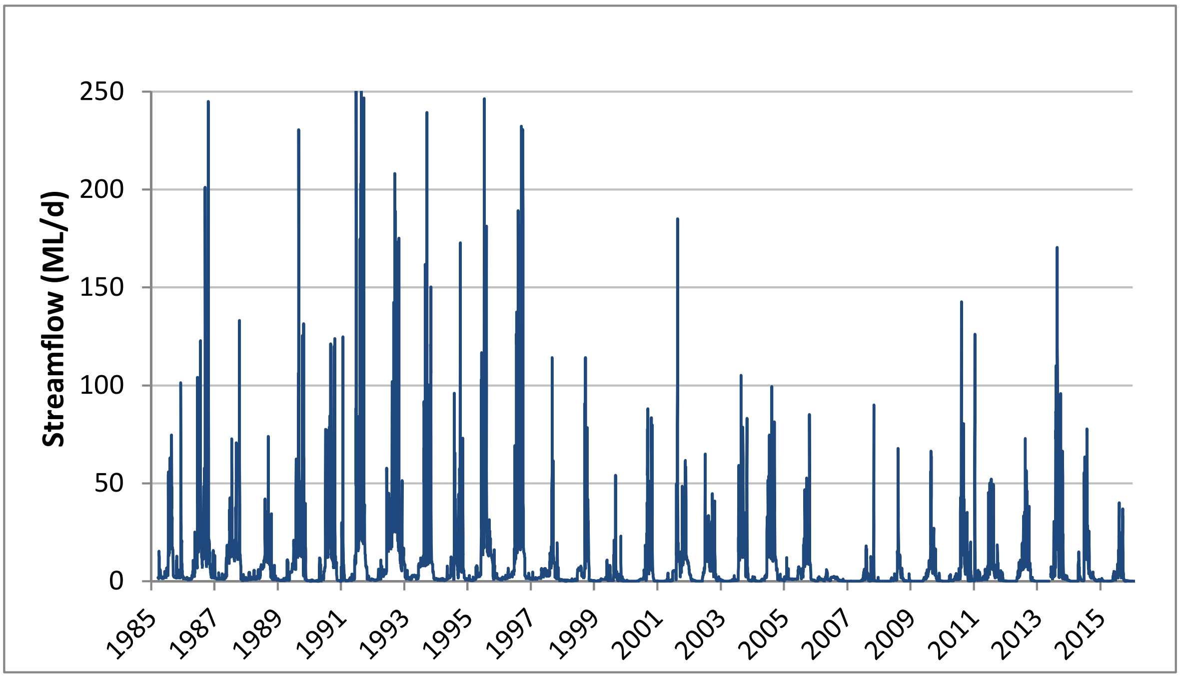
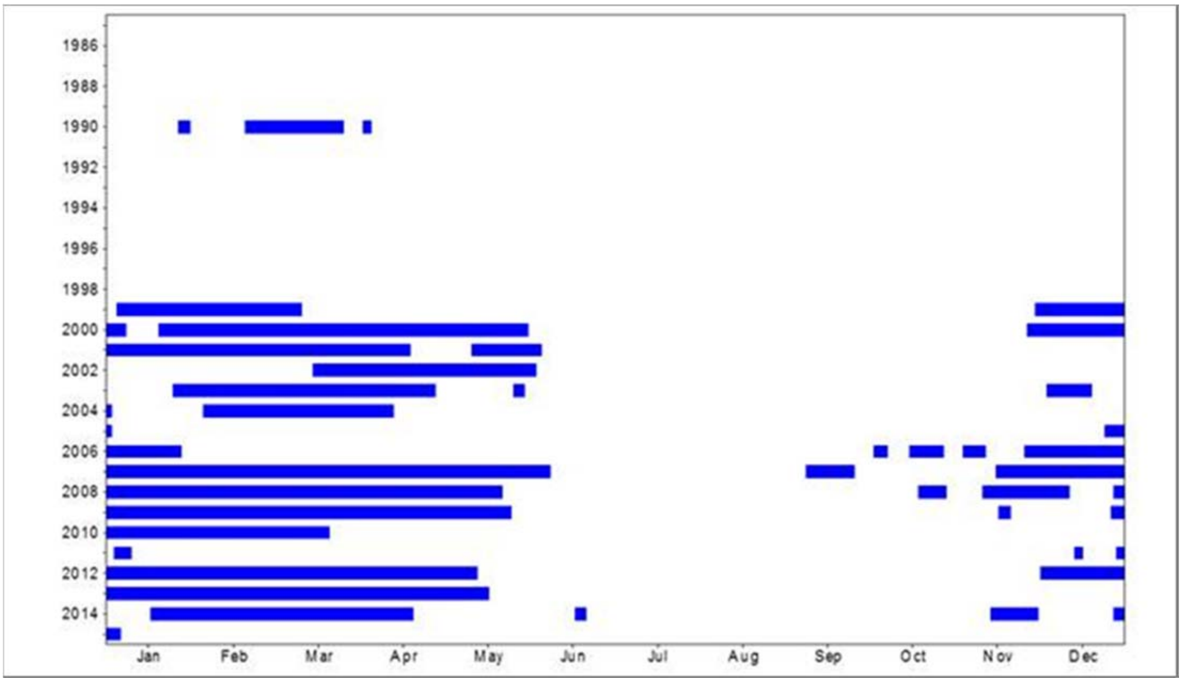


Figure 3-6 Spells plot showing flows less than 0.1 ML/day at Yeodene (233228A) in Reach 3



3.2.1.4 Recommendations

It is recommended that data loggers are downloaded at least twice a year and that the need for maintenance at each gauge be reviewed when the data loggers are downloaded.

Jacobs (2016c) also recommended that the current hydrogeological understanding of the catchment be reviewed to develop a detailed conceptualisation of the surface water-groundwater interactions that operate at Boundary Creek and incorporate the results of the numerical groundwater model to help quantify baseflow contributions to Boundary Creek. This is discussed further in section 4.5.

3.2.2 Gellibrand River

The Gellibrand River catchment occupies the south western part of the study area. The tributaries of the river originate in the Otway Ranges and the Barongarook High.

A review of the conceptual understanding of the Gellibrand catchment, including surface water monitoring in the upper part of the catchment, was completed by Jacobs (2015). As shown in Figure 3-8, there are six stream flow gauges in the Gellibrand catchment in the study area but only three are currently active. Monitoring of stream flow gauges on three tributaries in the upper Gellibrand catchment ceased in recent years.

3.2.2.1 Objective

The objective of the review completed under the Technical Works Monitoring Program was to investigate whether additional stream gauges were required in the upper Gellibrand catchment. Potential impacts to the Gellibrand catchment, particularly in terms of any reduction in base flow to the river due to groundwater pumping was raised as a topic of interest by the Community Reference Group.

3.2.2.2 Approach

The need for additional gauges was considered within the context of the conceptual understanding of the area and the potential for the Barwon Downs bore field to impact groundwater levels. The extent of drawdown as a result of groundwater extraction from Barwon Downs bore field was used to determine the potential for declining groundwater levels to impact on stream flow in the upper Gellibrand catchment.

The active and inactive stream flow gauges in the Gellibrand catchment are shown in Table 3-2.

Table 3-2 : Stream flow gauges in the Gellibrand catchment

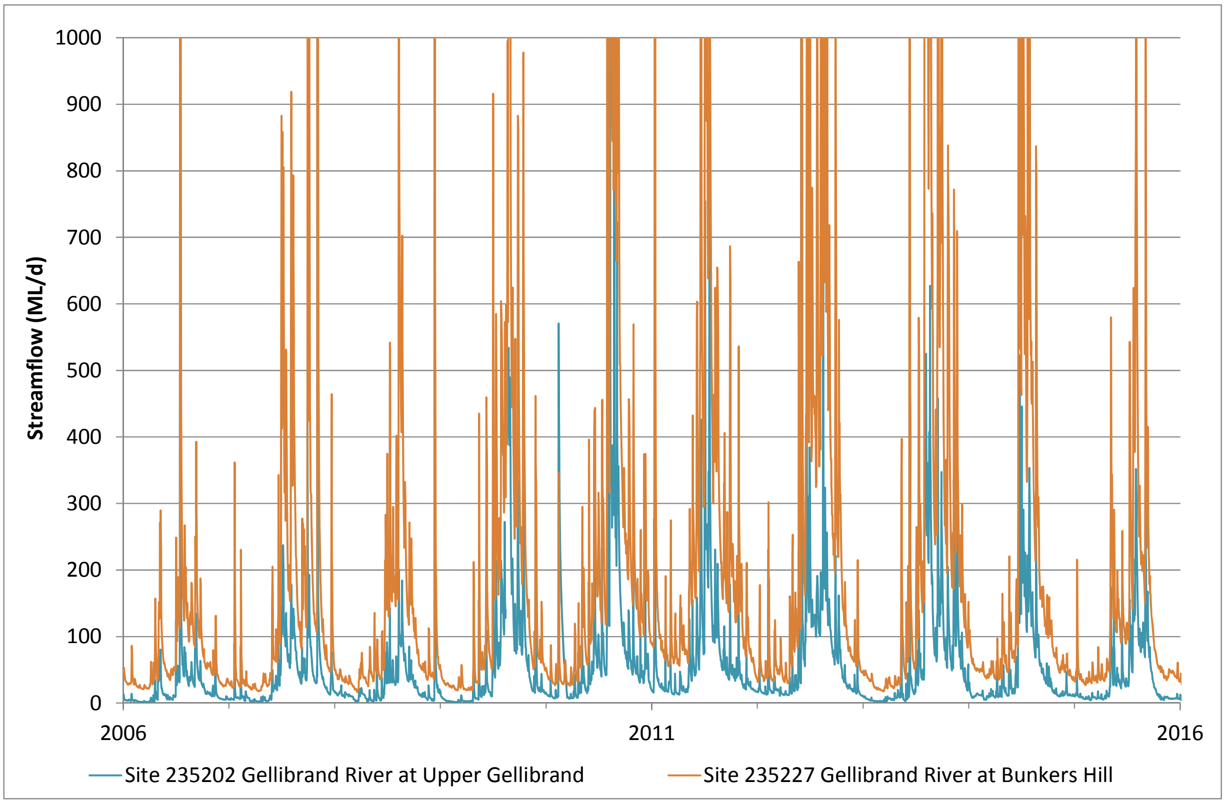
Gauge	Description	Record length	Confidence rating
235202	Gellibrand River at Upper Gellibrand	August 1949 to present	High
235239	Ten Mile Creek at Kawarren (Inactive)	April 1985 to July 2009	NA
235240	Yahoo Creek at Kawarren (Inactive)	March 1985 to July 1995	NA
235241	Porcupine Creek at Kawarren (Inactive)	March 1986 to July 2009	NA
235234	Love Creek at Gellibrand	May 1979 to present	High
235227	Gellibrand River at Bunkers Hill	March 1970 to present	High

3.2.2.3 Key Findings

The flow in the Gellibrand River at the Upper Gellibrand gauge and the Bunkers Hill gauge is shown in Figure 3-7. Flow in the Gellibrand River is significantly greater than Boundary Creek, with flows at the Upper Gellibrand River ranging between less than 10 ML/day during the summer months to in excess of 200 ML/day in the winter months. At the downstream Bunkers Hill gauge, low flows are 20-30 ML/day with flows often exceeding 1,000 ML/day multiple times in year.

Based on the results presented on the conceptual understanding of the catchment in Jacobs (2015), it was concluded additional monitoring gauges were technically not required as the drawdown in the watertable in the aquitard is expected to be negligible, particularly along Porcupine Creek. However, given the community interested in the Gellibrand catchment, additional stream flow gauges are recommended on Ten Mile Creek and Yahoo Creek as a precautionary measure, as these creeks flow over areas of outcropping LTA.

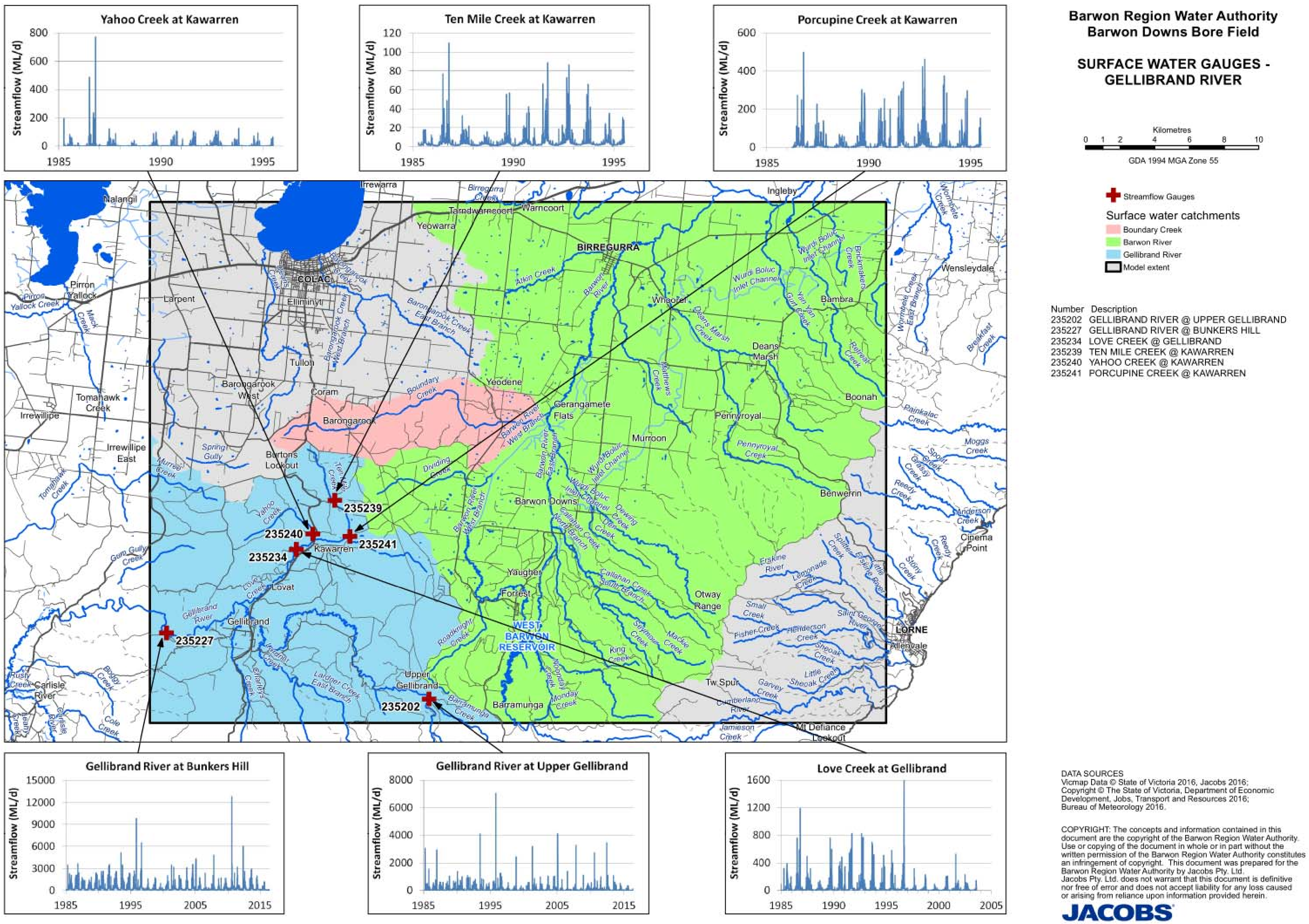
Figure 3-7 Hydrograph showing difference in flow in Gellibrand River at Upper Gellibrand and Bunkers Hill



3.2.2.4 Recommendations

Although additional stream flow gauges were not recommended for Porcupine, Ten Mile or Yahoo Creeks in the Gellibrand catchment based on a technical review, given the community interest in the Gellibrand catchment, additional stream flow gauges are recommended on Ten Mile Creek and Yahoo Creek as a precautionary measure for ongoing monitoring.

Figure 3-8 Location of Gellibrand River flow gauges



Refer to Jacobs document; J:\IE\Projects\03_Southern\IS129200\Spatial\ArcGIS\Stream_gauges_graphs_Gellibrand_River_A3.mxd

3.3 Aquatic groundwater dependent ecosystems (GDEs)

As described in previous sections, the Boundary Creek catchment has been highly modified over the last century. The changes to the catchment include both natural and anthropogenic factors ranging from the construction of drainage lines and surface water dams and groundwater extraction to climatic influences such as the Millennium Drought.

As part of the Technical Works Monitoring Program, Jacobs (2016c) completed an investigation into the aquatic ecology in Boundary Creek.

3.3.1 Objective & Limitations

The objective of this study was to understand the ecological condition of Boundary Creek and identify the ecological values the creek currently supports. This study also aimed to determine at a broad scale (i.e. qualitatively), the elements of the creek's flow regime that these values require.

This study was preliminary in nature and therefore has a number of limitations and assumptions that are outlined below:

- The study focused on surface water hydrology in Boundary Creek and did not explore in detail the groundwater-surface water interactions
- The study did not consider in detail the condition or ecological values supported by Yeodene (Big) Swamp.
- The study did not involve direct survey for fish, frogs, Platypus and vegetation. The presence of these ecological values was inferred using the techniques described below.
- Ecological values that the creek previously supported were also outside the scope of this study, given the many changes that have occurred in the catchment over the last 100 years. Further, there is insufficient historical stream gauge information to support such an assessment.

3.3.2 Approach

The study involved a combination of direct surveys for macro invertebrates and indirect assessment techniques for fish, frogs, Platypus and vegetation. Direct surveys were not completed for fish, frogs, Platypus and vegetation because the creek is relatively small and is likely to support only low numbers of aquatic animals, hence field surveys may not record many of the expected taxa (Jacobs, 2016c). As the failure to record a particular species during a field survey does not mean it is not present, even intensive field surveys may yield uncertain results.

Given these limitations, it was decided to use a combination of techniques to estimate the ecological values currently supported by Boundary Creek. Macro invertebrates were surveyed directly while the vegetation, fish, frogs and Platypus species and communities currently supported by Boundary Creek were estimated by considering historic records, other literature and the habitat present at the creek during field inspections.

3.3.3 Key Findings

The surface water hydrology of Boundary Creek was also reviewed to support the estimate of current ecological values and the key findings from this review are outlined in Section 3.2.1. The key findings from the hydrology review relevant to the ecological values are that:

- Supplementary flow makes up a significant portion of creek flow in the summer months.

- Boundary Creek rarely stopped flowing at any time of year prior to 1999, but since then has stopped flowing for long periods each summer and now rarely flows in summer downstream of Yeodene (Big) Swamp.
- Water in Reach 3 of Boundary Creek is highly acidic.

A summary of the ecological values in each reach along Boundary Creek is provided in Appendix B. The species and communities with either a ‘High’ or ‘Medium’ probability of being supported by the creek as identified in Jacobs (2016c) are summarised below.

3.3.3.1 Reach 1

In Reach 1, an overstorey of *Eucalyptus* and *Acacia* is supported, with a ground layer of weeds and occasional sedges and herbs. The channel supports Water Ribbons. Some fish are likely to be present including Short-finned Eels, Flathead Gudgeon and Mountain Galaxias. The macro invertebrate communities are in excellent condition (AUSRIVAS Band A). A range of common and widespread frog species is likely to be supported.

3.3.3.2 Reach 2

The majority of Reach 2 is a ‘dampland’ with a dense canopy of *Melaleuca squarrosa* and *Leptospermum lanigerum* and a wetland ground-layer of diverse sedges, rushes and reeds that are likely reliant on permanently waterlogged soils. The water in the channel is usually shallow and is therefore unlikely to be suitable for fish, although Flathead Gudgeon may be present. The macro invertebrate communities are significantly impaired (AUSRIVAS Band B) but the reach likely supports the Otway Bush Yabby and an assemblage of common frogs.

3.3.3.3 Reach 3

Reach 3 dries frequently in summer, has highly acidic water when it is flowing and has limited aquatic habitat. It is unlikely to support many resident aquatic species (although some frogs may use some habitat in the reach). The macro invertebrate community is in poor condition (AUSRIVAS Band C).

3.3.4 Recommendations

At present there is insufficient information available to quantify the flow requirements of the current ecological values. In order to quantify the flow requirements, further work is required to determine the groundwater surface water connectivity along the creek. Although efforts have been made to recalibrate and update the numerical groundwater model, improvement is required on the flanks of the Barongarook High where the LTA transitions from confined to unconfined. Together with a hydraulic model, baseflow contributions to the creek will be able to be quantified in terms of both flow volumes and depths.

Jacobs (2015c) recommended the following additional work to improve the conceptual understanding of Boundary Creek:

- Use the available hydrogeological information to produce a detailed conceptualisation of the surface water-groundwater interactions that influence Boundary Creek. This is discussed further in section 4.5.
- Use the numerical groundwater model to help quantify baseflow contributions to Boundary Creek.
- Develop hydraulic models at representative sites in the creek to the link the depth of water in the channel with flow volume.
- Determine the quantitative flow needs of the identified aquatic values in Boundary Creek

3.4 Terrestrial vegetation groundwater dependent ecosystems (GDEs)

Barwon Water undertakes a monitoring program as set out in the licence conditions. Current licence conditions for the groundwater extraction licence for Barwon Downs specify that Barwon Water monitor and protect riparian vegetation, especially vegetation that is groundwater dependent. While this program was good practice at the time of the last licence renewal, and continues to comply with licence conditions, the community has raised concerns about potential environmental impacts linked to groundwater extraction. A key area of community interest identified through the Barwon Downs Groundwater Community Reference Group was the protection of terrestrial vegetation that was of ecological value.

Vegetation condition across the catchment has been monitored regularly since the mid 1990s, although previous flora surveys were inconclusive due to difficulties in separating the influences of surface water, groundwater, land use change and the provision of environmental flows.

A review completed by SKM (2008) concluded that drought, groundwater extraction and provision of supplementary watering had a significant effect on riparian vegetation. However, given the complex interaction of many factors on vegetation condition, the study was unable to untangle the impact of groundwater extraction on the drying of the vegetation from other environmental processes, such as drought, climate change and other catchment and hydrological factors. This was due to the presence of factors which may have disguised the impact of groundwater extraction (e.g. supplementary watering of Boundary Creek, possibility of highly localised perched water tables, and the masking influence of outflow from adjoining stream and river systems).

The study recommended that a long term vegetation and hydrological monitoring program be designed and implemented to ensure the protection of riparian zones within the study area.

A revised monitoring network was established in 2014/15 and comprises 14 vegetation monitoring transects located in potential groundwater dependent ecosystems throughout the Otway Forest. Reference and impact sites were selected in areas where the LTA is unconfined and confined, to attempt to compare and contrast the likely causes of potential changes in vegetation condition.

Three separate studies on vegetation have been undertaken using the revised vegetation monitoring network as part of the Technical Works Monitoring Program.

- In 2014 and 2015, a vegetation survey was completed to assess health and condition of vegetation (Jacobs, 2015b).
- A separate study was also undertaken to understand the groundwater dependency of deep rooted species (i.e. trees) at the vegetation monitoring sites (Jacobs, 2016d).
- In response to below average rainfall conditions, another vegetation survey was undertaken in 2016 to assess the health and condition of the vegetation prior to the Barwon Downs borefield being turned on in April 2016 (Jacobs, 2016e).

The key findings of these studies are discussed below.

3.4.1 Objective

The overall objective of the vegetation studies was two-fold:

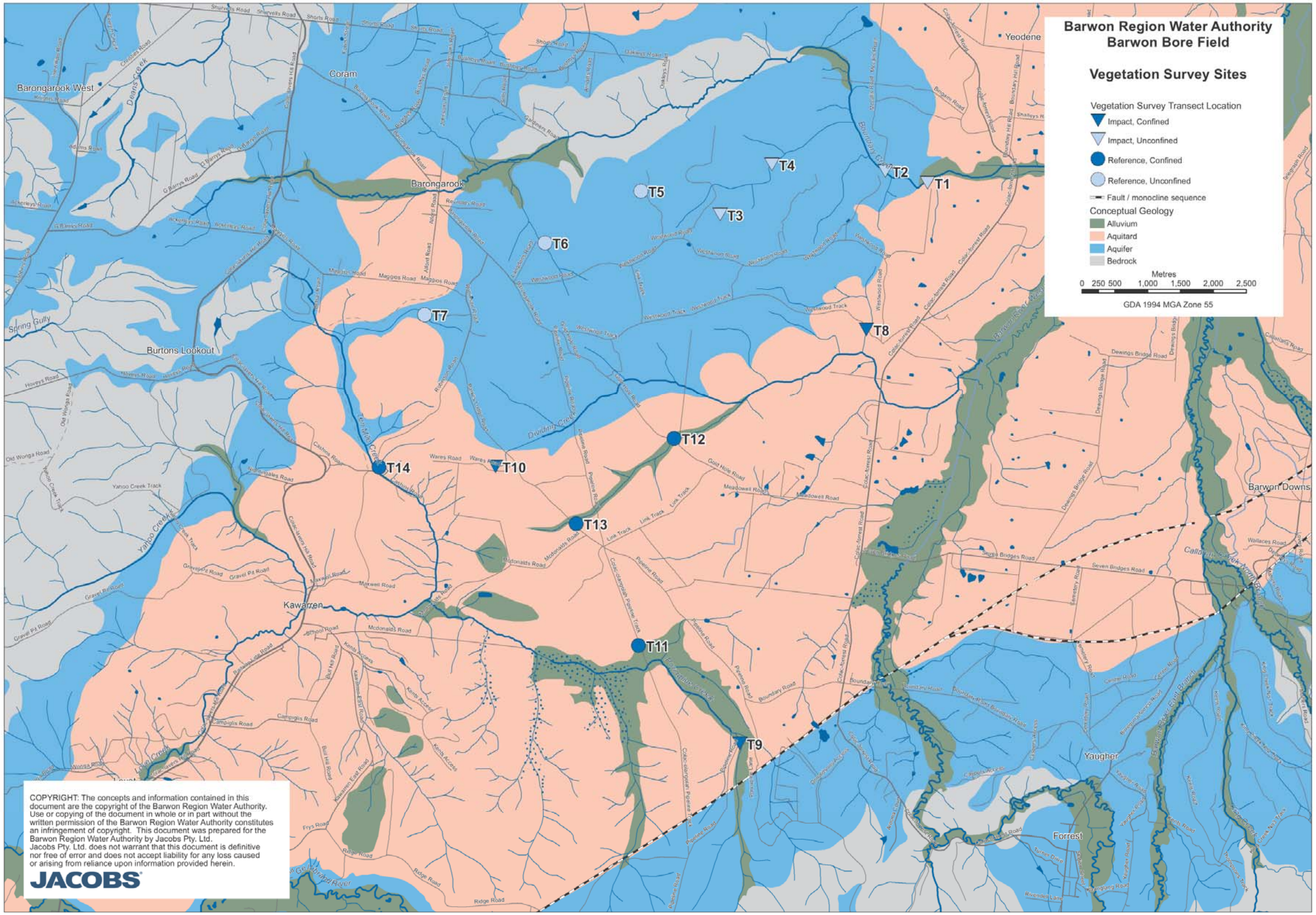
- Monitor the vegetation condition at the 14 monitoring sites to ensure there is adequate baseline information prior to the Barwon Downs borefield being turned on, and
- To determine whether terrestrial vegetation at the monitoring sites is using groundwater and if there has been an impact from historical groundwater pumping on the condition of groundwater dependent vegetation.

3.4.2 Approach

In 2013, fourteen vegetation monitoring sites were selected and these are shown in Figure 3-9 (SKM, 2013). The sites were selected based on a binomial design to monitor changes to potential GDE located in both confined (pink areas on map) and un-confined (blue areas on map) areas of the LTA and in areas that could be impacted by pumping at Barwon Downs borefield and areas that are not impacted (Jacobs, 2016e.) Impact sites were located in areas of the aquifer where the watertable was either known to have been affected from past pumping or potentially affected by the Barwon Downs borefield. Reference sites were located in parts of the aquifers where no impact on water levels from the Barwon Downs borefield has been observed.

The approach adopted for the vegetation surveys and the groundwater dependency study involved a combination of baseline information and a separate technical study to understand groundwater use by deep rooted vegetation such as trees. These studies are described below.

Figure 3-9 Location of Vegetation Monitoring sites



Refer to Jacobs document; J:\IE\Projects\03_Southern\IS129200\Spatial\Working\ArcGIS\Vegetation_monitoring_A3.mxd

Baseline Vegetation Surveys

The vegetation monitoring sites were first inspected between late 2014 and early 2015 (see Figure 3-9) (Jacobs, 2015b). The majority of sites were assessed between 25 November and 2 December 2014, while those located in the Greater Otway National Park were assessed between 6 February and 5 March 2015. The delay between survey periods was due to the delay in receiving a permit to work in the Greater Otway National Park.

The sites were assessed again early 2016 (Jacobs, 2016e). Similar to the previous assessment, the sites located outside the national park were monitored first and there was a short delay (1 month) between assessments of the sites in the national park as a result of the delay in receiving a permit to work.

Both vegetation surveys used the same approach in the data collections and analysis. Each transect was assessed using eight 5 x 5 m quadrats located along each transect, with the exception of T1 which is longer, so 14 quadrats were assessed (Jacobs, 2016b). In each quadrat the cover of each species located within the quadrat was estimated to the nearest 5 per cent, including any dead material still attached to plants. Due to many strata overhanging each other (i.e. trees over shrubs over ferns etc.), totals generally added up to more than 100 per cent. This is common in ecological surveys.

Vegetation types were categorised into functional groups with similar water requirements, for example:

- Functional group 0 – vegetation is most unlikely to use groundwater.
- Functional groups 1 and 2 – vegetation may use groundwater opportunistically, in particular species with shallow root systems.
- Function groups 3 to 6 – vegetation is highly likely to use groundwater and may be dependent on groundwater.

The functional groups along each transect were described in each survey and in 2016, any changes noted since the last vegetation survey in 2015 were also documented. Statistical analysis was undertaken using the data analysis pack of Microsoft Excel. One way and Two-way ANOVA tests were undertaken with variables being local hydrogeology (confined versus unconfined aquifer) and impact (reference/control versus impact sites).

In 2016, there was more information available on the local hydrogeology at each site and vegetation condition was considered in the context of the local hydrogeology and depth to watertable to determine the likelihood of vegetation being groundwater dependent.

Assessing the Groundwater Dependency

To determine if vegetation is using groundwater and whether there has been any impact from the borefield, this study involved a field program and remote sensing analysis. The field sampling program provided a snapshot in time of vegetation water use, while the remote sensing analysis enabled spatial comparison between sites across the study area over many years.

A field sampling program involved measurement of water potential and analysis of stable isotopes from vegetation, soils and groundwater which were used to determine the likely source of water for the vegetation at the time of sampling.

The remote sensing assessment measured vegetation condition and health by using the Normalised Difference Vegetation Index (NDVI), which measures the health of active vegetation. The active vegetation was compared between sites and across periods of expected high and low water stress. NDVI data was captured for four dates that represent one time period representing a baseline, two time periods showing water stress due to drought and borefield pumping and another time period representing a borefield recovery period. For each time period, the vegetation condition was assessed during the winter and summer to allow assessment of seasonal differences.

3.4.3 Key Findings

Baseline Vegetation Survey 2014/15

The 2014/15 vegetation survey determined that some groundwater dependent vegetation was present at most sites (Jacobs, 2015b). All vegetation assessed was considered to be in good condition with the exception of site T1 which was recovering from recent burning and acidic soil and groundwater conditions. In addition to this, no significant difference was detected between reference and impact sites. There was insufficient information available in 2014/15 to determine sensitivity of the groundwater dependent vegetation to groundwater level changes.

Baseline Vegetation Survey 2016

The 2016 vegetation survey was undertaken following a period of below average rainfall conditions and the vegetation condition across the catchment showed signs of decline since the previous survey was completed (Jacobs, 2016e). Given the borefield had not operated since 2010; the difference in results between the 2014-15 survey and this survey highlighted the vegetation's response to natural climate variability. Decline in vegetation condition was consistent across the monitored sites. Similar to 2014/15, there were no noticeable differences between impact/reference sites and confined/unconfined sites. This result is expected, given the borefield has not be used since 2010. The changes were also not statistically significant across the catchment. Overall vegetation species abundance had not changed markedly since the last vegetation survey. However, two sites (T5 and T13) had been burnt by controlled burns since the last survey. Vegetation is regenerating at both sites with almost all species previously detected re-recorded.

Jacobs (2016e) drew linkages between the vegetation condition and the local hydrogeology using the monitoring data collected between 2014 and 2016. A groundwater monitoring bore is located in close proximity to most vegetation transects. Groundwater levels across the study area show declining trends in response to below average rainfall conditions. This is a natural response to less rainfall.

At most sites, the groundwater levels are relatively close to the surface and accessible by some of the vegetation. Although groundwater levels have declined, the watertable at all sites remains reasonably shallow at the monitoring sites and is accessible to at least the deep rooted vegetation (i.e. trees and shrubs). There was little change detected in the condition of the larger deep-rooted vegetation, however significant changes were noted in shallow rooted vegetation at some sites.

Jacobs (2016e) highlighted that although the link between groundwater and vegetation present is highly variable and localised; all sites are considered to be groundwater dependent to some extent. The vegetation condition is likely to continue to decline if rainfall remains below average as water availability is reduced across the catchment.

Assessing Groundwater Dependency

The key findings from Jacobs (2016d) echoed the results of the vegetation survey conducted in 2016. Vegetation at most sites was found to rely on a combination of soil water and groundwater to meet their water requirements.

The field program determined that the majority of sites had evidence of vegetation using groundwater currently or in the past. The remote sensing analysis highlighted that deep-rooted vegetation uses groundwater during periods of low rainfall, as vegetation health was higher where the watertable was shallow and within root depths, compared to where the watertable is deep and beyond root depth.

There is no evidence that groundwater extraction from the Barwon Downs borefield has had a negative impact on vegetation activity or condition. While drawdown in the LTA has extended to where the aquifer outcrops (around the Barongarook High), this study determined that trees using groundwater have not been adversely affected.

3.4.4 Recommendations

The optimal frequency of future monitoring was considered using a risk-based approach (Jacobs 2016e). To increase confidence in the results and improve understanding of key drivers of potential changes in vegetation condition, the following recommendations are made:

- Vegetation surveys to be conducted every 2 years, whilst the borefield is operating and every 5 years when the borefield is not operating, in mid to late autumn when vegetation is most reliant on groundwater.
- No targeted fauna monitoring is recommended at this time. The ongoing presence of the burrowing cray holes indicates that the species is still present at site. Should the vegetation show evidence of change, or should the holes not be detected, then monitoring of the burrowing crays should be instituted here and at other sites along Boundary Creek.
- Relocate transect at site T11 to better connect with the groundwater dependent ecosystems in the area.

3.5 Potential acid sulphate soils (PASS)

Acid sulphate 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 sulphate soils (ASS).

There are several naturally occurring areas in the Barwon River catchment with ASS. The most well know of these is Yeodene (Big) Swamp, which causes water quality issues in the lower reach of Boundary Creek. Given the interest the community and local landholders have expressed in understanding what potential impacts there are from groundwater extraction in exposing acid sulphate soils, Barwon Water initiated a review of potential acid sulphate soils across the catchment.

3.5.1 Objective

The aim of the study is to provide a baseline condition assessment of four monitoring sites that are known to contain acid sulphate soils so potential changes to the sites can be monitored to understand key drivers. All four sites are located in areas susceptible to watertable fluctuations as a result of climatic changes (e.g. extended dry periods) or groundwater extraction.

3.5.2 Approach

SKM (2013) completed a desktop study to identify areas with PASS. The desktop assessment considered the physical landscape such as, where swamp areas were known to exist, geology, geomorphology, topography and vegetation, as well as where water levels in the watertable aquifer is predicted to drawdown. This process identified nine locations with PASS.

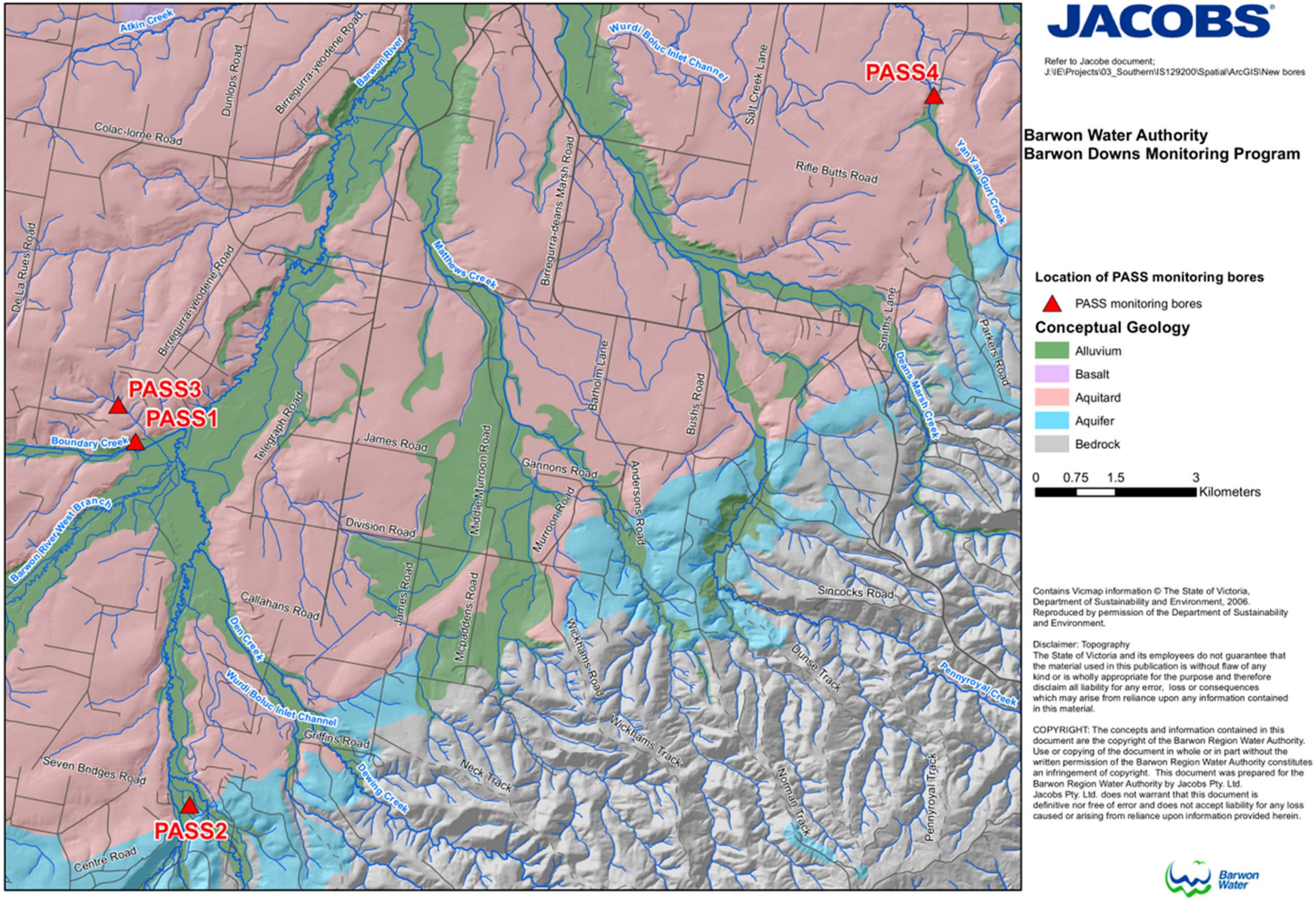
In addition to these nine locations, the Community Reference Group identified a further five sites for investigation. The 14 sites were reassessed using the same method as previously adopted in SKM (2013) and eight sites were subsequently recommended for field investigation.

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

The four PASS monitoring sites were monitored three times between late 2015 and mid-2016. Monitoring involved inspection of ground conditions, surface water quality, groundwater quality and groundwater levels. The borefield was turned on in April 2016, but was not operational for the monitoring rounds in November 2015 and March 2016.

The need for PASS monitoring in Porcupine Creek was reviewed again in 2014 in response to a study conducted by Glover and Webb (2014), where PASS soils were confirmed in Porcupine Creek. SKM (2013) did not recommend additional monitoring as there is limited potential for drawdown in the watertable due to groundwater extraction. While the scientific justification for this recommendation remains valid, community concern about the potential for ASS in this catchment may drive additional monitoring. This recommendation is discussed further in Section 3.5.4.

Figure 3-10 : PASS Baseline Monitoring Sites.



3.5.3 Key Findings

The baseline monitoring was completed during a period of below average rainfall conditions. Groundwater levels at each of the monitoring sites exhibit seasonable fluctuations, increasing by around 0.5 m in the wetter months (March-August) before declining by about the same in drier months (September-March).

At PASS 1, soils samples indicated the presence of severe PASS and AASS (Jacobs, 2016g). Groundwater at the site was around neutral and of the three sampling events; surface water was only flowing in Boundary Creek during the June 2016 sampling. The pH of Boundary Creek was 3.03 at this time and most likely reflects acidic drainage from Yeodene (Big) Swamp which is around 2.5 km upstream of the monitoring site. Groundwater quality is around neutral (pH 7), which indicates that acid sulfate soils have not affected groundwater at the site.

At PASS 2, soils sampling indicated the presence of severe AASS and some PASS (Jacobs, 2016g). Both the groundwater and surface water monitored at the site were around neutral. Groundwater quality monitoring indicates that ASS has not influenced the groundwater or surface water quality.

Previous soil characterisation at PASS 3 indicates the presence of of AASS and minor PASS (Jacobs, 2016g). Surface water at the site was acidic and groundwater at PASS 3 was highly acidic, suggesting an influence from actual acid sulfate soils. The concentration of metals in groundwater generally increased during wetter conditions, suggesting the mobilisation of metals from the soils into groundwater during rainfall infiltration at the site seasonally. The ratio of chloride to sulfate also decreased under wetter conditions, suggesting the mobilisation of sulfate from soils.

At PASS 4, soils sampling indicated the presence of severe AASS and PASS. Groundwater at the site was circum-neutral and did not vary greatly over the monitoring period. Similar to PASS 3, the concentration of metals in groundwater increased significantly in wetter conditions, suggesting the mobilisation of metals from the soils into groundwater seasonally. While the ratio of chloride to sulfate did not vary significantly seasonally, the ratio was the lowest (around 6.5) of all the sites monitored, suggesting that previous mobilisation of sulfate into the groundwater may have occurred.

In summary, changes noted in ground conditions, surface water and groundwater over the monitoring record were consistent with what would be expected under typical seasonal fluctuations. The groundwater quality did not change and the water levels are typically shallow (within 1 m below the surface) and display typical seasonal fluctuations of around 0.5 m, rising during the winter months and declining during the summer months. Changes in surface water salinity were consistent with seasonal fluctuations e.g. higher salinity during summer months when evaporation is higher.

The pH of surface water and groundwater generally remained constant over the monitoring period:

- At two sites (PASS2 and PASS4), the pH of the surface water and groundwater quality is neutral.
- At PASS1 located on Boundary Creek, the surface water is acidic as a result of acidic flows from Yeodene (Big) Swamp, and the groundwater is neutral.
- On a tributary of Boundary Creek (PASS3), both the surface water and groundwater are slightly acidic.

3.5.4 Recommendations

Ongoing monitoring is recommended at all four sites to continue to monitor changes. Ongoing monitoring should be conducted annually so that a baseline encompassing inter-annual variation can be established and potential changes in the soil and water quality at the sites can be monitored to understand key drivers. .

Additional work is recommended to select a PASS monitoring site in the Porcupine Creek catchment and complete baseline monitoring on groundwater and surface water quality.

3.6 Existing monitoring licence conditions for land subsidence

Land subsidence is monitored as part of existing licence conditions. SKM (2013) completed a review of subsidence to date, indicates that subsidence is very minor and is not an issue of concern, which is in general agreement with a subsidence prediction review conducted in the 1980s (RWC, 1986 and RWC, 1987). This review predicted that subsidence related to groundwater pumping (over long timeframes) would be very small.

Monitoring of land subsidence across the region is within licence conditions. The licence conditions specify a maximum of 200 mm subsidence permitted in licence conditions. To date, the maximum recorded subsidence is 76 mm in 2010. Some rebound has occurred since then and in 2015 the subsidence was recorded as 42 mm.

To date there have been no issues identified relating to land subsidence that would influence the licence renewal. Ongoing monitoring in accordance with the licence conditions is recommended; along with an investigation to assess the potential reduce the monitoring frequency.

3.7 Summary

The Technical Works Monitoring Program has established a sound baseline network to monitor potential impacts to groundwater, surface water, vegetation, aquatic ecology in Boundary Creek and PASS. This program has considered both technical limitations and community interest when being scoped.

In terms of **groundwater**, the Technical Works Monitoring Program has established a sound baseline monitoring network to assess changes to groundwater levels which can influence surface water, aquatic and terrestrial ecological values and PASS. This monitoring network provides strong evidence and a sound technical basis on which to assess the past effects and predict future effects with the use of a calibrated numerical model.

The additional work completed to improve the conceptual understanding in **Boundary Creek** has established a sound baseline monitoring network to assess streamflow. There is a perception amongst some community members that pumping from Barwon Downs has caused the drying of Yeodene (Big) Swamp which has subsequently caused changes to hydrology and water quality downstream (Reach 3). Further technical work is required to understand the swamp dynamics which will assist with understanding of the contribution of pumping to the issues in Reach 3. Further work is also required to understand the relative contribution of climate conditions and pumping to declining stream-flow to inform future operating regimes and licence conditions (e.g. timing and volumes pumped). Finally, additional work is required to understand the role of Yeodene (Big) Swamp in the hydrology and water quality of Reach 3 in Boundary Creek to inform licence conditions relating to supplementary flow.

In the **Gellibrand River catchment**, additional streamflow gauges are recommended on Ten Mile Creek and Porcupine Creeks. Previous work completed by Jacobs (2015a) did not recommend additional gauges as drawdown from the borefield is negligible in this area. However given the community interest, additional streamflow gauges are recommended as a precautionary measure to collect information to assist to demonstrate that are no predicted impact. In addition to this the calibrated numerical model can be used to quantity impacts to the Gellibrand River.

The Technical Works Monitoring Program has also developed a sound understanding of the **existing ecological values, including aquatic GDEs, in Boundary Creek** and their qualitative flow requirements. Further work is required to quantify the flow requirements and to understand the role of the supplementary flow in maintaining the current ecological values. This work should also consider alternative scenarios for the supplementary flow that would deliver greater benefits.

A substantial amount of work has been done as part of the Technical Works Monitoring Program to improve the understanding of **groundwater use by vegetation (terrestrial GDEs)** across the area. A baseline network has been established, comprising 14 vegetation monitoring sites. The sites have been surveyed twice and although the health of vegetation declined between the surveys, this is consistent with the climate conditions at the time.

Groundwater dependent vegetation has been identified at the majority of monitoring sites, however there have been no vegetation health issues identified that would influence the licence renewal.

A PASS baseline monitoring network has also been established as part of the Technical Works Monitoring Program. The four highest priority PASS sites are being monitoring regularly which provides a sound baseline to assess potential changes. Outside of Yeodene (Big) Swamp, no ASS issues have been identified in the area that would influence the licence renewal. Further work is recommended to select an additional PASS monitoring site in the Gellibrand River catchment on Porcupine Creek and undertake groundwater and surface water monitoring

Land subsidence has been monitored as part of the existing licence conditions. Subsidence is within the guidelines and no issues relating to land subsidence have been identified that would influence the licence renewal. Further work is recommended to understand if the subsidence monitoring could be decreased for the new licence.

4. Hydrogeological conceptual model

4.1 Stratigraphy

4.1.1 Key Formations

The stratigraphy of the Barwon Downs Graben includes a series of sedimentary units overlying Basement. These units have been deposited in a series of transgressive and regressive cycles and include the Pebble Point Formation, Pember Mudstone, Dilwyn Formation, Mepunga Formation, Narrawaturk Marl, Clifton Formation, Gellibrand Marl and Quaternary Alluvium. A representative cross section of the Barwon Downs Graben is illustrated in Figure 4-2. This shows a progressive thickening of the sedimentary units from the Barongarook High in the west into the centre of the Graben, before being truncated by the Bambra Fault in the east.

A brief description of these nine layers including the basement is provided in Table 4-1. Due to the relatively very small spatial extent of the Quaternary Alluvium, this unit has been excluded from the numerical model.

Figure 4-1 shows the surficial hydrogeology of the key formations listed above. The stratigraphy of the graben is often hydrogeologically simplified into the following units:

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

The grouping of the formations into the four simplified units is provided in Table 4-1.

Figure 4-1 : Location of the Barwon Downs Graben

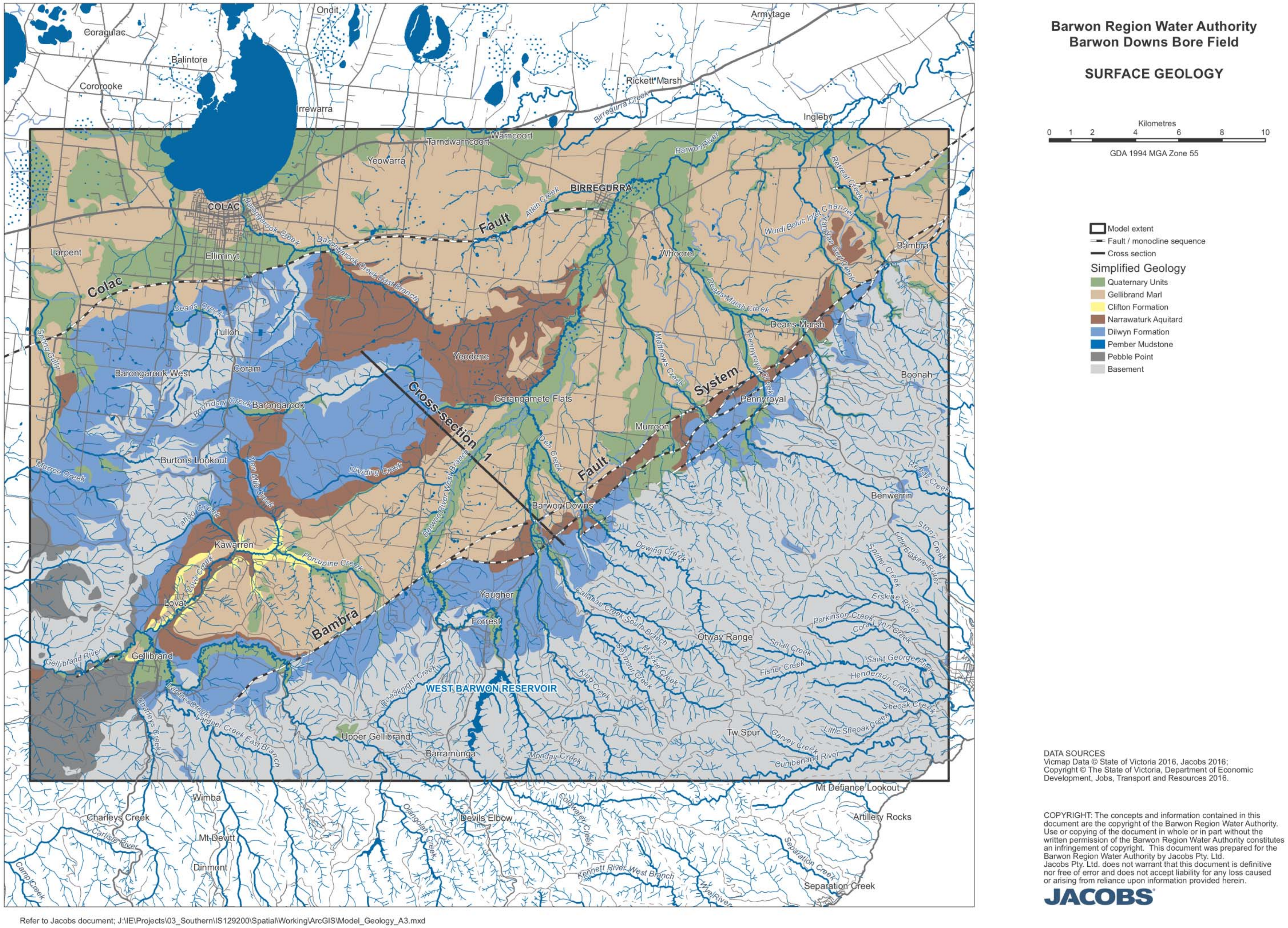


Figure 4-2 Representative cross section of the Barwon Downs Graben (refer Figure 4-1 for section location)

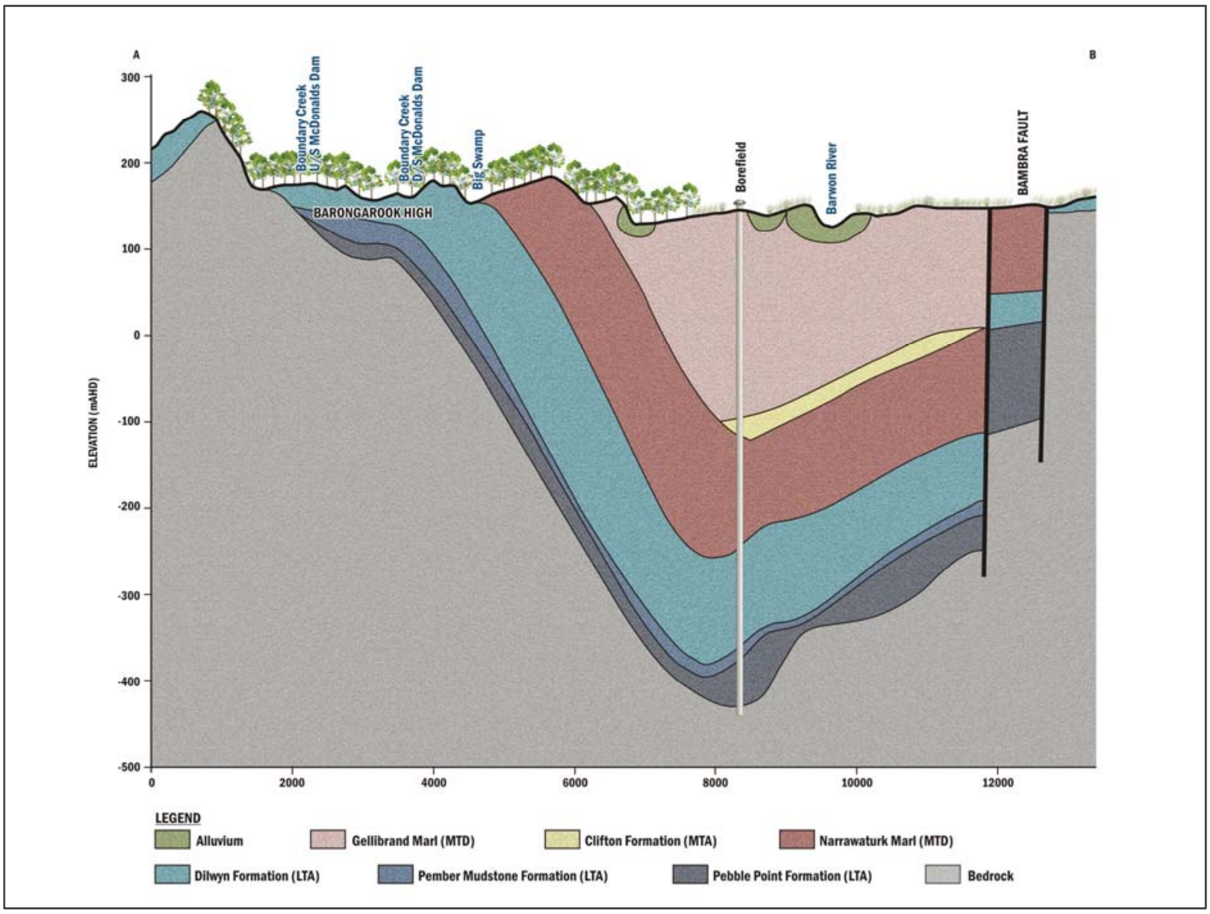


Table 4-1 Stratigraphy of the Barwon Downs Graben and relationship to model layers in the groundwater model

System	Geological Unit	Description	Type	Model layer
Minor surficial sediments	Quaternary Alluvium	Sands, silts and gravels.	**Aquifer (minor)**	incorporated into layer 1
Mid Tertiary Aquitard (MTD)	Gellibrand Marl	Calcareous silty clay and clayey silt. Fossiliferous.	**Aquitard**	1
	Clifton Formation	Calcarenite with marine fossils and minor quartz and limonite sands	**Aquifer (minor)**	2
	Narrawaturk Marl	Calcareous mudstone with thin carbonaceous beds, sand beds and fossiliferous beds	**Aquitard**	3
Lower Tertiary Aquifer (LTA)	Mepunga Formation	Medium to coarse grained quartz sand with some carbonaceous clays and silt layers	**Aquifer**	4
	Dilwyn Formation	Carbonaceous, sandy clays and silts, with some quartz sand and silty sand beds, and minor gravel. Coal and carbonaceous clays also occur in this unit.	**Aquifer**	
	Pember Mudstone	Clays, silts and fine grained sand with carbonaceous, micaceous and pyritic horizons.	**Aquitard (minor)**	5
	Pebble Point Formation	Fine-grained sand with carbonaceous silt and quartz pebble beds. This unit is an equivalent to the Moomowroong Sand Member, Wiridjil Gravels that occur in the Gellibrand sub-basin to the south west of the study area.	**Aquifer (minor)**	6
Bedrock (BSE)		Sandstone, siltstone and mudstone with feldspar and quartz grains, well-bedded and consolidated.	Aquitard	7

4.1.2 Key findings from the review of stratigraphy

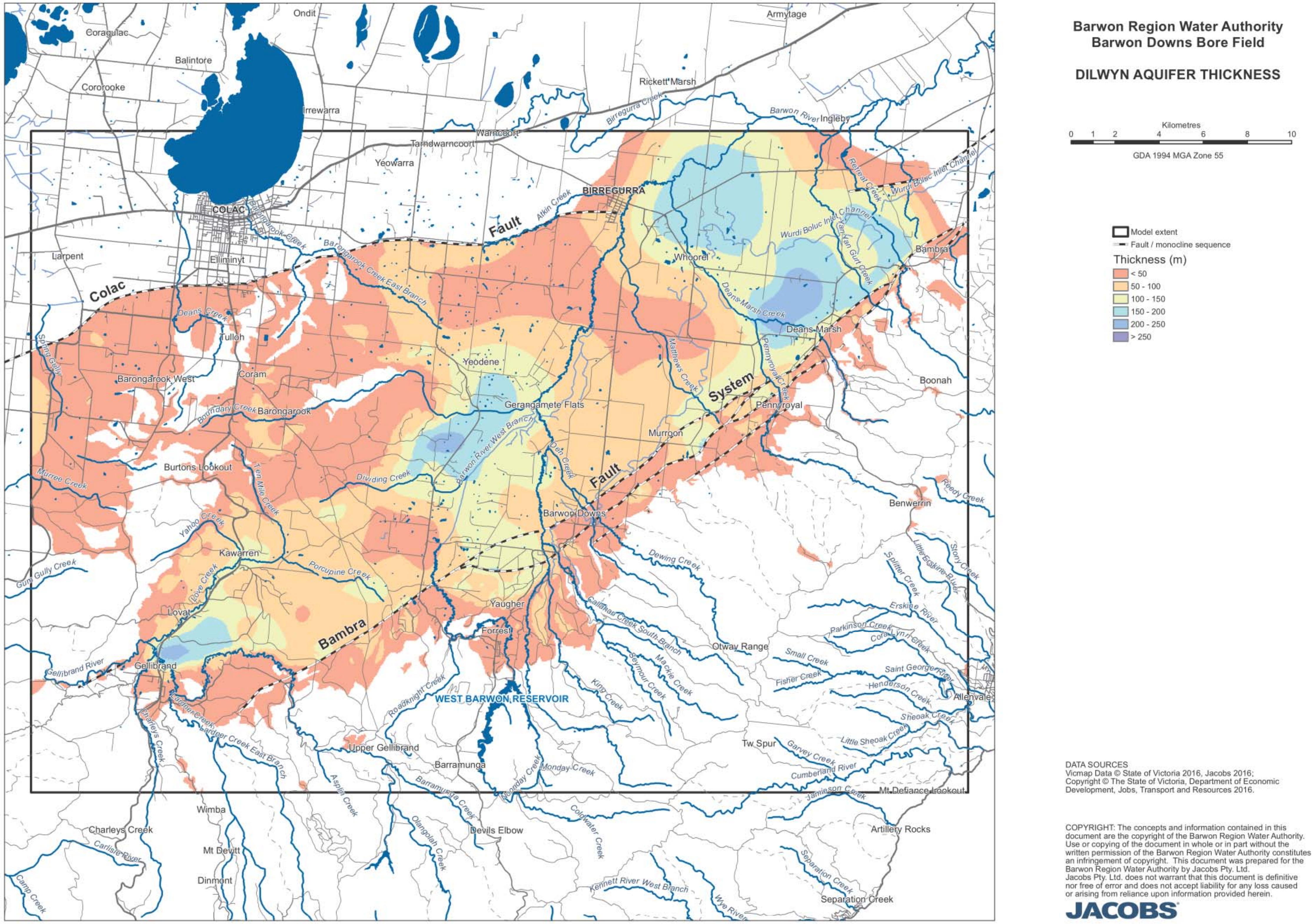
Previous versions of the numerical model (SKM, 2001 and 2011) included five layers. In these previous versions, the Bedrock and the Pember Mudstone were not included. The confining nature of the Pember Mudstone was represented as a low vertical hydraulic conductivity assigned to the Dilwyn and the Pebble Point Formations.

In 2016, Jacobs reviewed the structure and thicknesses of each formation to update the numerical model. The key findings from the review include:

- Low permeability zones in the shallow aquifer at the Barongarook High are stratigraphically consistent with the Pember Mudstone in the deeper parts of the graben.
- Steep dipping beds are present at the interface between the graben and the Barongarook High (refer Figure 4-2). Review of existing and new bore logs support the presence of continuous, steep dipping beds and not fault driven discontinuous beds. This was supported by the occurrence of basement at greater depths in some stratigraphic logs closer to the centre of the graben.
- Revisions to the extent and thickness of the LTA include:
  - Reduced extent/thickness of the LTA north of the Colac Fault.
  - Increased thickness of the Pebble Point Formation in the southwest of the graben
  - Removal of the Dilwyn Formation around Tulloh and Burtons Lookout.
- Minor revisions to the MTD including a general increase in the thickness of the Narrawaturk Marl and an increase in the extent of the Gellibrand Marl in the southwest of the model.

These findings were used to help refine the stratigraphic conceptualisation of the graben, principally resulting in revisions to unit thicknesses/extents and the recognition of the Pember Mudstone as a continuous layer. These changes were then reflected in the model structure.

Figure 4-3 Extent and thickness of the Dilwyn Formation (LTA)



Refer to Jacobs document; J:\IE\Projects\03_Southern\IS129200\Spatial\Working\ArcGIS\A11100_Dilwyn_Aquifer_A3.mxd

4.2 Faults

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

Faults are generally found on the steeply dipping sides of the graben. The Colac Fault was previously used to define the northern groundwater model boundary (SKM, 2001 and SKM, 2011). Recent work indicates that there is a continuation of stratigraphic units across the fault, suggesting that it may not necessarily act as a groundwater flow boundary (Jacobs, 2015a). However, a further assessment of drawdown responses found that there was limited connectivity across the Colac Fault (Jacobs, 2015b). This indicates that the fault acts as a boundary that significantly reduces the migration of groundwater responses to the north of the fault.

The Bambra Fault, or Bambra Fault zone, is characterised by a number of sub-parallel faults that have resulted in the upward displacement of stratigraphy to the southeast of the fault. In a recent review of borefield related groundwater responses in the Lower Tertiary Aquifer, Jacobs (2015b) found that the Bambra Fault was best represented by a 95% reduction in aquifer transmissivity to the southeast of the fault. The apparent loss of transmissivity to the southeast of the fault is due to the combined effects of aquifer thinning and displacement related disruption to aquifer continuity. The section of the Bambra Fault located further to the southwest is likely to have an even lower apparent transmissivity and could potentially be represented as a no-flow boundary in a numerical model.

4.3 Groundwater recharge and discharge

Figure 4-2 shows that the LTA, consisting of the Pebble Point, Dilwyn and Mepunga Formations, is the major aquifer in the region. The aquifer has various recharge and discharge processes. Recharge processes include rainfall infiltration, downward leakage from overlying formations and leakage from some rivers where the aquifer outcrops at the surface. Discharge processes include evapotranspiration from vegetation, aquifer throughflow to the north and south of the graben, upward leakage to the overlying formation and discharge to some rivers.

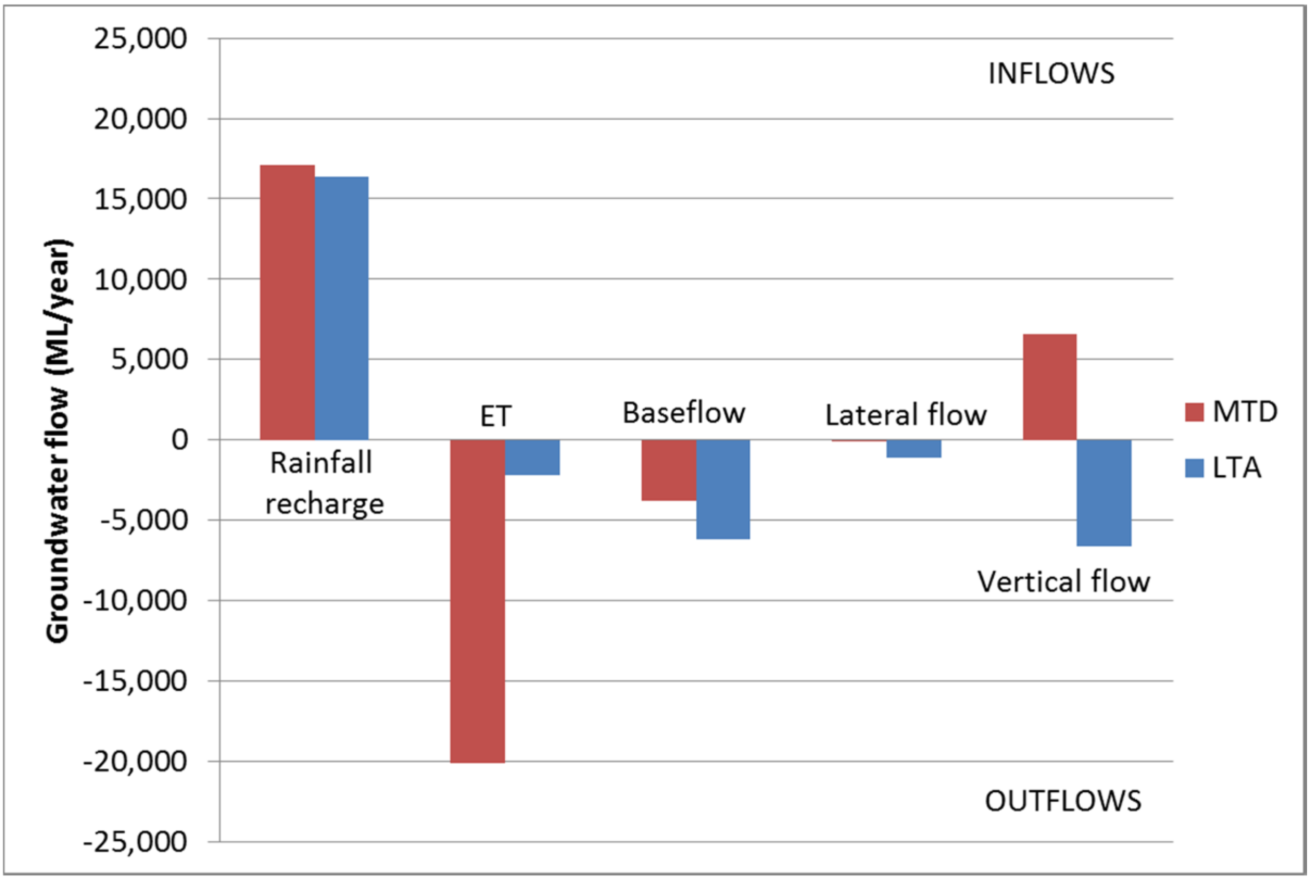
When an aquifer is in equilibrium, recharge to the aquifer will be similar to the discharge from the aquifer and groundwater level fluctuations will be stable. If there is more recharge than discharge, for example during periods of above average rainfall, the storage in the aquifer will increase and groundwater levels will rise. If there is more discharge from an aquifer, such as pumping or higher evapotranspiration, water is removed from storage and groundwater levels will decline. All groundwater systems respond constantly to variable climate conditions so fluctuations in groundwater levels are normal.

The recharge and discharge processes for the LTA are described in more detail in the following sections. Given the relationship between the aquifer and rivers in the catchment is variable (between recharge and discharge processes), this is discussed as a separate section.

The conceptual water balance presented in Jacobs (2016h) is shown in Figure 4-4. This shows that the primary recharge mechanism (inflow) for the LTA is recharge from rainfall. Groundwater discharges from the aquifer via vertical flow to the overlying MTD, baseflow to rivers and smaller amounts to ET and lateral groundwater flow. The MTD is recharged from rainfall and from the underlying LTA and discharge mechanisms are primarily ET and baseflow to rivers with a very small amount of lateral groundwater flow.

These processes are discussed in more detail below.

Figure 4-4 Conceptual water balance of the Barwon Downs groundwater model domain



4.3.1 Recharge from rainfall

The key recharge process for the LTA is recharge from rainfall. Recharge from rivers is discussed in Section 4.5.

Recharge to groundwater occurs through rainfall infiltration to the shallowest aquifer across the entire study area. It is expected that the most significant recharge will occur at those locations where surface sediments are coarse grained and/or more permeable. In the catchment area this generally corresponds with the major aquifer units outcrop (as shown in Figure 4-1). Less recharge is expected across the remainder of the model domain where the low permeability Gellibrand Marl outcrops at the surface.

Previous studies have provided some estimate of groundwater recharge to the LTA; however these often incorporate little or no field data and provide a broad range of recharge estimates. Blake (1974) estimated recharge using a recharge rate of 5% of rainfall, but it is unclear what the percentage was based on. It is expected that a generalised “rule of thumb” was used. Lakey and Leonard (1984) used flow net and baseflow analysis to estimate a recharge rate of 14% of rainfall for the Barongarook High. More recent work conducted by Atkinson *et al.* (2014) focussed on using groundwater hydrographs to estimate recharge to the LTA in the Gellibrand River catchment. These recharge estimates were between 11% and 32% of rainfall, however as the study focussed on recharge processes around the rivers, these estimates are not considered to be representative of the recharge in the aquifer outcrop area, which is the focus for this work.

Numerical modelling of the Barwon Downs Graben by SKM (2001) was undertaken and calibration was achieved incorporating a recharge rate of 20% of rainfall to the LTA at the Barongarook High, 8% for the LTA south of the Bambra Fault and 3% for the other sediments (mainly Gellibrand Marl). Subsequent modelling by SKM (2011) included further spatial subdivision of these areas into five different zones of recharge, representing 0.2%, 3.0%, 5.2%, 23.5% and 28.3% of rainfall.

The recharge rates for the outcropping aquifer areas and in areas where the Gellibrand Marl is found at the ground surface have been estimated by Jacobs (2016) using both analytical studies and modelling including:

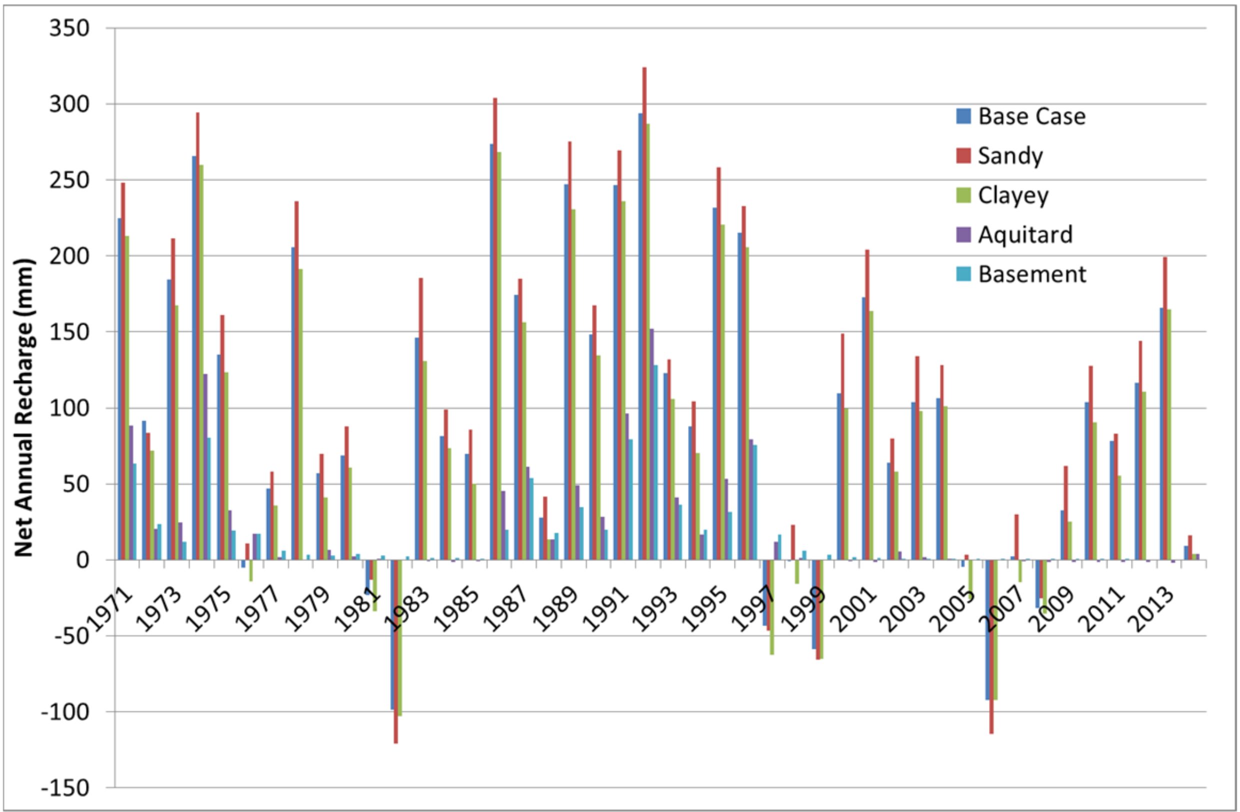
- Isotope analysis,
- Chloride mass balance, and
- 1-D unsaturated zone modelling.

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

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

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

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



4.3.2 Discharge Processes

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

Evapotranspiration

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

Aquifer throughflow

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

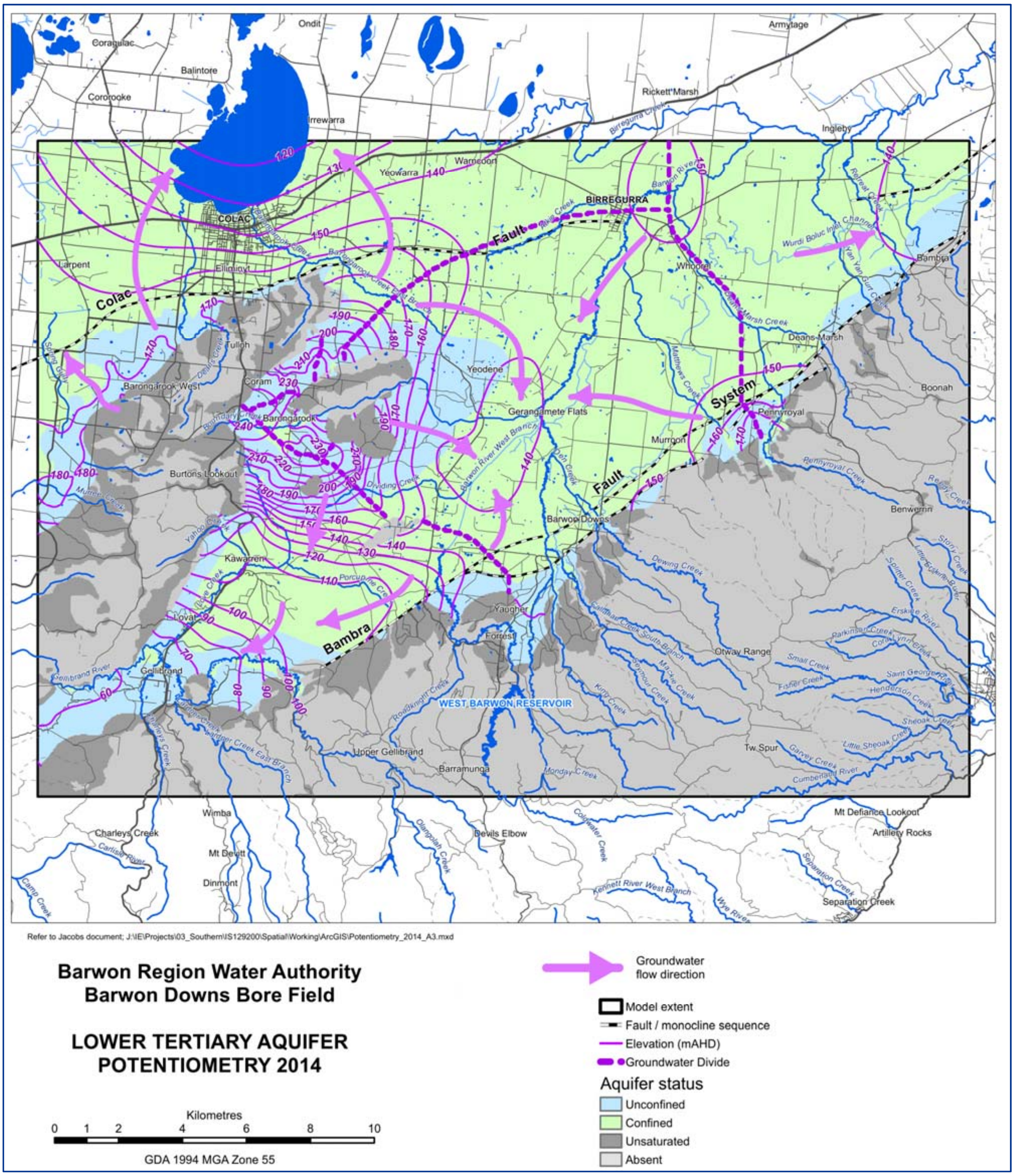
Since borefield operation began in 1982, groundwater levels in the Lower Tertiary Aquifer (LTA) system have changed over time. The changes are principally a result of drawdown centred in the borefield as a result of groundwater extraction, but also represent climatic impacts over time (i.e. periods of reduced rainfall recharge). The current (2014) groundwater levels/flow directions in the LTA are shown in Figure 4-5 while those at 2012 and 1987 are illustrated in Appendix A.

The highest groundwater levels in the LTA were observed on the Barongarook High where the Basement and the LTA outcrop. Groundwater flow from the high was predominantly east towards the Gerangamete Flats and to the south towards Gellibrand. These major flow paths are separated by an east-west trending groundwater divide. Groundwater flow to the north was also apparent, facilitated in part by the basement ridge through the Barongarook High which acts as a geological divide from the rest of the Barwon Downs Graben. Groundwater flow from the Gerangamete Flats occurred in a north-east direction towards Deans Marsh (Appendix D).

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

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

Figure 4-5 Groundwater flow direction in the LTA in 2014



Vertical flow processes

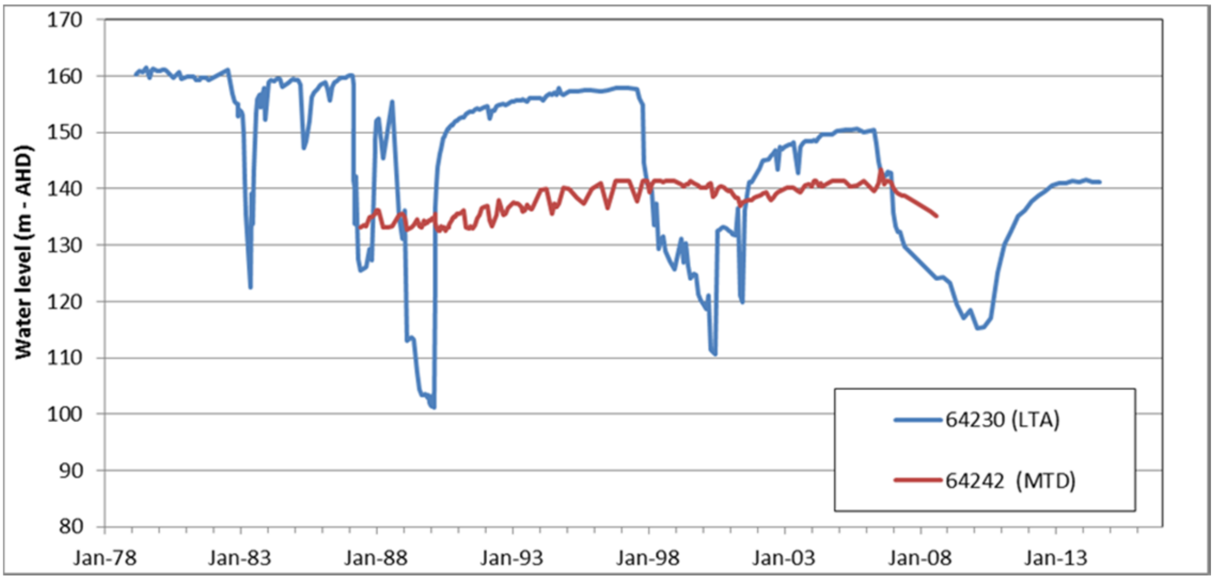
Previous assessments of hydraulic gradients between aquifers and aquitards in the Barwon Downs Graben have been limited. It is generally understood that upward hydraulic gradients exist between the Dilwyn and Pebble Point aquifers and the overlying Narrawaturk Marl aquitard through the central portion of the graben. This facilitates upward leakage from the aquifers into the overlying aquitard and is a key discharge process for the aquifer.

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

As part of recent investigations between 2014 and 2016, bores were constructed in the Gellibrand Marl above the LTA (Jacobs, 2016). Groundwater monitoring in these bores indicates upward hydraulic gradients from the LTA to the Gellibrand Marl, consistent with those observed by Witebsky (1995) Shallow monitoring bores located throughout the Barongarook High as part of the same program identified perched, shallow groundwater systems in a number of areas around the north east side of the Barongarook High.

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

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



4.4 Aquifer Drawdown

Groundwater levels fluctuate in response to climate conditions and groundwater extraction. When the borefield is operational the drawdown cone spreads in the shape of a symmetrical elongated ellipse along the axis of the graben from northeast to southwest. The cone of depression is generally steep which reflects the low regional transmissivity of the aquifer (Witebsky, 1995).

Figure 4-7 shows two hydrographs for the LTA in the centre of the study area near Seven Bridges Road (see Figure 3-1). In the deeper LTA where the groundwater is extracted there is a strong response to pumping whereas shallower bores in the LTA show a subdued response to pumping.

Figure 4-8 shows hydrographs from the MTD and the alluvial aquifer. The alluvial aquifer shows strong seasonal trends while the aquitard bore does not respond strongly to seasonal effects. The alluvial aquifers are typically more permeable and the watertable is shallower which means responses to rainfall recharge and evapo-transpiration are rapid. The MTD is significantly less permeable which means recharge via rainfall is takes longer.

As shown in Figure 4-9, drawdown in the Lower Tertiary Aquifer (LTA) from the Barwon Downs borefield has propagated in an elongated drawdown cone that extends north east and south west within the Graben. An investigation by Jacobs (2016f) confirmed that drawdown extends to Kawarren area. However there are others bores located closer to the borefield (between the borefield and the Kawarren area) that have reported negligible drawdown. The absence of drawdown is likely to be related to zones of reduced hydraulic conductivity in localised areas and the development of this conceptual understanding was incorporated into the numerical model.

Drawdown in the LTA is less than predicted throughout areas of the Barongarook High, including Yeodene (Big) Swamp and a number of drainage lines to the east of the high. This is consistent with stratigraphic variability in the LTA as suggested by SKM (2008) and represents an improved conceptual understanding of the system for incorporation into the numerical model. A number of shallow bores throughout these areas has also helped to identify the presence of minor perched aquifer systems at the high.

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

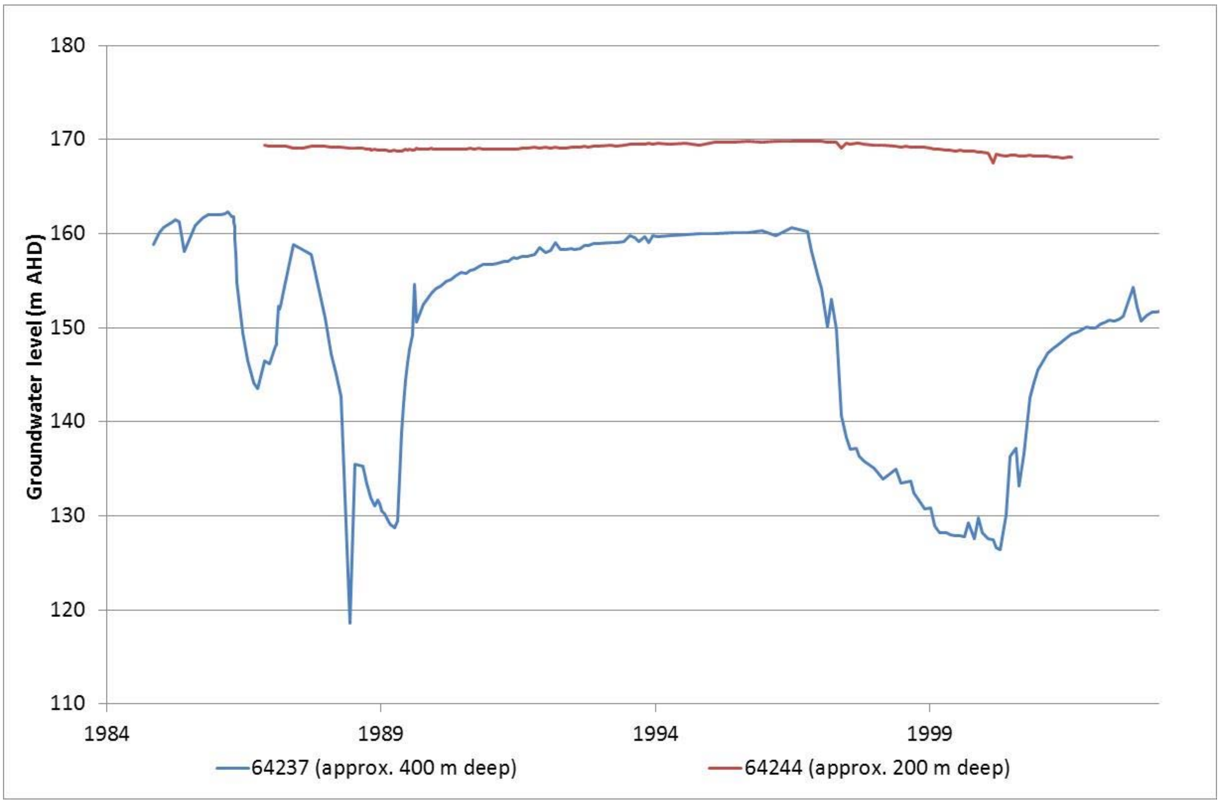


Figure 4-8 Examples of groundwater level trends in the Alluvial aquifer and the MTD (Aquitard)

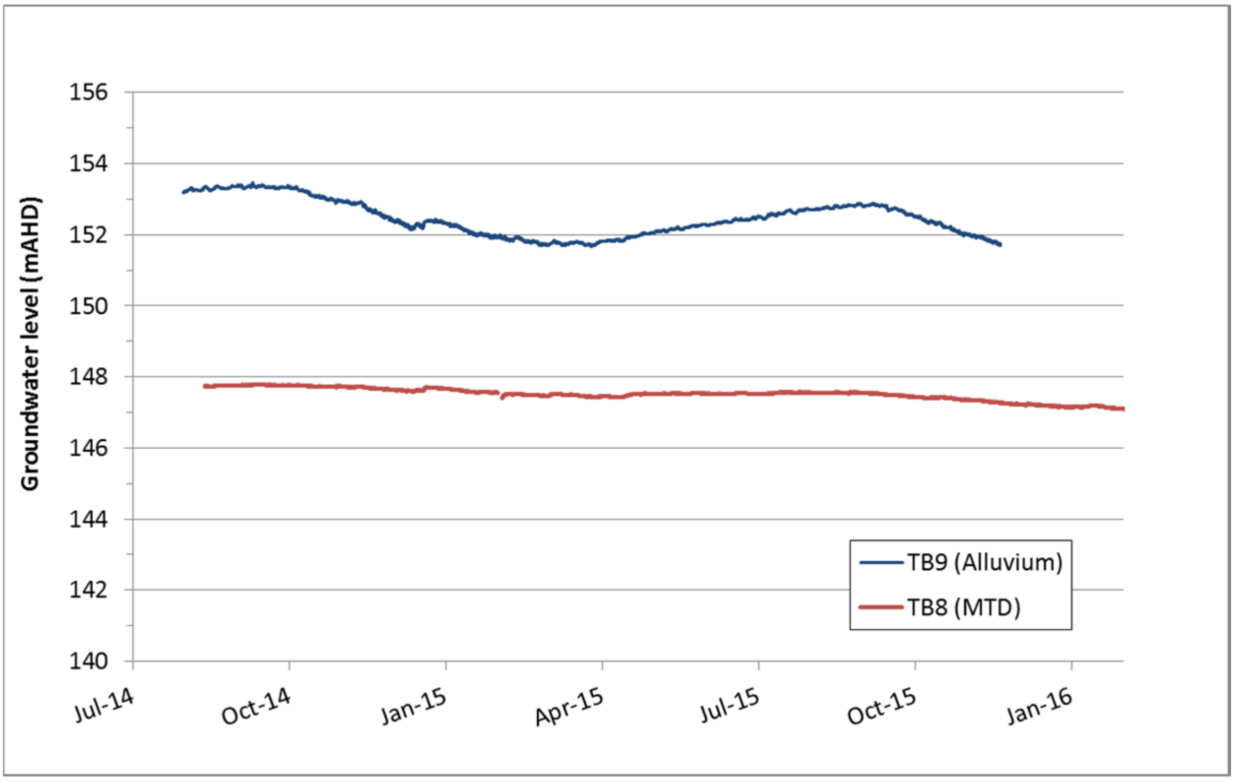
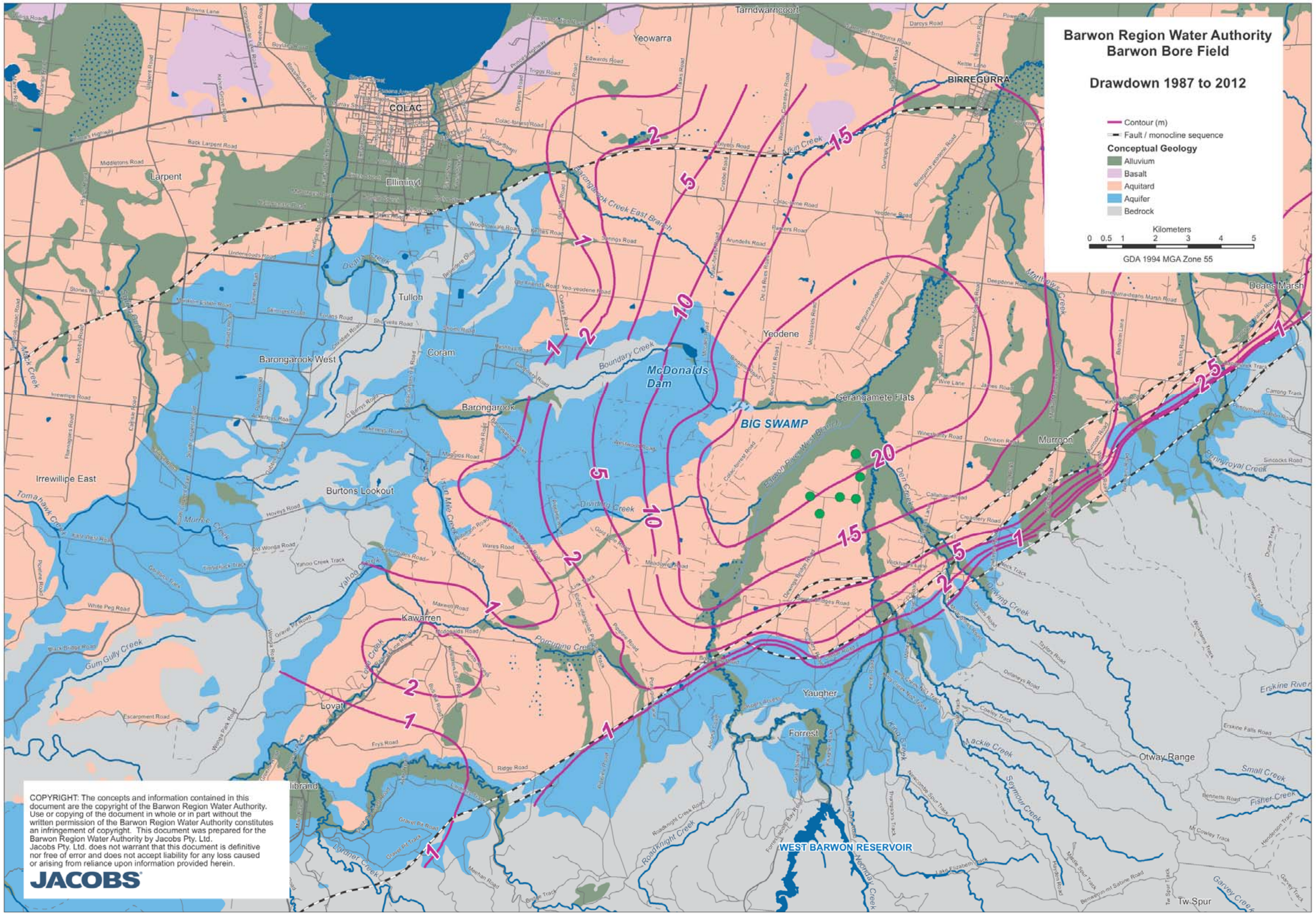


Figure 4-9 Drawdown in the LTA (1987-2012) (Jacobs, 2015b)



Refer to Jacobs document; I:\VWES\Projects\VW07575\Technical\Spatial\Working\ArcGIS\D_down_geology_2012_A3.mxd

4.5 Groundwater surface water interaction

The major river systems in the study area are the Barwon River and the Gellibrand River. The groundwater-surface water interaction between the LTA and the rivers is spatially and temporarily variable.

An overview of the conceptual understanding of the groundwater surface water interactions in each catchment is provided below.

4.5.1 Gellibrand River Catchment

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

Porcupine Creek flows over outcropping MTA and Clifton Formation which is a minor aquifer. There are several springs that provide base flow to headwaters of the creek. The creek is therefore gaining in the upper reaches and then becomes losing as it approaches the confluence of Ten Mile Creek (SKM, 2012).

SKM (2012) confirmed that there are several springs along Ten Mile Creek, Yahoo Creek and Love Creek. These springs flow from the MTD, which is supported by an upward gradient from the underlying LTA (SKM, 2012). Importantly these springs are not interpreted to be the result of flow out of the LTA, rather the underlying high LTA pressures preclude deep drainage and support the formation of springs. These springs provide baseflow to Ten Mile Creek and Yahoo Creek.

4.5.2 Barwon River Catchment

4.5.2.1 Overview of groundwater surface water interactions across catchment

The majority of tributaries of the **Barwon River** rise in the Otway Ranges to the south. These tributaries flow over the Basement and then the LTA in the vicinity of the Bambra Fault zone. The LTA is likely to provide base flow to these tributaries east of the Bambra fault zone, however no field studies have been undertaken to confirm this. The significance of the groundwater surface water interaction on the south east side of the fault zone is considered to be low as work done to date indicates a low degree of connection across the fault zone.

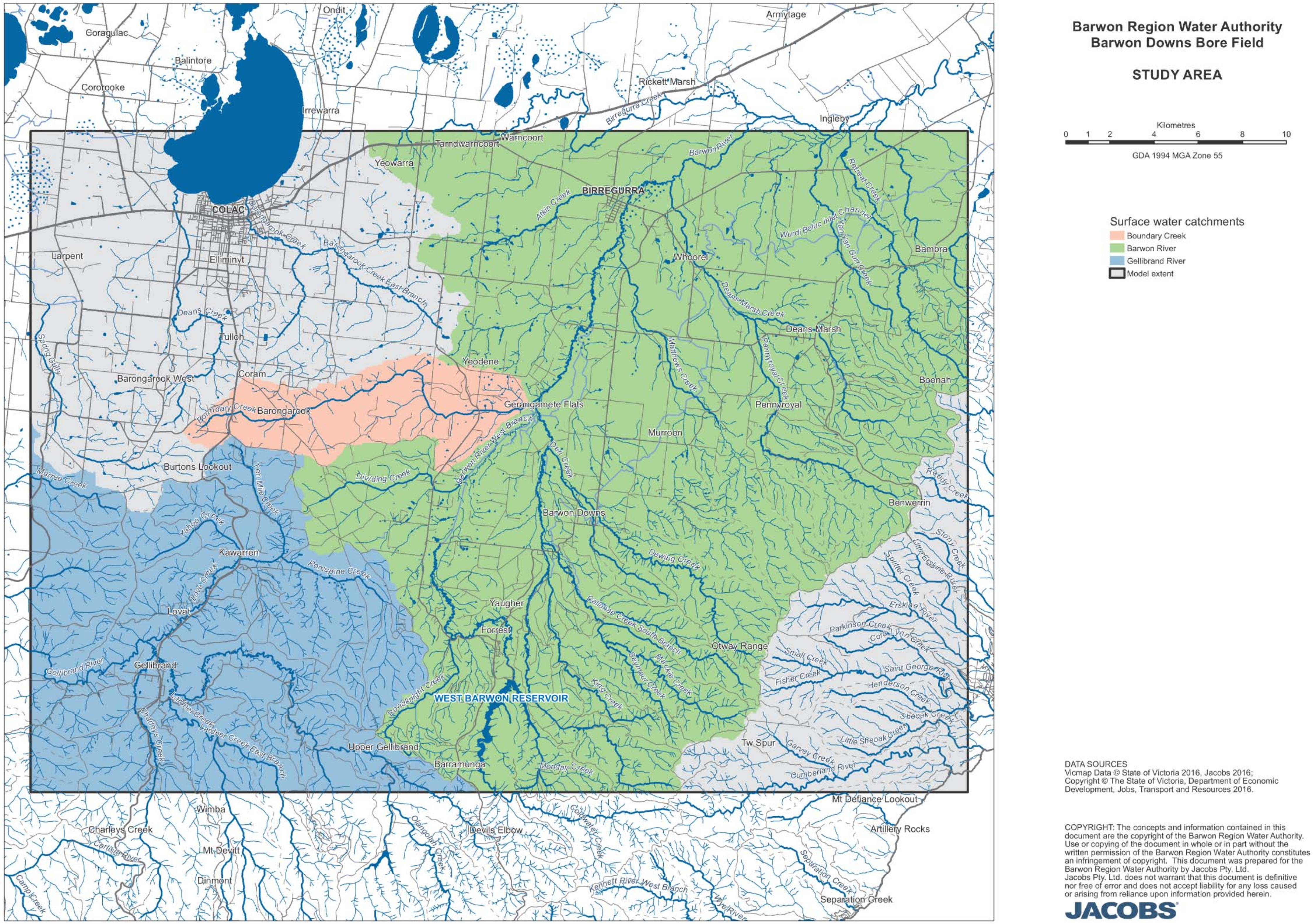
Two tributaries of the Barwon River rise on the Barongarook High – Dividing Creek and Boundary Creek. Some reaches along both creeks flow over the LTA and these areas have the most potential for groundwater surface water interactions.

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

There are no stream flow gauges on **Dividing Creek,** because the creek does not flow all year round**.** Based on available information, the creek drains rainfall runoff and groundwater from the LTA does not provide a baseflow to creek. The creek is thought to recharge the LTA in the upper reaches.

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

Figure 4-10 : Location of surface water catchments in the Barwon Down region



Refer to Jacobs document; J:\IE\Projects\03_Southern\IS129200\Spatial\Working\ArcGIS\Study_Area_A3.mxd

4.5.2.2 Boundary Creek

Local hydrogeology and groundwater surface water interactions

A long section along Boundary Creek is showed in Figure 4-11 and the surficial hydrogeology is shown in Figure 4-12. These figures which shows where the LTA, MTD, bedrock and alluvial sediments outcrop at the surface.

The **LTA** outcrops in the upper part of the catchment (Reach 1) and for a 2 to 3 km section downstream of McDonalds Dam (Reach 2). Due to the relatively high permeability of these sediments, the contribution to baseflow is higher than in other sections of Boundary Creek. Downstream of the dam, Boundary Creek was historically gaining along this reach. During the Millennium drought, groundwater levels declined in this part of the catchment in response to the combined impact of drought and pumping from Barwon Downs borefield. This is discussed in more detail in the following section.

The creek is incised into outcropping **bedrock** for a distance of around 5 km in Reach 1 upstream of McDonalds Dam. A bore transect installed in 2014 confirms that Boundary Creek receives baseflow from the bedrock through this area. The bedrock has lower permeability than the LTA so the relative contribution of baseflow will be lower than for the LTA. Witebsky (1995) and field investigations indicate that indirect discharge from springs at the bedrock-aquifer interface and then overland flow to the creek also contribute to baseflow.

For the final 4 km of Reach 3, Boundary Creek overlies the **MTD**. A shallow bore installed in the aquitard, near Boundary Creek at Colac Forest Rd in 2014, indicates that groundwater levels in the aquitard are approximately at creek level, with a slight gradient towards the creek. The contribution of baseflow (from groundwater) to Boundary Creek will be significantly smaller than from the LTA, due to the lower permeability of the aquitard. This section of the creek has been dry for long periods in recent years, so baseflow contributions are likely to be minimal.

Alluvial material overlies the sediments in a number of places along Boundary Creek. Alluvial material can form important local aquifers, however the extent of alluvium on Boundary Creek is relatively small and the underlying material (LTA, MTD or bedrock) is expected to be the main control on discharge to the creek. The most significant alluvial deposit on Boundary Creek is at Yeodene (Big) Swamp. The role of groundwater in supporting the swamp is not well understood and will be the subject of further investigations in 2017.

Changes in groundwater levels and groundwater surface water interactions over time

The Barwon Downs borefield was used to augment Geelong water supply over three time periods – early 1987 to early 1990; late 1997 to mid 2001 and early 2006 to mid 2010. Over this time, groundwater levels in the LTA declined in response below average rainfall conditions and extraction from Barwon Downs. The impacts on groundwater levels are compounded as Barwon Downs is only utilised when there has been insufficient rainfall and subsequent runoff into the storages, which also means less recharge for the aquifer. The drawdown in the LTA aquifer between 1987 and 2012 is shown in Figure 4-9.

Upstream of the bedrock outcrop (upstream of Bushby's Lane), Figure 4-9 shows that drawdown does not extend to this part of the catchment and groundwater levels have not changed as a result of groundwater extraction from Barwon Downs. Around the bedrock outcrop area, drawdown in the LTA ranges between 10 m in the eastern part of the area to less than 1 m at the western end. Any decline in water levels in the bedrock aquifer is not known as there are no long term monitoring bores in the location. Two bores were installed recently in 2014 to fill this data gap (UBCk1 and UBCk2) and the groundwater levels in these bores are higher than the creek level which indicates that the creek is gaining at this location. The impact of changes in LTA water levels on springs at bedrock – LTA interface and subsequent overland flow to Boundary Creek is not well understood.

The groundwater levels in the **LTA downstream of McDonalds Dam** are monitored by Bore 109130. This bore is located about 50 metres from the creek and the hydrograph for this bore is shown in Figure 4-13. Bore 109130 is a shallow bore (17.5 m deep) monitoring the unconfined (outcrop) LTA. This shows that groundwater levels in the LTA have declined in response to pumping from Barwon Downs and below average rainfall conditions.

Figure 4-11 Long section along Boundary Creek

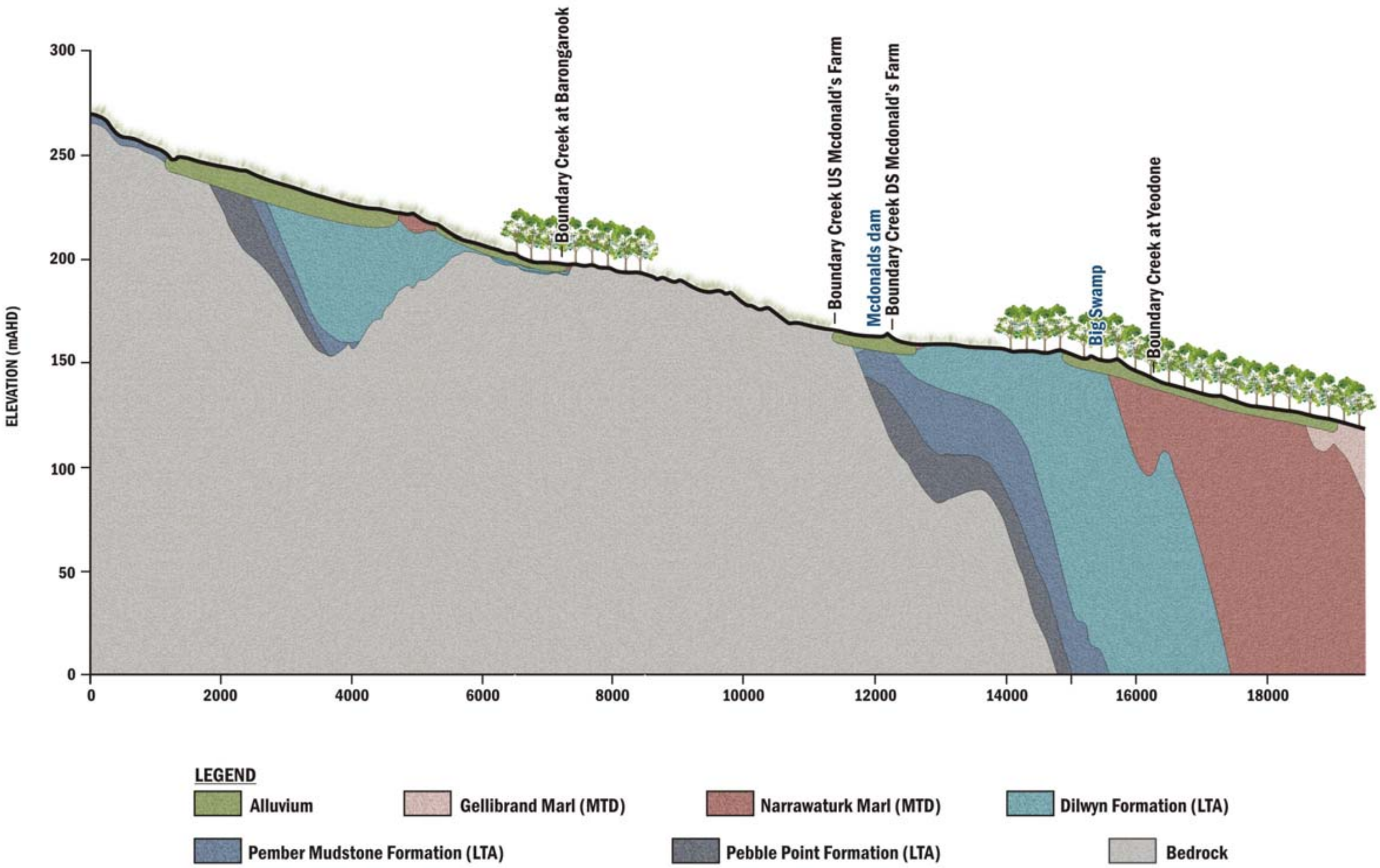
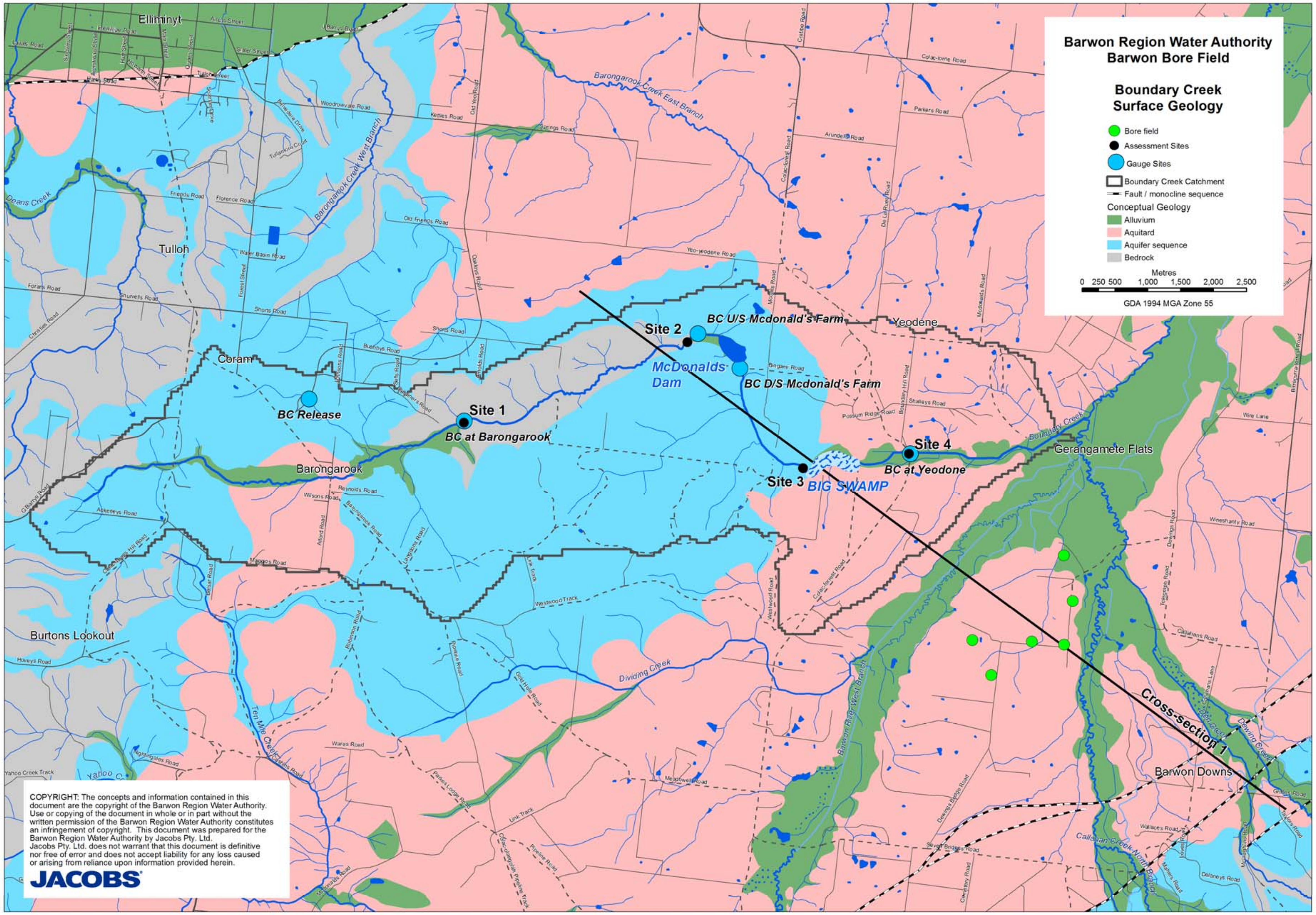


Figure 4-12 Surface hydrogeology in the Boundary Creek area



Refer to Jacobs document; I:\VWES\Projects\VW07575\Technical\Spatial\Working\ArcGIS\Boundary_creek_A3.mxd

•

Figure 4-13 shows the groundwater levels in bore 109130, together with residual rainfall and the periods of groundwater extraction from Barwon Downs borefield. The residual rainfall is from Forest State Forest gauge and shows the trend in rainfall. Periods of above average rainfall are represented as rising trends and periods of below average rainfall are shown as declining trends. If the trend is steady, the rainfall is average. Key observations are outlined below:

- The residual rainfall trend shows above average rainfall conditions between 1983 and 1998.
- Between 1998 and 2010 rainfall was generally been below average, typical of the Millennium Drought, with some wetter periods in the mid 2000s. The borefield was used during this period.
- Average rainfall conditions prevailed until 2015, since then, rainfall has been significantly below average, represented by the sharp decline in the residual rainfall plot.

Groundwater level fluctuations in Bore 109130 appear to be influenced by the combine effect of below average rainfall and groundwater pumping from Barwon Downs borefield. Groundwater levels declined significantly during the late 1980s in response to pumping, in contrast to average rainfall conditions. Groundwater levels recovered when pumping ceased and then declined again, this time more significantly, in response to the combined influence of the Millennium Drought and pumping from Barwon Downs. Groundwater levels again recovered after pumping ceased in 2003 and rainfall conditions returned to average. However the groundwater levels did not reach pre-pumping levels before declining again in response to less rainfall and pumping. In recent times, groundwater levels have risen, as the aquifer recovers.

Groundwater levels in Bore 109130 were above the elevation of the streambed prior to 1998 and since then, groundwater levels have been below the base of the stream. In other words, prior to 1998 Boundary Creek was gaining and it is now losing along this reach. It is important to note that the impact of declining groundwater levels on streamflow has not been quantified. The operation of McDonalds dam also impacts streamflow in this reach.

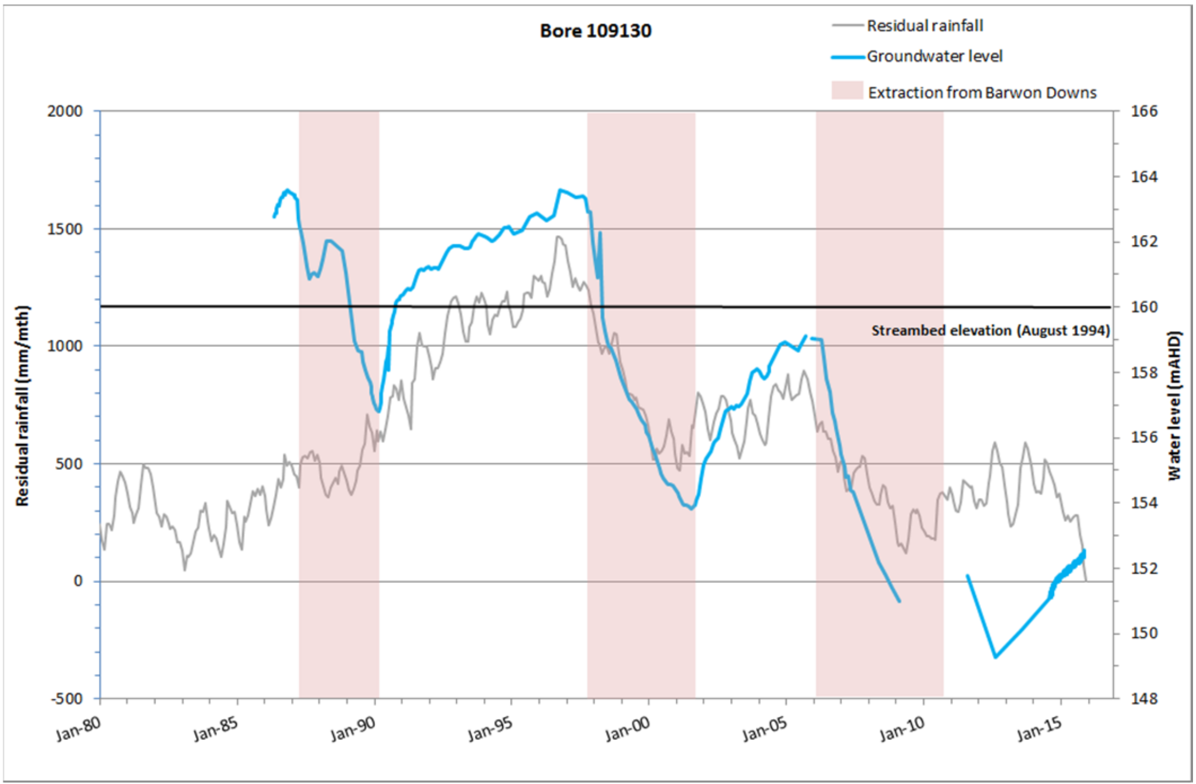


Figure 4-13 Hydrograph of Bore 109130

Two monitoring bores were re-instated (109140 and 109143) **between McDonalds Dam and Yeodene (Big) Swamp** that had not been monitored since the late 1980s. TB2b was installed approximately 500 m upstream of the swamp and the groundwater levels have declined in that bore and the bore is currently dry.

There are two distinct areas between McDonalds Dam and Yeodene (Big) Swamp. The upper (approximate) third of this reach downstream of the dam is comprised of a well defined channel in open farmland, and there is very limited alluvium. Further downstream the creek flows through the 'damplands', which are a series of small braided channels. The damplands are supported by a localised perched aquifer in the alluvial sediments that is fed by rainfall and surface water flows. The groundwater in the LTA at this location is more than 3 m below the surface in the valley floor, which suggests that the LTA doesn't not contribute baseflow to this creek at this location under current conditions.

At **Yeodene (Big) Swamp** three groundwater monitoring bores at the one location (targeting different depths) were installed in 2014/15 (Jacobs, 2016b). The bores monitor three different hydrogeological units beneath Yeodene (Big) Swamp – the shallow alluvial aquifer (TB1a), the underlying aquitard (TB1b) and the LTA (TB1c). The groundwater level in these bores since 2014 is shown in Figure 4-14. The hydrograph shows how groundwater levels in each unit change over time in response to rainfall recharge, climate conditions and other influences like groundwater extraction.

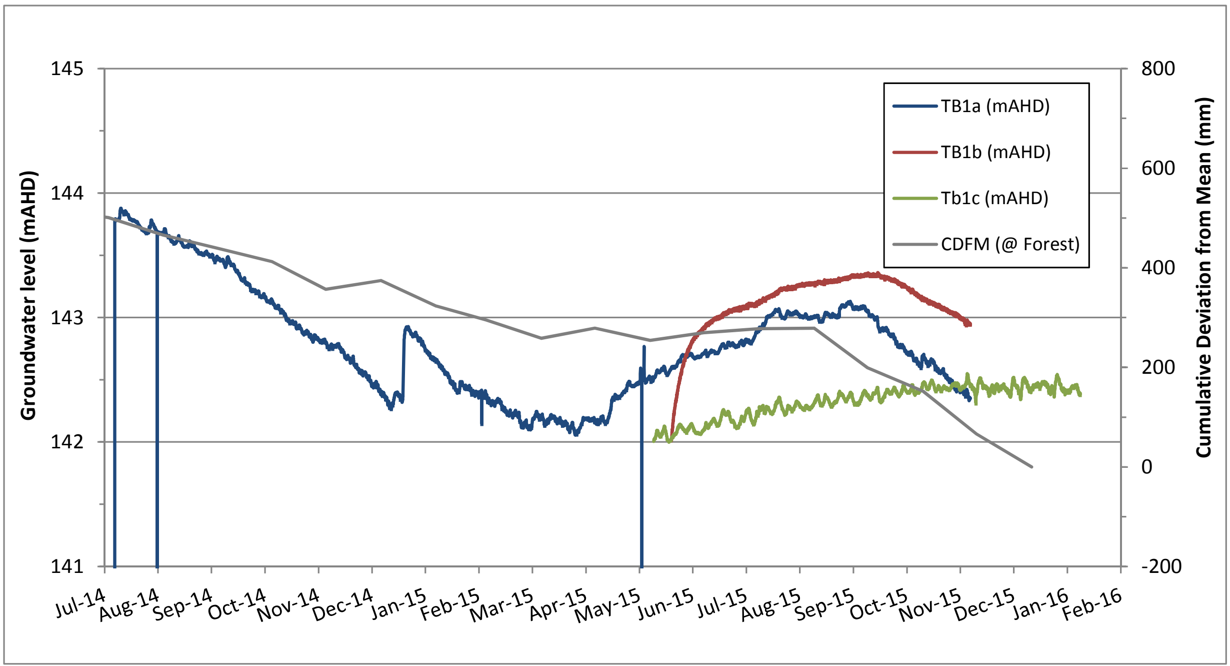
Since 2014, groundwater levels in the shallow alluvial aquifer (TB1a) have declined slightly in response to below average rainfall conditions. The rainfall at the Forest rainfall gauge is also shown on the hydrograph and the declining trend in the cumulative departure from the mean demonstrates that rainfall has been below average over this time period. Groundwater levels in the aquitard took some time to recover after the bore was constructed (until August 2015), and the water level in this unit also appears to decline in response to below average rainfall conditions (from September 2015).

Groundwater levels in the LTA show a rising trend in response to the aquifer recovering from groundwater extraction from Barwon Downs which ceased in 2010. Figure 4-14 shows that the drawdown in the LTA was around 20 m in this area of the aquifer and while groundwater levels have recovered since 2010, the water level remains lower than pre-pumping levels. It is most likely that there was historically an upward gradient from the LTA through the aquitard to the alluvial aquifer at Yeodene (Big) Swamp. An upward gradient still exists from the aquitard to the alluvial aquifer, which demonstrates that these units have been buffered somewhat from the drawdown measured in the LTA. Available information suggests that Yeodene (Big) Swamp is a groundwater discharge site.

The groundwater level in the alluvial aquifer at this location is above the base of the creek, indicating the creek is gaining along this reach. The lithological logs for Bores TB1a and TB2c indicate that there is a perched aquifer in the alluvial deposits which is hydraulically buffered from the underlying regional LTA aquifer.

There has been no historical groundwater level monitoring in the **aquitard downstream of Yeodene (Big) Swamp**. A recently installed bore at Colac-Forrest Rd indicates groundwater levels are approximately at Creek level, which suggests that there has not been a significant decline in groundwater level in the aquitard through this area.

Figure 4-14 Hydrograph of bores TB1a, TB1b and TB1c



Summary of Boundary Creek

In summary, upstream of the Barongarook gauge (Reach 1), Boundary Creek flows over a mixture of outcropping LTA, alluvial aquifer and outcropping bedrock. Groundwater levels in this part of the catchment have not been influenced significantly by groundwater extraction from the Barwon Downs borefield. This suggests that the nature of groundwater surface water interaction has also not changed significantly over time.

Between the Barongarook gauge and the gauge upstream of McDonalds Dam (Reach 1), Boundary Creek flows over outcropping bedrock. Two bores recently installed in the basement aquifer show that groundwater levels are higher than the stream bed which indicates that the creek is gaining in this part of the catchment.

Downstream of McDonalds Dam (Reach 2) groundwater levels have been heavily influenced by extraction from the borefield with drawdown in the LTA ranging between 15 and 20 metres below pre-pumping groundwater levels. The water levels in bore 109130 suggest that the creek was historically gaining in this location and is now losing. This section includes the Damplands and Yeodene (Big) Swamp. The extent of drawdown in shallow alluvial systems in response to LTA drawdown in this area is variable and is discussed further below.

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

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

5. Implications for the revised numerical model

5.1 Background to the numerical model

Groundwater modelling of the Barwon Downs Graben was initially undertaken by Barwon Water (Barrow *et al.*, 1994). In 2001 SKM carried out an extensive groundwater modelling study, to support Barwon Water's licence application. This resulted in the development and calibration of a large three dimensional groundwater model of the Barwon Downs Graben (SKM, 2001). The model was calibrated by matching predicted groundwater levels to observed levels in a set of 24 monitoring bores spread throughout the Graben.

The groundwater model was updated in 2006 with the aim of assessing appropriate trigger levels to be used in the groundwater licence conditions and to determine appropriate locations for new production bores. The work included re-calibration of the groundwater model by comparing model estimates to observed groundwater behaviour over the period 1979 to 2006 (SKM, 2007).

The model was again re-calibrated in 2011 during an investigation to help illustrate the potential impacts of future climate change on the groundwater resources of the Graben (SKM, 2011).

In 2016, the model was expanded, re-built and re-calibrated to support the upcoming renewal of the groundwater extraction licence for the borefield due in 2019. The update of the model includes new features and conceptual understanding that has arisen from related work undertaken as part of the overall work program. The revised modelling has a much broader focus than previous work that had concentrated primarily on undertaking a resource assessment to determine the availability of groundwater.

5.2 Objective of the numerical model

The overall objective of the revised model was to create a new and updated model that builds on earlier model versions that can be used with confidence to assess future impacts associated with groundwater extraction from the Barwon Downs borefield (Jacobs, 2016f).

The hydrogeological conceptualisation of the model has been updated through work completed as part of the Technical Works Monitoring Program. As described in Jacobs (2016f) significant advances in the conceptualisation have been achieved through the following:

- Re-evaluation of borelogs to develop a revised geological model
- Additional groundwater monitoring bores
- Field based estimates of hydraulic parameters, and
- Groundwater recharge estimates (based on multiple lines of evidence including isotope analysis, chloride mass balance and one dimensional unsaturated zone modelling).

5.3 Key Findings

5.3.1 Updates to the model structure and inputs

The model builds on earlier models developed by SKM (2001 and 2011) with significant extension to the west of the previous model boundary to incorporate groundwater discharge features in the Kawarren and Gellibrand area. It also includes two additional model layers. The Pember Mudstone is an aquitard present between the Dilwyn and Pebble Point Formations and the upper part of the basement rocks is considered to be a minor aquifer and is also included in the model.

The development of the geological model improved the conceptual understanding of the structure of several layers. The interface between the graben and the Barongarook High were also confirmed to be steeply dipping continuous beds, rather discontinuous layers with faults. Around the Barongarook High, there are areas of low permeability zones in the LTA, which were found to be stratigraphically consistent with the Pember Mudstone in the deeper parts of the graben.

The extent and the thickness of the LTA were also refined in the geological model. The LTA has been reduced in extent and thickness north of the Colac Fault and increased in thickness in the south west of the graben. The Dilwyn Formation was removed around Tulloh. The MTD was also increased in thickness and extended to the southwest of the model.

Aquifer testing on additional groundwater monitoring bores also provided information on aquifer parameters to aid calibration. The hydraulic properties for each formation are described in Jacobs (2016f). Groundwater recharge was also reduced across the model domain, consistent with recharge rates described in Section 4.3.1 and Jacobs (2016f). Recharge rates of 15% of rainfall to the area of the outcropping LTA and 5% of rainfall to the area of outcropping MTD were selected. These rates are consistent with upper estimates from recharge analysis but are lower than previous modelling estimates of up to 20% (SKM, 2001).

5.3.2 Model calibration

The updated model is considered to be well calibrated as a regional model. A brief description of the calibration in different areas within the model is discussed below and more detail is provided in Jacobs (2016e).

5.3.2.1 Central region

Drawdown response propagates most widely through the central region of the model. In this region the LTA is generally deep and confined by the MTD. Calibration hydrographs shown in Figure 5-1 illustrate that the model has a reasonable level of calibration throughout the LTA with a few exceptions that are discussed in Jacobs (2016e). In areas where the model is not well calibrated, the model under predicts groundwater levels and recovery of water levels between pumping periods. In this sense, the model is providing conservative results and would provide conservative (i.e. likely to be larger than observed) estimates of predicted impacts.

The model is reasonably well calibrated in the MTD in the central region, but calibration in the Clifton Formation is not as good as the MTD. The Clifton Formation is a minor aquifer that is limited in extent and thickness and the current calibration is considered adequate given the aquifer's contribution to the overall water balance.

5.3.2.2 Boundary Creek region

The Boundary Creek Region is centred on the Barongarook High and includes the aquifer outcrop areas where the aquifers are unconfined. Previous modelling of the Barwon Downs aquifer system has demonstrated that calibration in the vicinity of the confined/unconfined aquifer transition area is difficult. In the updated model, calibration results in the western half of this region are more consistent than the eastern half, which is closer to the transition between the confined and unconfined LTA.

As shown in Figure 5-2 and described in Jacobs (2016e), the variability in calibration results in this region is due to the complexity of the processes that control groundwater drawdown propagation and in particular the transition between confined and unconfined conditions and how this transition changes spatially and temporally as drawdown propagates through the region. While the model over predict heads in some areas, under predicts heads in other areas and has difficulty matching some observed drawdown responses, overall the model is considered to represent the regional response in the Boundary Creek catchment reasonably well.

5.3.2.3 Gellibrand River

The updated model has been extended to include the Gellibrand River as there are a number of surface water features in this area. The calibration in this area in the LTA is generally very good where the modelled head responses and values match the observed data well. This outcome provides confidence that the model is able to provide reliable predictions in this area regarding groundwater levels and groundwater surface water interactions.

5.3.2.4 South of the Bambra Fault

The Bambra Fault is an important hydrogeological feature that acts as a barrier to groundwater flow to the south east. The interruption to the aquifer at the fault generally leads to suppression of drawdown and recovery responses arising from borefield pumping in bores located south of the fault. The model is able to replicate this behaviour quite well, despite the fact that at some locations the model predicts more drawdown than observed.

In summary, the model is reasonably well calibrated at a regional scale; however there are some areas where the calibration against the monitoring bore data is poorly represented. The key area of concern is the area on the flanks of the Barongarook High where the aquifer transition from confined to unconfined across a small area. Further work is recommended to improve the calibration in this area.

5.3.3 Recommendations

Additional work is recommended to improve the calibration of the model around Boundary Creek as this is an important area of potential impact on stream flow as well as an area where there has been some community concern. Further work is likely to include reviewing the local conceptualisation of groundwater trends and groundwater surface water interactions, consolidating the number of calibration bores to include key representative bores and including additional surface elevation data (e.g. LIDAR) if available.

Figure 5-1 Example calibration hydrographs in the Central Region (blue lines show actual groundwater levels and red lines show modelled levels)

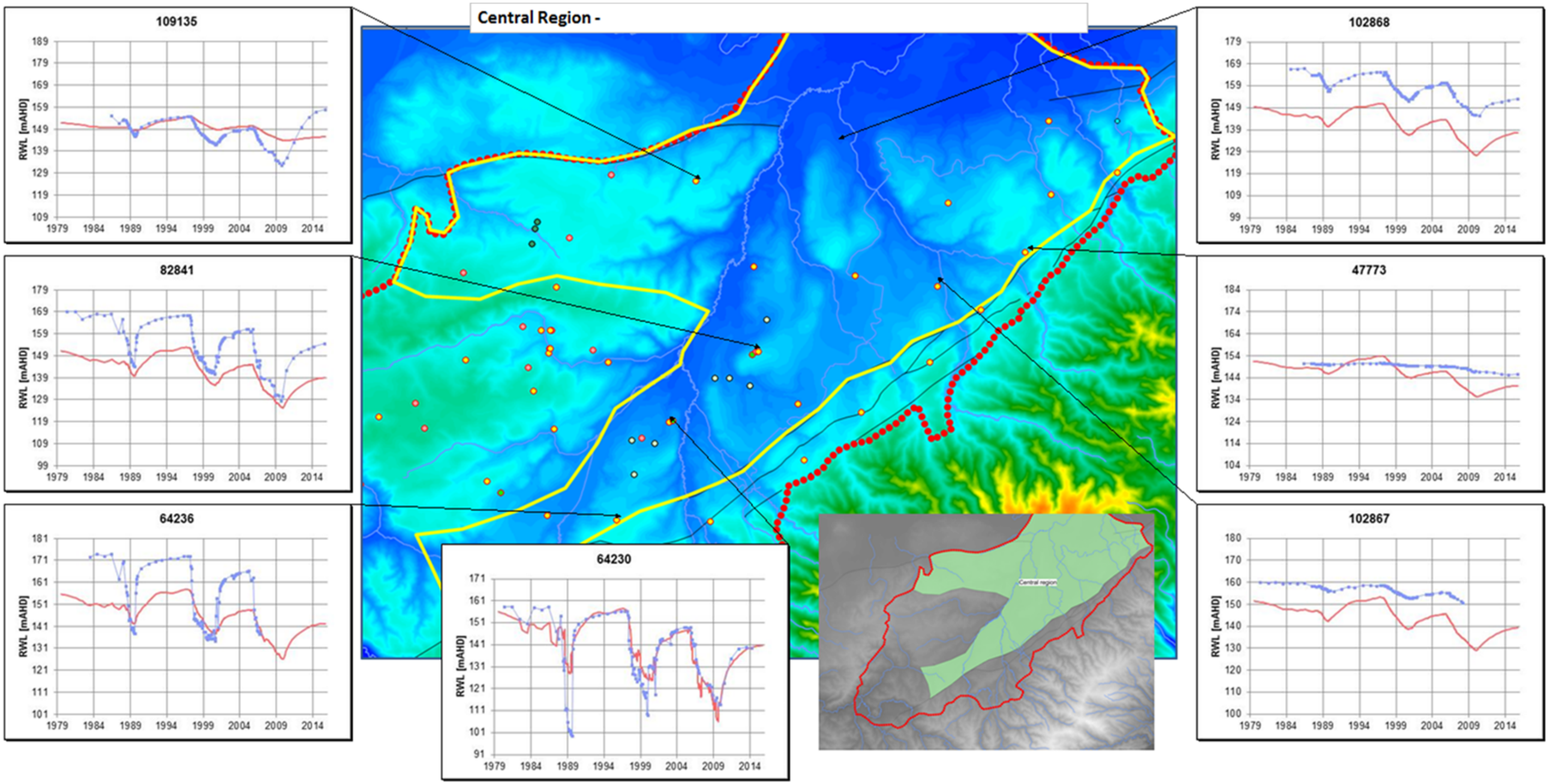
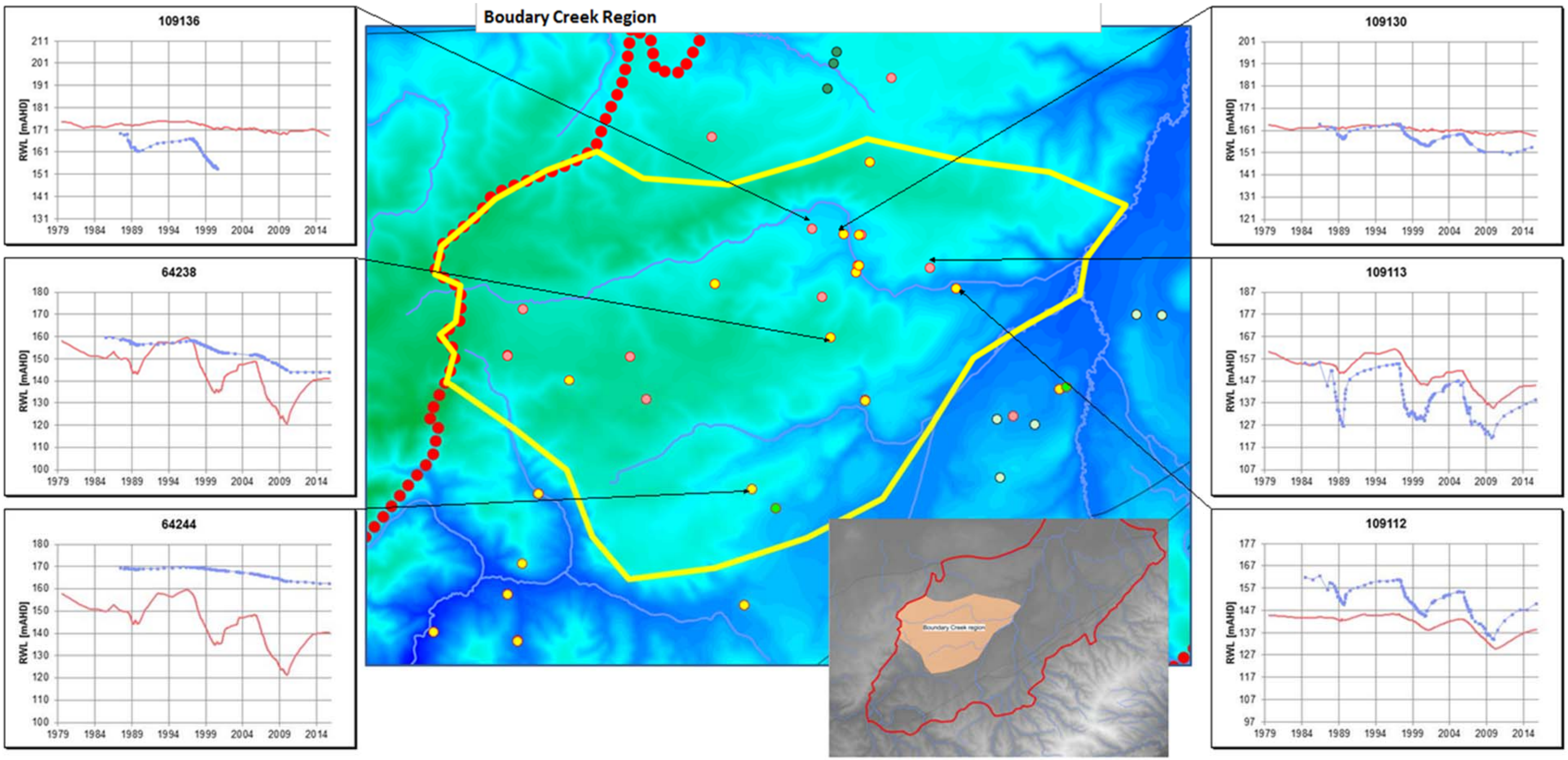


Figure 5-2 Example calibration hydrographs in the Boundary Creek Region (blue lines show actual groundwater levels and red lines show modelled levels)



6. Conclusions

The Technical Works Monitoring Program has established a sound baseline network to monitor any potential impacts to groundwater, surface water, vegetation, aquatic ecology in Boundary Creek and PASS linked to groundwater extraction from the Barwon Downs borefield.

Key conclusions from the work undertaken to date as part of the Technical Works Monitoring Program are outlined below.

6.1 Groundwater

- Operation of the borefield has caused groundwater levels to decline, but the drawdown effect is not uniform across the region and is buffered at the top of the LTA and the MTD. The buffering effect has also protected groundwater levels in the MTD and alluvial aquifers.
- Appropriate monitoring is in place with the addition of 34 monitoring bores (including replacement of one bore) and refurbishment of 3 existing bores.
- Groundwater levels in shallow aquifers and MTD have declined over the last 18 months, consistent with the below-average rainfall conditions. Groundwater levels in the shallow aquifers did not respond to the short pumping period in 2016.
- Local perched alluvial aquifers in some parts of the catchment are recharged from rainfall and surface water and are independent of the LTA.
- Rising groundwater levels recorded in bores monitoring the LTA and the lower MTD are consistent with groundwater levels recovering after pumping ceased in 2010.
- Implications for the licence renewal are:
    - Sound baseline monitoring network has been established to assess changes to groundwater levels which can influence groundwater-surface water interactions and streamflow, aquatic GDEs, terrestrial GDEs and PASS
    - Strong evidence base is now available on which to assess past effects and to predict future effects. This means the licence renewal application will be underpinned by a sound technical basis.

6.2 Surface water

6.2.1 Boundary Creek catchment

- There have been significant changes in the Boundary Creek catchment including land use, climate, construction of a dam, private diverters, groundwater extraction from Barwon Downs, drying of Yeodene (Big) Swamp and subsequent fires and fire management practices (such as trenching) and the supplementary flow release in Reach 1.
- Appropriate stream flow monitoring is in place with one new gauge installed and two existing gauges replaced to collect data on streamflow at various sections of Boundary Creek.
- Supplementary flow makes up a significant portion of the flow in upper reaches of the creek during summer and autumn.
- Throughout the summer months, flow is recorded upstream of Yeodene (Big) Swamp, but rarely downstream of the swamp (at the Yeodene gauge), making the effect of the swamp on flow hard to determine.
- Boundary Creek rarely stopped flowing during summer months prior to 1999, but since then has stopped flowing for varying periods in each summer. Various factors contributing to these ongoing cease of flows events have yet to be untangled and will be the focus of technical works in 2017.
- Water downstream of Yeodene (Big) Swamp is highly acidic.

- Existing information on groundwater surface water interactions suggests most of the creek remains unchanged with the exception of the reach between McDonalds Dam and Yeodene (Big) Swamp. Historically the creek was gaining along this reach and evidence suggests the creek is now losing.

- Implications for the licence renewal are:
  - Sound monitoring network has been established to assess fluctuation in stream-flow.
  - Further technical work is required to improve the understanding of drying of Yeodene (Big) Swamp. This work will improve the understanding of the functions of the swamp which will assist with understanding the contribution of pumping to issues in Reach 3.
  - Improve understanding of relative contribution of climate conditions and pumping to declining stream-flow to inform future operating regimes and licence conditions (e.g. timing and volumes pumped).
  - Improve understanding of the role of Yeodene (Big) Swamp in the hydrology and water quality of Reach 3 in Boundary Creek to inform licence conditions relating to supplementary flow.

6.2.2 Gellibrand River

- Gellibrand River is connected to the LTA and is a key discharge area for the aquifer.
- Most of the tributaries flow over the MTD, and springs from the MTD provide baseflow to some of the creeks. The MTD protects (buffers) the tributaries from drawdown in the LTA.
- Drawdown from pumping the Barwon Downs borefield does not appear to have affected the Gellibrand River to date.
- Implications for the licence renewal are:
  - Additional stream-flow gauges are recommended on Ten Mile and Porcupine Creeks as a precautionary measure to ensure there is sufficient baseline information to assess future impacts.
  - Need to quantify potential impacts to Gellibrand River and tributaries (through the groundwater model).

6.3 Aquatic GDEs

- Ecological values are good in Reach 1 where the supplementary flow is released, but decline downstream of the dam as flow and water quality decline.
- Reach 1 (upstream of McDonalds Dam) has been artificially enhanced by the supplementary flow and current ecological values are good. Macro invertebrate communities are in excellent condition and the channel supports Short-finned Eels, Flathead Gudgeon, Mountain Galaxias and a range of common and widespread frog species is likely to be supported.
- Reach 2 includes the ‘dampland’ area downstream of McDonalds Dam and upstream of Yeodene (Big) Swamp and Yeodene (Big) Swamp itself. The water in the channel is usually shallow and unlikely to be suitable for fish. The macro invertebrate communities are significantly impaired (AUSRIVAS Band B) but the reach likely supports the Otway Bush Yabby and the assemblage of common frogs.
- Reach 3 (downstream of Yeodene (Big) Swamp) dries frequently in summer, has highly acidic water when it is flowing and has limited aquatic habitat. The macro invertebrate community is in poor condition (AUSRIVAS Band C).
- Note that Platypus surveys were not conducted.
- Implications for the licence renewal are:
  - Sound understanding of existing ecological values in Boundary Creek and qualitative flow requirements.
  - Need to quantify flow requirements of current ecological values.
  - Improve understanding of the role of the supplementary flow in maintaining the current ecological values and consider alternative scenarios for the supplementary flow that would deliver greater benefits.

6.4 Terrestrial GDEs

- Baseline monitoring network including 14 sites was established to monitor the relationship between vegetation health and groundwater pumping. Monitoring was undertaken in 2014/15 and 2016.
- 2016 vegetation survey showed declines in vegetation health, in response to below average rainfall conditions. Given the borefield had not operated between 2010 and mid 2016 the results of this survey highlight vegetation's response to natural climate variability.
- Groundwater monitoring bores are located at all the vegetation monitoring sites and although the link between groundwater and vegetation present is highly variable and localised, all sites are considered to be groundwater dependent to some extent.
- Additional work was completed to determine if deep rooted vegetation species, like trees, use groundwater.
- Results showed that deep rooted vegetation at most sites was found to rely on a groundwater during times of drought and where the watertable is shallow.
- No evidence was found that declining groundwater levels caused by groundwater extraction at Barwon Downs had a negative impact on vegetation health in the catchment.
- Implications for the licence renewal are:
  - Sound baseline monitoring network has been established to assess potential changes to terrestrial GDEs, although no changes due to operation of the borefield detected to date.
  - No vegetation health issues identified that would influence the preparation for the upcoming licence renewal.

6.5 PASS

- Natural PASS existing across the study area.
- Review of potential ASS sites in the region was completed and a baseline monitoring network including 4 sites has been established. Monitoring was undertaken in 2015 and 2016.
- Changes noted in ground conditions, surface water and groundwater were consistent with seasonal fluctuations.
- Groundwater quality did not change over the monitoring period.
- Groundwater levels are typically shallow (within 1 m below the surface) and display seasonal fluctuations of around 0.5 m, rising during the winter months and declining during the summer months.
- Changes in surface water salinity were consistent with seasonal fluctuations e.g. higher salinity during summer months when evaporation is higher.
- Implications for the licence renewal are:
  - Highest priority PASS sites are being monitored regularly.
  - Sound baseline monitoring network to assess potential changes to PASS
  - No ASS issues outside of Yeodene (Big) Swamp were identified that would influence licence renewal.
  - Establish a PASS monitoring site in the Porcupine Creek catchment and complete baseline monitoring on groundwater and surface water quality to demonstrate no impact.

6.6 Land subsidence

- Monitoring of land subsidence across the region is within licence conditions:
  - 200 mm subsidence permitted in licence conditions
  - Maximum recorded 76 mm (2010)
  - Some rebound has occurred since. Subsidence water 42 mm in June 2015.
- Implications for the licence renewal are:
  - No issues identified relating to land subsidence that would influence the licence renewal.
  - Investigate potential to reduce monitoring frequency of subsidence.

6.7 Update of the numerical model

Work completed under the Technical Works Monitoring Program improved the hydrogeological conceptual understanding the Barwon Downs region. The revised hydrogeological conceptual model was included in the update and recalibration of the groundwater numerical model.

Key improvements are outlined below:

- The extent and thicknesses of key formations were revised and the Pember Mudstone and Basement units were included as two new layers in the numerical model.
- Improved understanding of groundwater inflow across faults.
- Recharge rates have been revised based on site specific data.
- Improved understanding of drawdown in the LTA and propagation through overlying formations.
- Understanding of changes in groundwater surface water interactions along Boundary Creek.

The updated model is reasonably well calibrated at a regional scale; however there are some areas where the calibration against the monitoring bore data is poorly represented. The key area of concern is the area on the flanks of the Barongarook High where the aquifer transition from confined to unconfined across a small area. Further work is recommended to improve the calibration in this area before the model is used to run predictive scenarios and this is discussed further below.

Recommendations for further work are discussed in the following section.

7. Recommendations

Ongoing monitoring of all existing assets is recommended to continue. The monitoring network is the minimum required to monitor potential impacts from the Barwon Downs borefield. Recommendations from individual studies completed during the Technical Works Monitoring Program are outlined in the table below.

Technical Works Monitoring Program	Recommendation
Groundwater	1. Installation of loggers in A6a, TB1c, and 109136 (loggers ceased working) 2. Ongoing monitoring of existing bores with interpretation.
Surface water	3. Improve calibration of the numerical model around Boundary Creek to better investigate base flow changes. 4. Use the calibrated numerical model to quantify stream-flow reduction due to climate and pumping from Barwon Downs borefield. 5. Quantify supplementary flow requirements to maintain current ecological values of Boundary Creek. 6. Determine supplementary flow requirements to provide stock and domestic flow in the downstream reaches of Boundary Creek and prevent inundation events to properties upstream near the current release point. 7. Use the calibrated numerical model to assess future groundwater development scenarios and their potential impact on Boundary Creek stream-flow. 8. Install additional stream flow gauges on Ten Mile and Porcupine Creeks. 9. Use the calibrated numerical model to assess potential stream-flow reduction to Gellibrand River and its tributaries.
Aquatic ecology	10. Develop a detailed conceptualisation of the surface water-groundwater interactions that influence Boundary Creek. 11. Use the numerical groundwater model to help quantify baseflow contributions to Boundary Creek. 12. Develop hydraulic models at representative sites in the creek to the link depth of water in the channel with flow volume. 13. Determine the quantitative flow needs of the identified aquatic values in Boundary Creek. 14. Develop recommendations to improve the effectiveness of the supplementary flow.
Terrestrial GDEs (Vegetation)	15. Vegetation surveys to be conducted every 2 years, whilst the borefield is operating during mid to late autumn and every 5 years when borefield not operational. 16. Relocate transect at site T11 to better connect with the groundwater dependent ecosystems in the area. 17. Review of remote sensing data after each period of borefield use to monitor potential changes in the regional vegetation condition that is not possible in the site by site assessment.
PASS	18. Establish a PASS monitoring site in the Porcupine Creek catchment and complete baseline monitoring on groundwater and surface water quality to demonstrate no impact.
Land subsidence	19. Ongoing monitoring as part of existing licence conditions. 20. Investigate the potential to reduce monitoring frequency and recommend revised

Technical Works Monitoring Program	Recommendation
	monitoring frequency.
Groundwater modelling	21. Improve the calibration of the model around Boundary Creek. 22. Use the calibrated model to run predictive scenarios to understand potential impacts to environmental and social receptors under future development (pumping) scenarios.

8. References

Glover, F. and Webb, J (2014) Characterisation of acid sulfate soils in south-west Victoria, Australia. Thesis submitted in total fulfilment of the requirements for the degree of Doctor of Philosophy School of PhD thesis. School of Life Sciences Faculty of Science, Technology and Engineering

Jacobs (2015a) Barwon Downs Monitoring Program – Review of conceptual model and numerical model boundaries. Final. 28 August 2015

Jacobs (2015b) Barwon Downs Vegetation Monitoring – Vegetation Monitoring Report. Final report 29 June 2015.

Jacobs (2016a) Field Investigations Report – Installation of new monitoring assets. Final. 5 August 2016

Jacobs (2016b) Boundary Creek aquatic ecology investigation. Draft. 24 August 2016.

Jacobs (2016c) Barwon Downs Groundwater Dependent Terrestrial Vegetation Investigations – Understanding Tree Water Use. Final 5 August 2016

Jacobs (2016d) Barwon Downs Vegetation Monitoring – Barwon Downs Vegetation Survey. Final 22 August 2016.

Jacobs (2016e) Barwon Downs Groundwater Model – Model Development and Calibration. Draft 26 August 2016

Jacobs (2016f) Barwon Downs PASS Monitoring – Baseline Assessment. Draft

Jacobs (2016g) Barwon Downs Technical Works Program - Integration Report. 22 March 2017

Orellana, F., P. Verma, S. P. Loheide II, and E. Daly (2012), ‘Monitoring and modeling water-vegetation interactions ingroundwater-dependent ecosystems, Rev. Geophys., 50, RG3003, doi:10.1029/2011RG000383.

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

SKM and Ecology Australia (2008). Barwon Downs Flora Study. Report prepared by Sinclair Knight Merz, Armadale, Victoria. SKM reference VW04550

SKM (2013) ‘Barwon Downs Monitoring Program - STAGE 1 Field Investigations and Monitoring Program Scope’, Unpublished report for Barwon Water prepared by SKM.

SKM (2014) Need for PASs sampling and shallow monitoring bore in Porcupine Creek Catchment. File note to Barwon Water 17th March 2014.

Appendix A. Groundwater levels in new monitoring bores

A.1 Corrected water levels

The data loggers used in the monitoring program measure the groundwater level as a pressure (in kPa) that is then converted into groundwater elevation (mAHD). The measured water pressure includes both groundwater pressure and atmospheric pressure, so the effect of atmospheric pressure must be removed to calculate the water level as an elevation. Atmospheric pressure in the project area is monitored at two locations; at bores TB7 in the west and A5b in the east. Each groundwater monitoring bore was assigned a set of atmospheric pressure data based on proximity to the pressure monitoring site in order to undertake the correction.

It should be noted that the effect of atmospheric pressure on logged groundwater levels can be seen in the 'squiggliness' of hydrographs for many bores (see Appendix A). The natural daily variation in atmospheric pressure is not removed by the correction described above.

A.2 Hydrograph data analysis

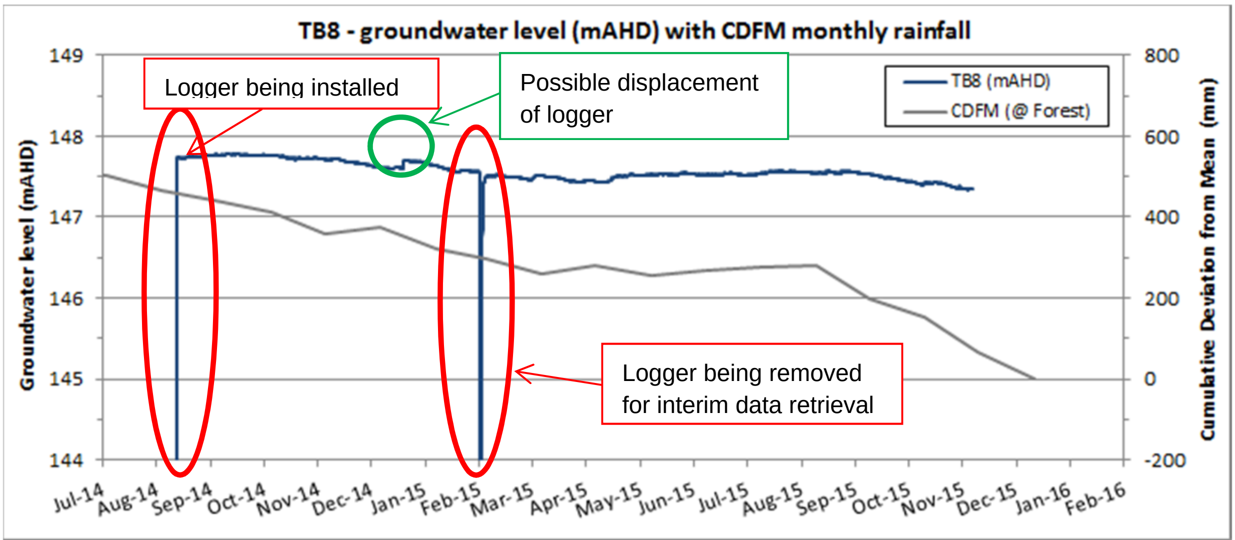
Hydrographs can often include data that does not represent changes in the water level. These can include:

- Logger installation/removal

  Vertical lines on the plots are typically indicative of points in time where the loggers have been installed or removed from the bores and are not representative of groundwater levels. An example from bore TB8 is given below.

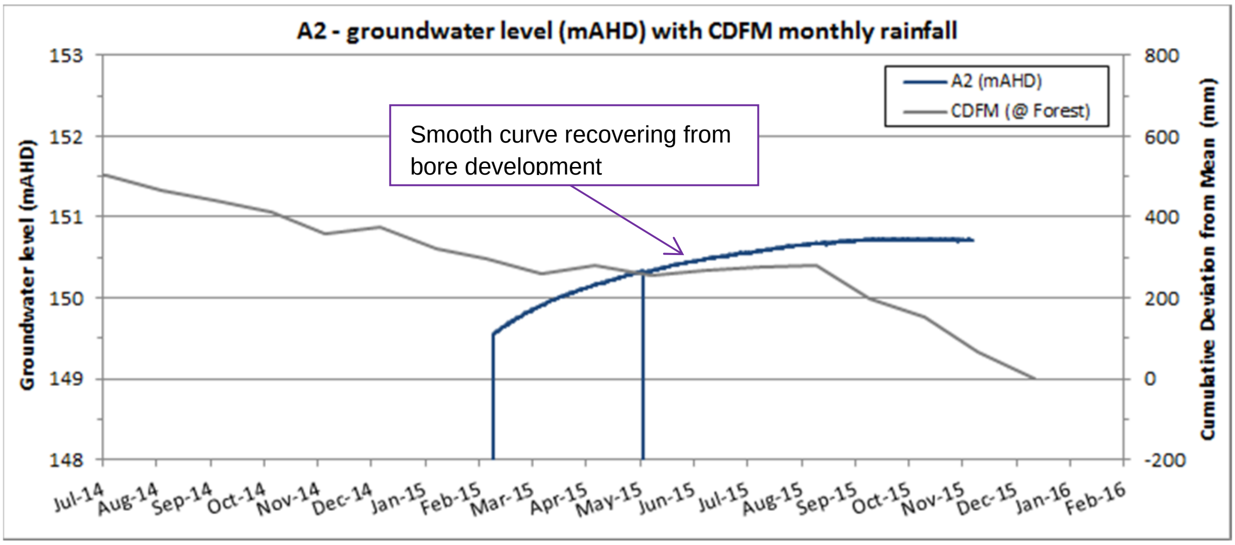
- Logger displacement

  Data loggers are typically hung on a wire down the bore. If the length of the wire changes (due to re-installation error or tangling of the wire) during the period of monitoring, this can be noticed as a sharp movement in the hydrograph before the water level trend continues. A possible example from bore TB8 is given below.



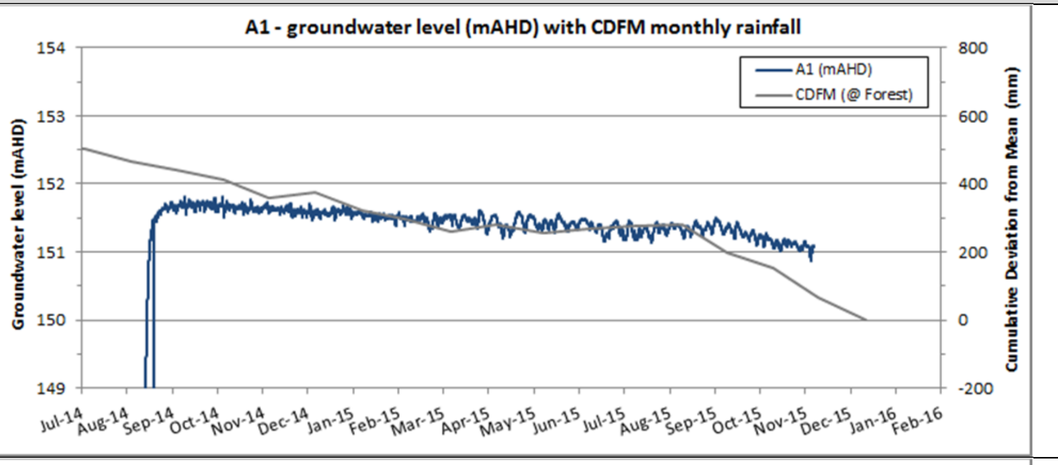
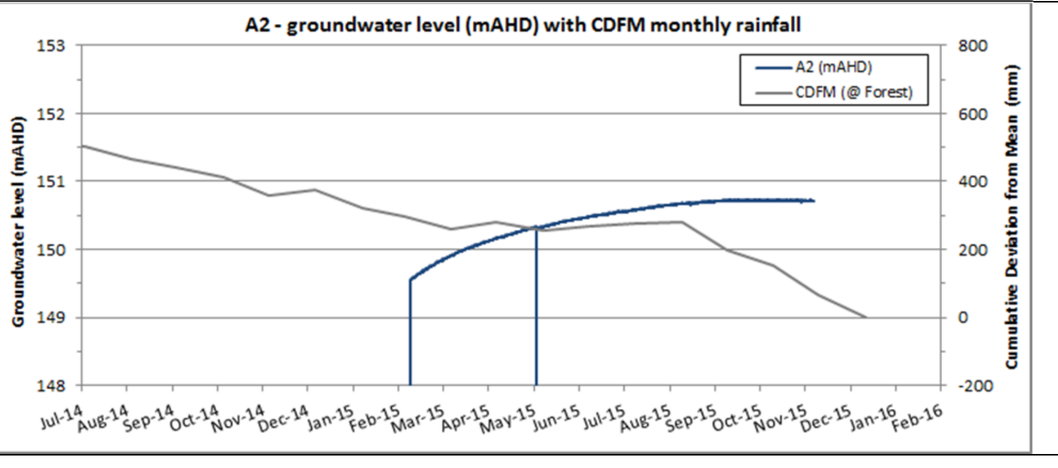
- Recovery from development/hydraulic testing

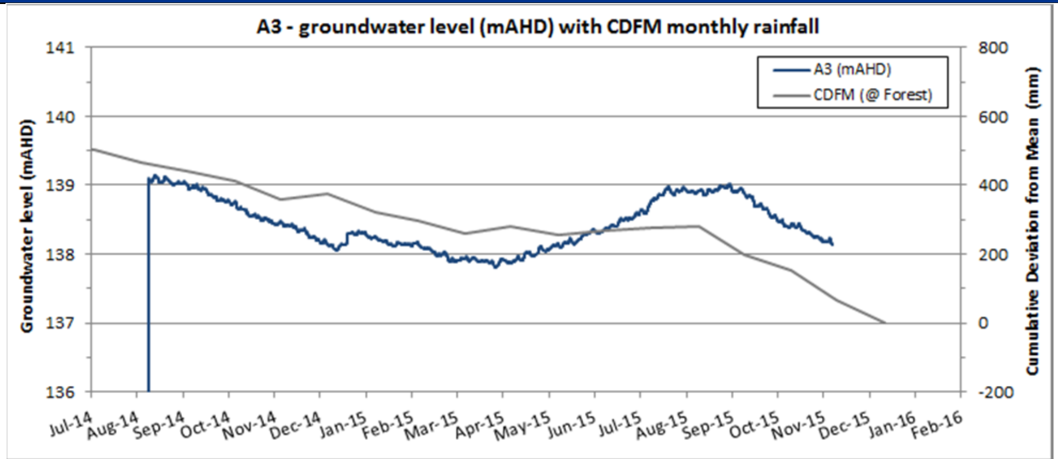
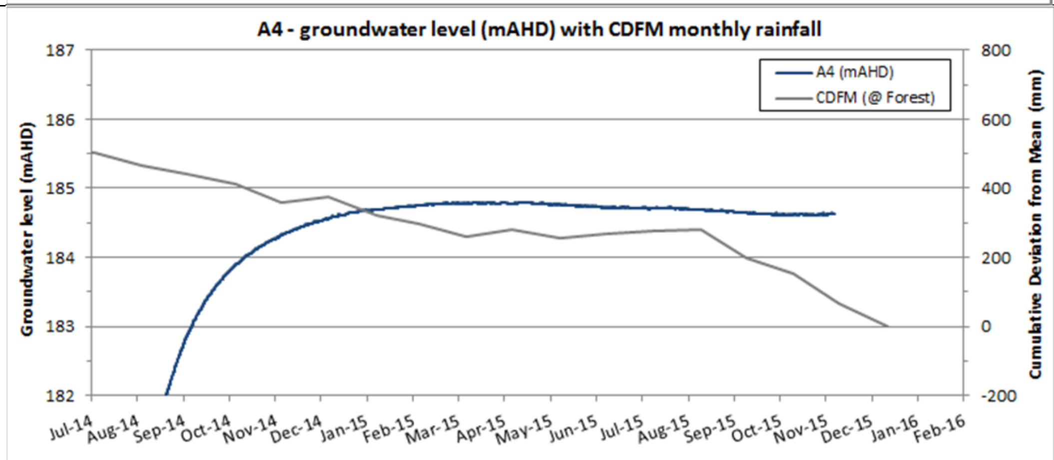
  If a data logger is installed soon after a bore was constructed or hydraulically tested, the logger data can capture the recovery of the bore from water level changes. Bore development (where the bore is flushed to establish the pack and soil around the screen) and hydraulic testing like slug or pump testing) can both result in a change in bore water level compared to standing water level. A bore recovering from a change to standing groundwater level typically exhibits a smooth curve toward the longer term trend (rising if the induced water level is below standing water level, and falling curve if water level is above standing water level). An example from bore A2 is given below.

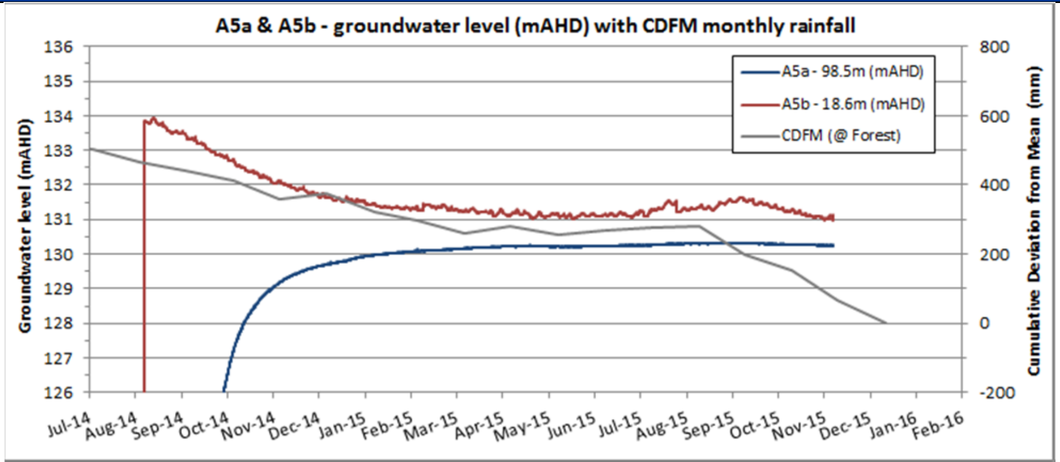
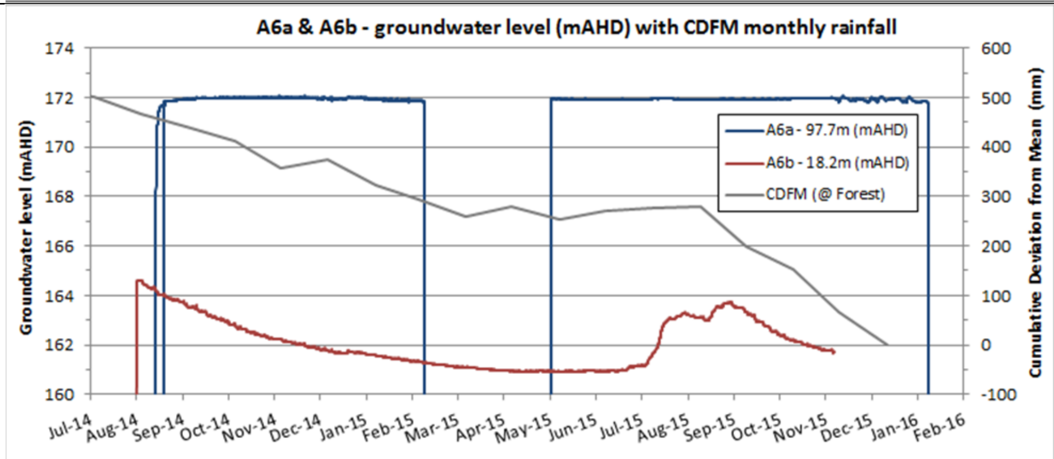


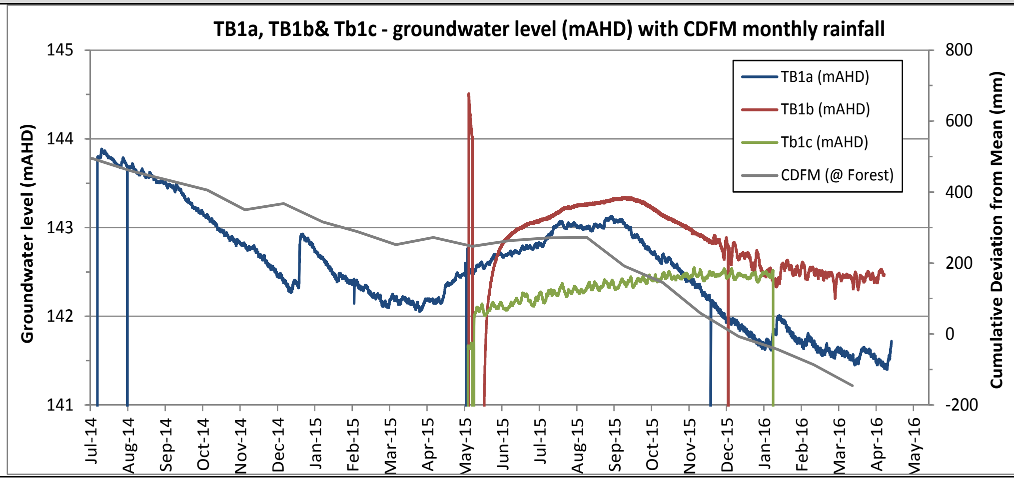
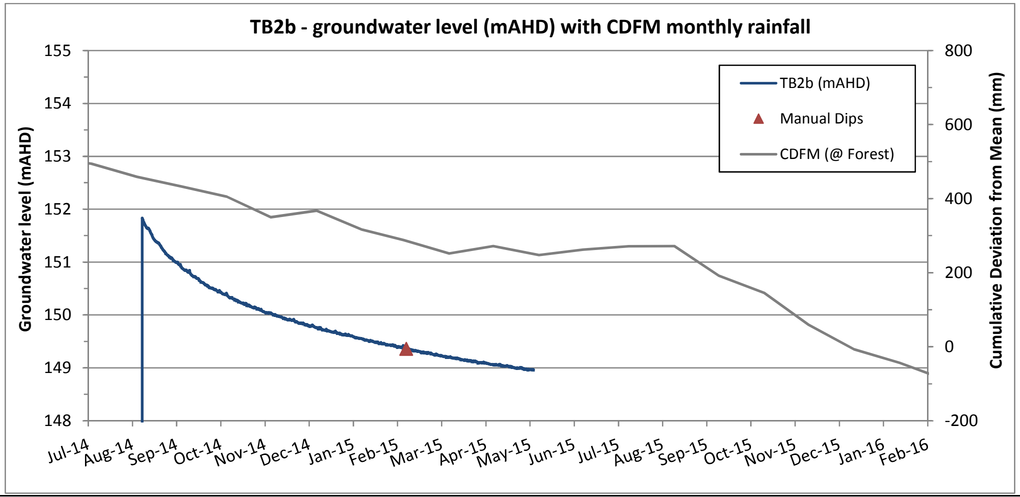
A.3 Bore hydrographs

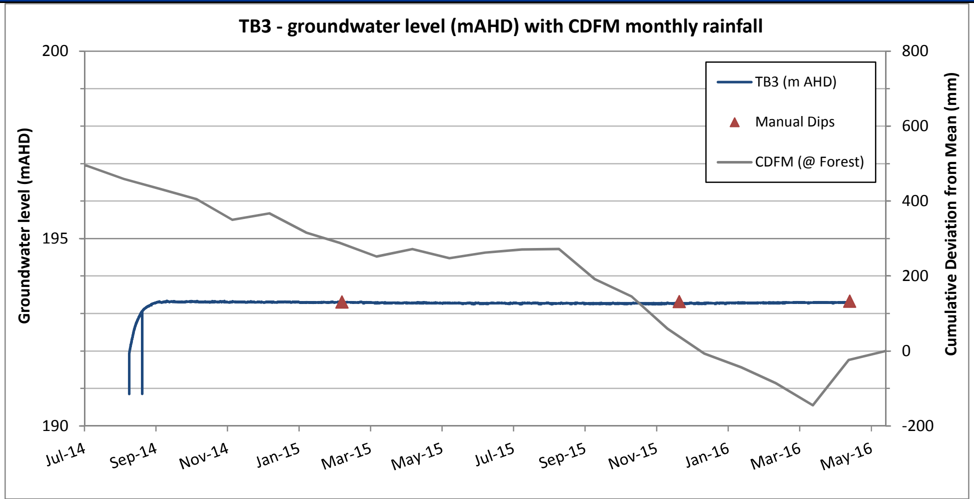
The hydrographs for each bore are shown in the table below and a brief description of each trend is also provided.

Bore ID	Aquifer & Depth	Description	Hydrograph
Aquitard bores			
A1	MTD (41.7m)	Bore A1 is located east of the Barwon River East Branch. The bore screens the aquitard at 41 m depth and shows a slight declining trend, which is consistent with below average rainfall conditions	
A2 & A3	MTD (40.1m/ 13.6m)	Bores A2 and A3 are both screened in the aquitard along Reach 3 near Boundary Creek. Bore A2 is shown in the top chart is deeper (40 m) than A3 and while the waterlevels are rising, the trend is consistent with a slow recovery from bore development. This suggests it has a very low hydraulic conductivity. In contrast, Bore A3 in the bottom chart, is shallower (13.6 m) and the waterlevel trend a steady, with seasonal fluctuations up to 1 m in amplitude.	

Bore ID	Aquifer & Depth	Description	Hydrograph
			
A4	MTD (40.5m)	Bore A4 is located further north of Boundary Creek and is 40 m deep. The bore shows a very steady waterlevel trend with no seasonal fluctuations.	

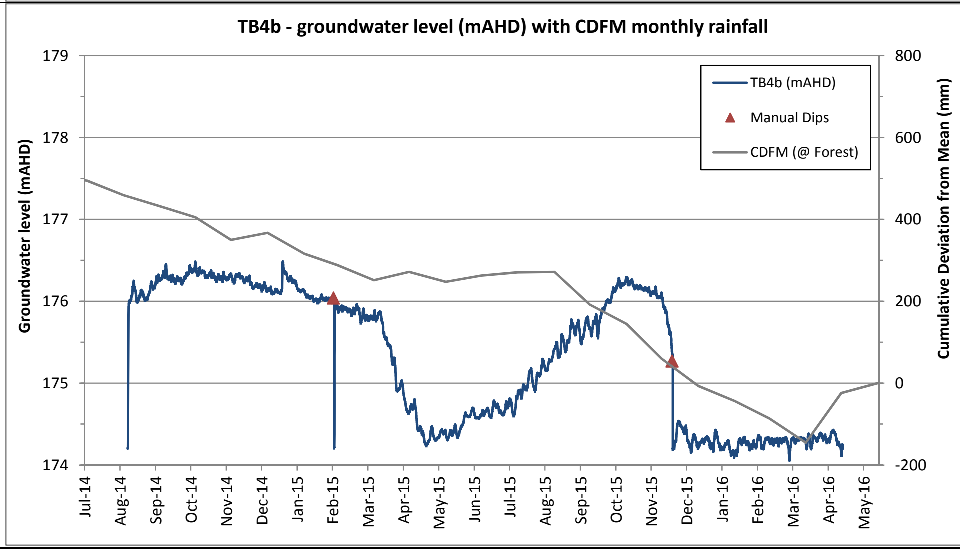
<table>
<tr><th>Bore ID</th><th>Aquifer & Depth</th><th>Description</th><th>Hydrograph</th></tr>
<tr><td>A5a/ A5b</td><td>MTD (98.5m/ 18.6 m)</td><td>Bores A5a and A5b are the most eastern new monitoring bores and are screened in the aquitard (MTD). The bores show steady water level trends, with minimal seasonal fluctuations. This is expected in tight clay formations. The nested site shows that there is a downward gradient from A5a (19 m deep) to A5b (99 m).</td><td>
</td></tr>
<tr><td>A6a/ A6b</td><td>MTD (97.7m/ 18.2m)</td><td>Bores A6a and A6b are nested bores located in the centre of the graben, south of Dividing Creek. The shallow MTD bore shows a slow recovery after the bore was constructed , followed by seasonal groundwater trends. The deeper bore shows very steady groundwater trends, with no seasonal fluctuations. The logger was removed from the bore for a couple of months in early 2015.</td><td>
</td></tr>
</table>

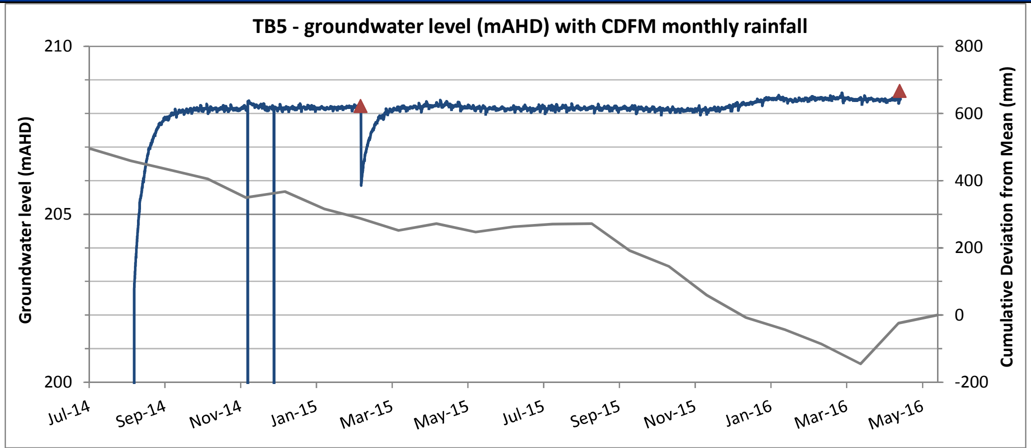
Bore ID	Aquifer & Depth	Description	Hydrograph
Vegetation Monitoring Sites			
TB1a **TB1b** **TB1c**	MTD (12.9m) QA (19.0m) LTA (36.5m)	TB1a, TB1b and TB1c are located downstream of Yeodene Swamp. TB1b is screened in the alluvial aquifer, TB1a is screen in the aquitard and Tb1c is screened in the aquifer. The alluvial aquifer (TB1b) shows a declining trend with seasonal fluctuations consistent with the rainfall conditions over the monitoring duration. The aquitard also shows seasonal fluctuations and an upward gradient to the alluvial aquifer also exists. The underlying aquifer shows a rising groundwater trend which is consistent with the aquifer recovering from previous pumping.	
TB2a **TB2b** **TB2c**	LTA (17.1m) QA (7.2m) QA (2.8m)	TB2a, TB2b and TB2c are located upstream of Yeodene Swamp. TB2c was installed in the alluvial aquifer, and groundwater level has since declined to below the base of the bore. The depth to watertable is at least 3 m. The topography rises away from the valley and TB2a is located on higher ground and is not deep enough to intersect the watertable in the LTA (17 m depth). TB2b was installed in an area of lower topography, with the aim of intersecting the watertable. This bore is 7 m deep and intersected the watertable at the time of drilling. The watertable has since declined 3 m and is now below the base of the bore (i.e. greater than 7 m depth).	

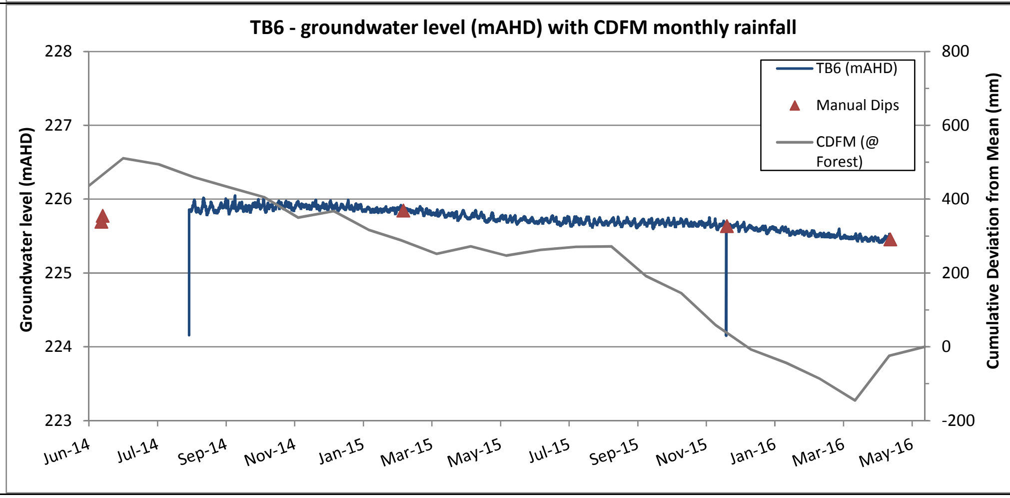
<table>
<tr><th>Bore ID</th><th>Aquifer & Depth</th><th>Description</th><th>Hydrograph</th></tr>
<tr><td>TB3</td><td>LTA
(39.5m)</td><td>TB3 is located in near the Barongarook High, where the LTA outcrops at the surface. The bore is reasonably deep and shows a very steady groundwater levels trend. A localised perched aquifer exists at this site which is supported by surface runoff (Jacobs, 2016e).</td><td>
</td></tr>
<tr><td>TB4a

TB4b

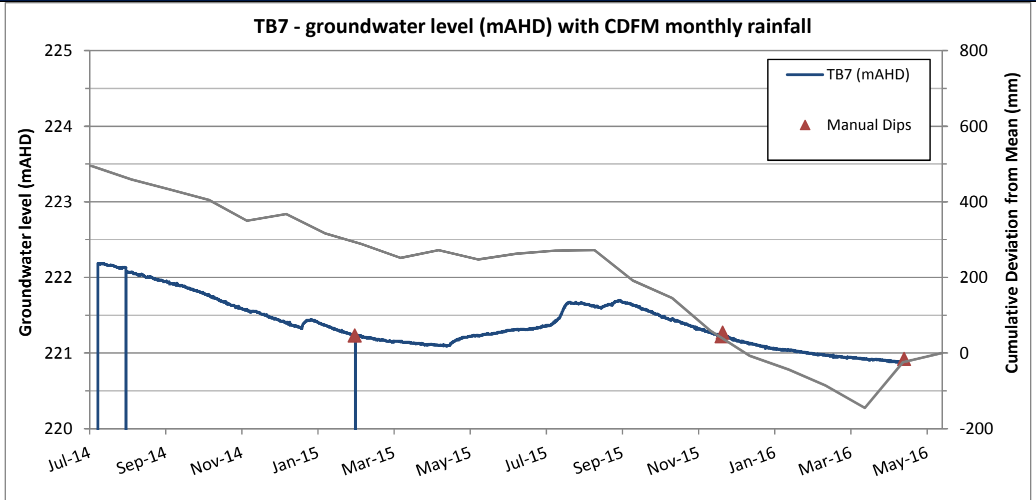
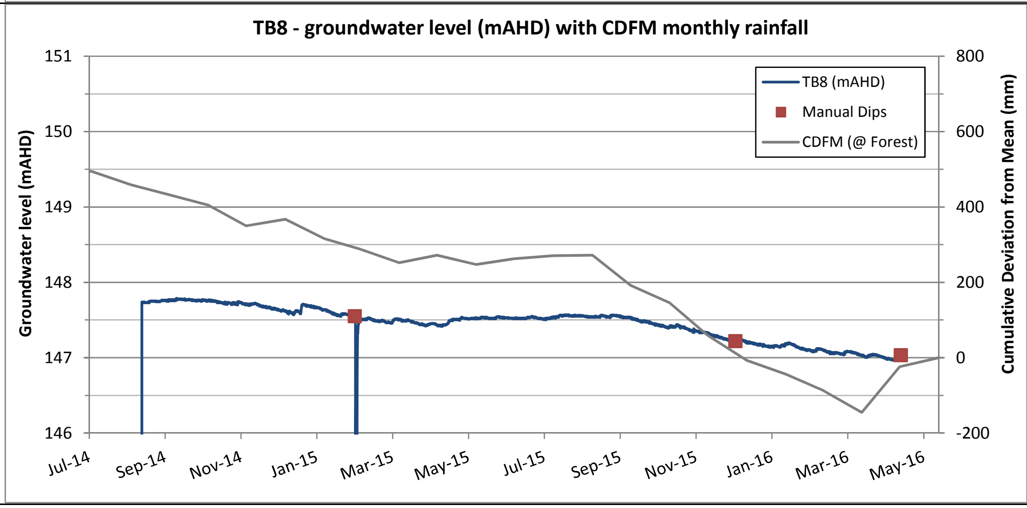
TB4c</td><td>LTA
(14.9m)
QA
(7.7m)
LTA
(31.0m)</td><td>TB4a, b and c are located to the north east of TB3 close to a tributary of Boundary Creek. TB4b monitors the local perched aquifer in the alluvium and the adjacent hydrographs shows that watertable fluctuates about 2 m. In December 2015, the groundwater level had declined and the bore was dry.

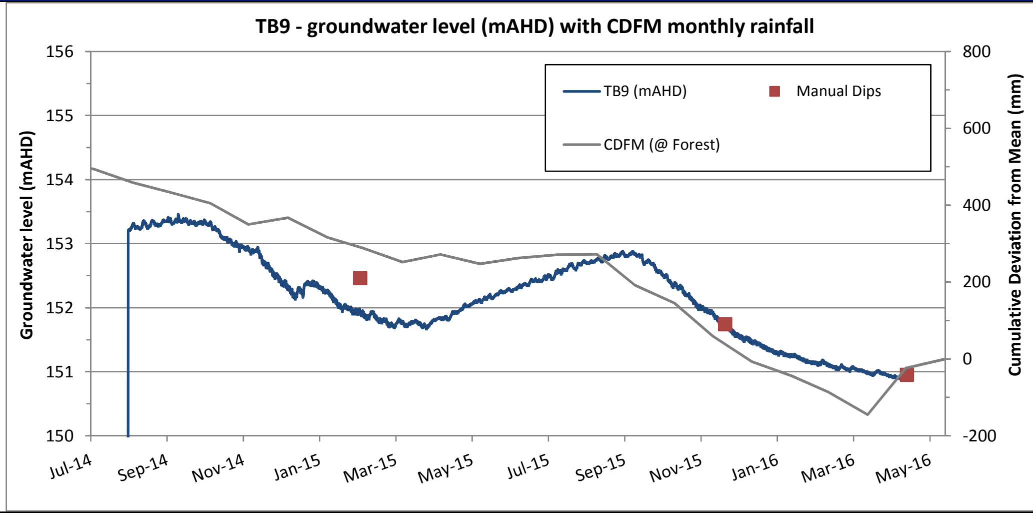
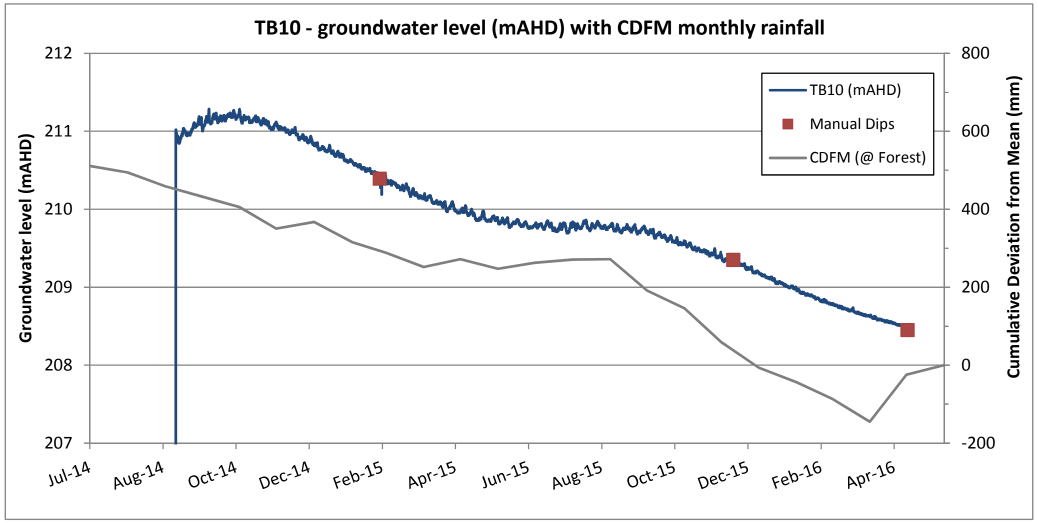
TB4c screening the LTA is also dry and the logger has been removed.</td><td>
</td></tr>
</table>

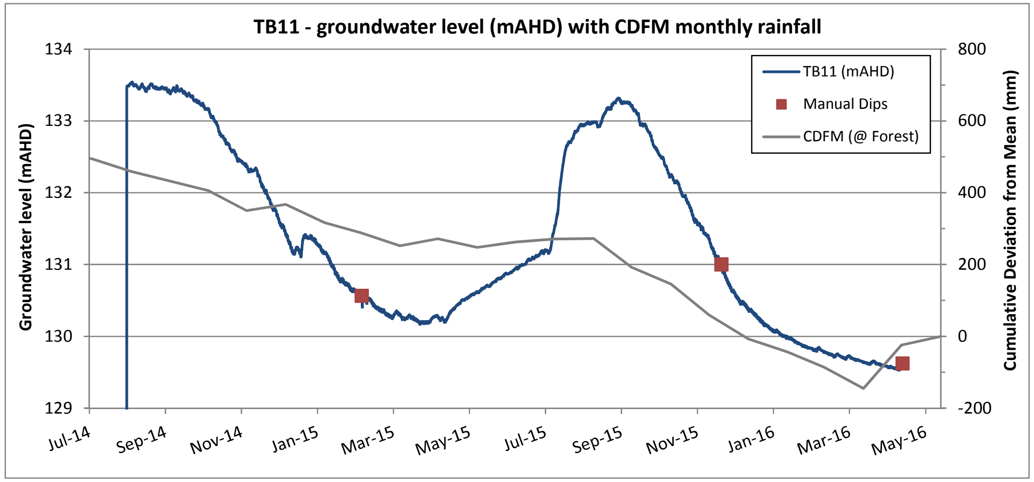
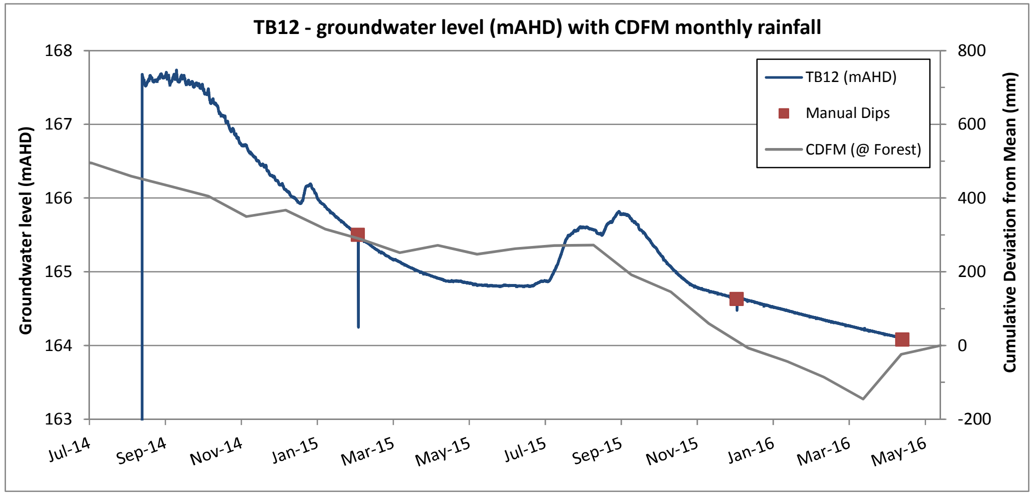
<table>
<tr><th>Bore ID</th><th>Aquifer & Depth</th><th>Description</th><th>Hydrograph</th></tr>
<tr><td>TB5</td><td>LTA
(32.6m)</td><td>TB5 is located to the west of TB3, on the Barongarook High, where the LTA is unconfined. Similar to TB3 this bore shows steady water levels.</td><td>


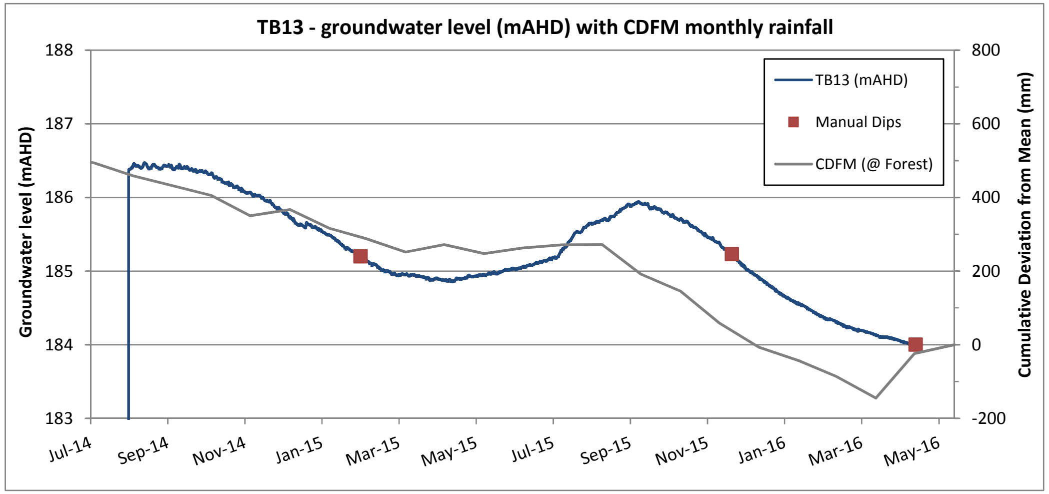
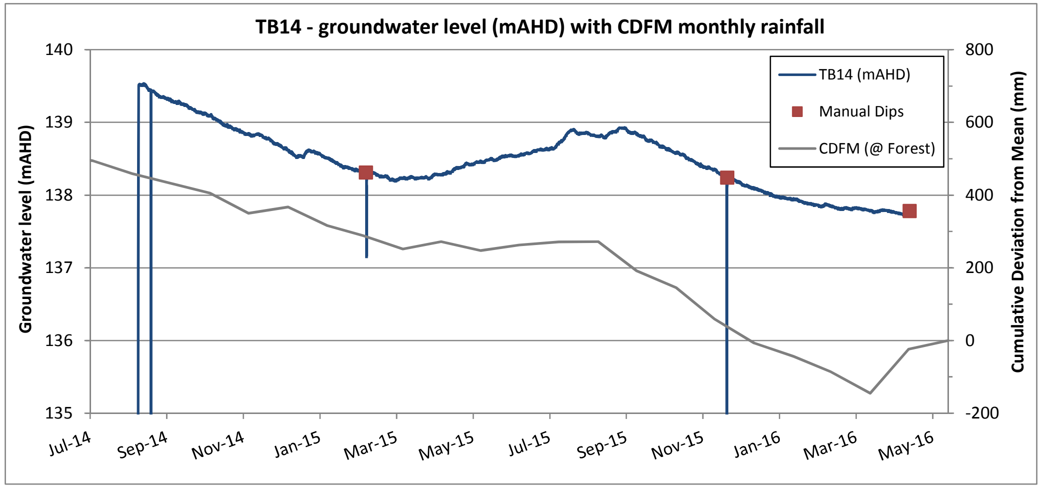
</td></tr>
<tr><td>TB6</td><td>LTA
(22.0m)</td><td>TB6 is located in a similar area to TB3 and TB5 where the aquifer is unconfined. The waterlevel trend is also steady in this location.</td><td>


</td></tr>
</table>

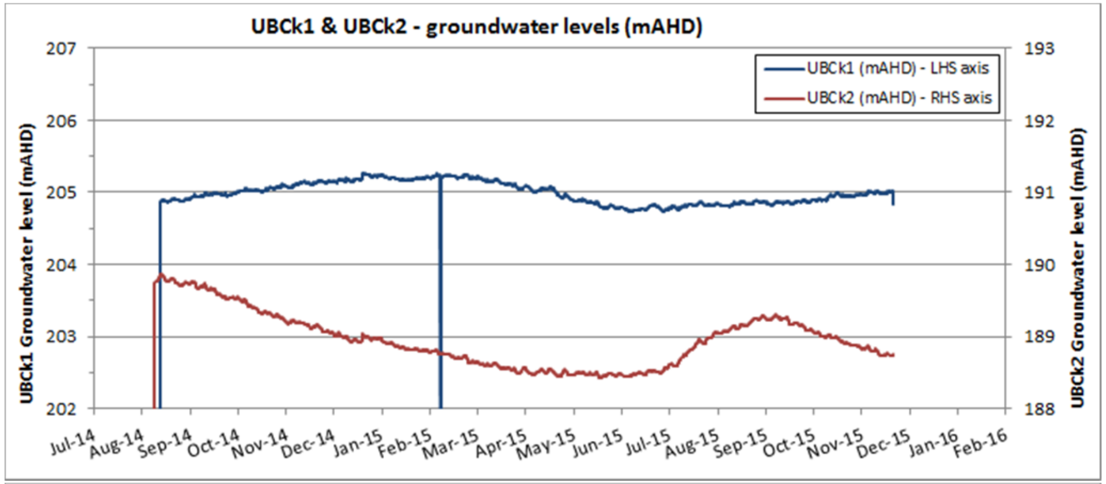
Bore ID	Aquifer & Depth	Description	Hydrograph
TB7	LTA (9.4m)	TB7 is located further west of TB6 on a tributary of Ten Mile Creek, which flows south of the Barongarook High. The bore is screened in the LTA, but is shallow and shows a slight declining trend with seasonal fluctuations.	
TB8	MTD (27.0m)	TB8 is located in in the centre of the study area, near a tributary of Dividing Creek. The bore is screened in the aquitard and shows a reasonably stable waterlevel, with a slight decline and seasonal response. This is consistent with rainfall conditions at the time of monitoring.	

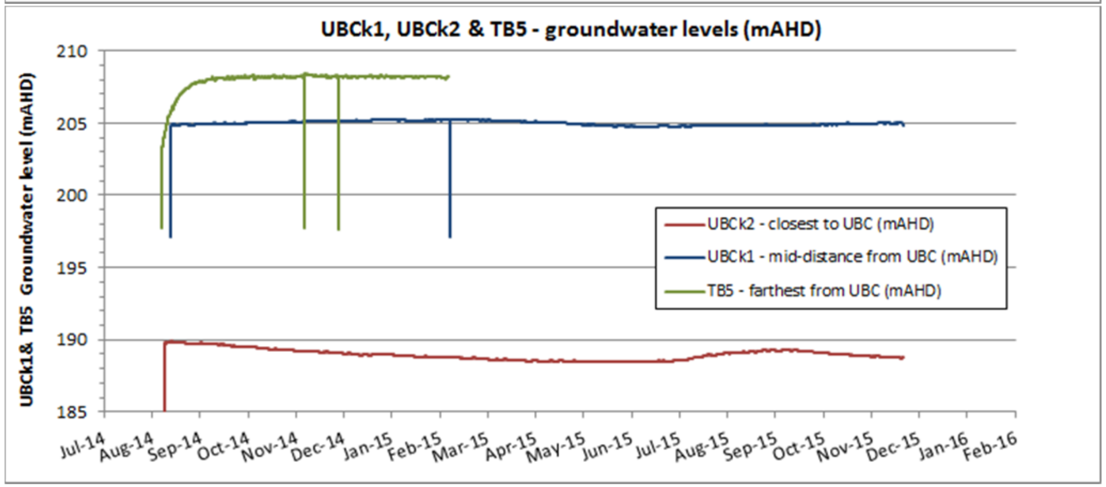
Bore ID	Aquifer & Depth	Description	Hydrograph
TB9	QA (12.0m)	TB9 is located in the south of the study area near the upper reaches of Porcupine Creek, and close to TB11. The alluvial aquifer is reasonably thick at this location (10-15 m). The waterlevel in the alluvial aquifer shows a slight declining trend with seasonal fluctuations, consistent with rainfall conditions at the time of monitoring.	
TB10	QA (10.9m)	TB10 is located in the western part of the study area, near a tributary of Dividing Creek. Although not shown on Figure 3-1, the alluvial aquifer is extensive at this location and is 10-15 m thick. The bore is screened in the lower half of the alluvial aquifer and show a declining trend with minimal seasonality. The waterlevel trend is consistent with rainfall conditions at the time of monitoring.	

Bore ID	Aquifer & Depth	Description	Hydrograph
TB11	QA (10.9m)	TB11 is located on Porcupine Creek, downstream of bore TB9. The alluvial aquifer is a reasonable significant aquifer at this location and is greater than 15 m thick. The aquitard underlies the alluvial aquifer. Similar to TB9, waterlevel in the alluvial aquifer shows a slight declining trend with seasonal fluctuations, consistent with rainfall conditions at the time of monitoring.	
TB12	QA (12.2m)	TB12 is located in a similar area to TB10, but to the east and close to another tributary of Dividing Creek. The alluvial aquifer is 10 to 20 m thick at this location and the waterlevel in the aquifer shows a declining trend with seasonal fluctuations. This is consistent with rainfall conditions at the time of monitoring.	

Bore ID	Aquifer & Depth	Description	Hydrograph
TB13	QA (13.2m)	TB13 is located to the south west of TB12, and further upstream on the same tributary of Dividing Creek. The alluvial aquifer is almost 20 m thick at this location, and the waterlevel trend is similar to that downstream, however the seasonal fluctuations are declining trend is less pronounced.	
TB14	QA (11.6m)	TB14 is located in the western half of the study area and close to Ten Mile Creek. Although not shown on Figure 3-1, the alluvial aquifer is extensive at this location and is 10-15 m thick. Similar to alluvial aquifers elsewhere in the catchment, the waterlevel shows a slight declining trend with seasonal fluctuations, consistent with rainfall conditions at the time of monitoring.	

<table>
<tr><th>Bore ID</th><th>Aquifer & Depth</th><th>Description</th><th>Hydrograph</th></tr>
<tr><td colspan="4">Groundwater-Surface Water Interaction</td></tr>
<tr>
<td>UBCk1

UBCk2</td>
<td>LTA
(21.5m)
Basement
(18.6m)</td>
<td>UBCk1 and UBCk2 are located on the Barongarook High and were installed to understand groundwater flow directions towards Boundary Creek. UBCk1 is located furthest from the creek and is screened in the LTA. The waterlevel trend is steady consistent with other bores in this area (TB3, TB4, TB5), with some seasonal fluctuations. UBCk2 is located close to the creek and is screened in basement where is outcrops at the surface. The groundwater levels show a slightly declining trend at this location with seasonal fluctuation, consistent with rainfall conditions at the time of monitoring. The groundwater flow direction is towards the creek.</td>
<td>




</td>
</tr>
</table>

<table>
<tr><th>Bore ID</th><th>Aquifer & Depth</th><th>Description</th><th>Hydrograph</th></tr>
<tr>
<td>109140

109130

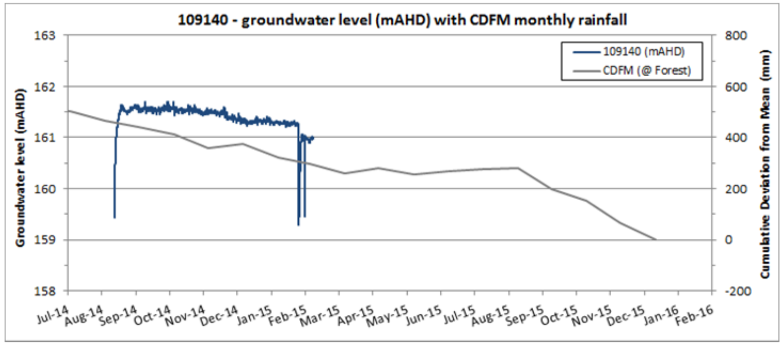
109143</td>
<td>LTA (11.0m)

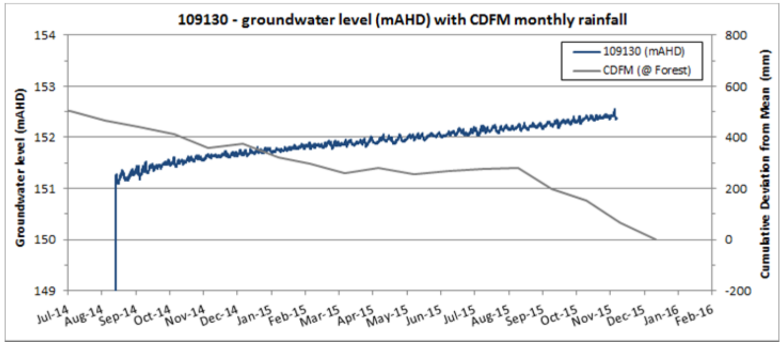
LTA (17.5m)

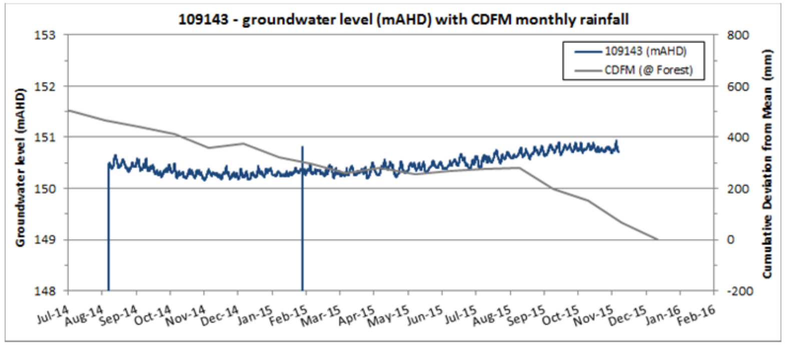
LTA (24.2m)</td>
<td>Bores 109140, 109130 and 109143 are all located on Boundary Creek, either adjacent to McDonalds Dam (109140) or downstream. All bores screen the aquifer at reasonable shallow depths.

Bore 109140 (top hydrograph) shows a slight declining trend whilst it was monitored, consistent with rainfall conditions.

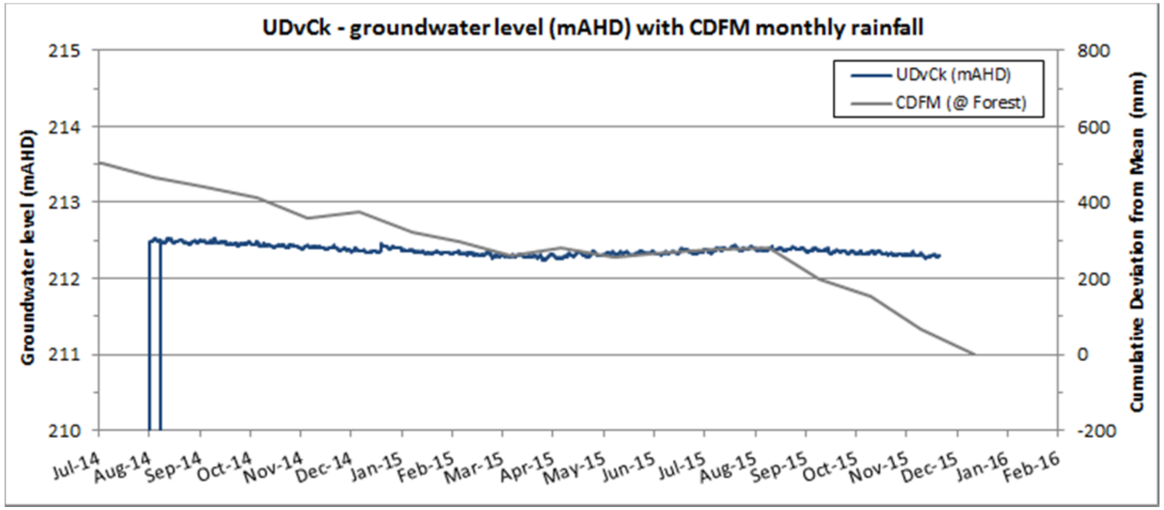
Bore 109130 (middle hydrograph) is located just downstream of the dam. The bore shows a rising groundwater trend and this is consistent with the aquifer being in a recovery phase after pumping. Groundwater levels have risen over a meter in just over a year of monitoring.

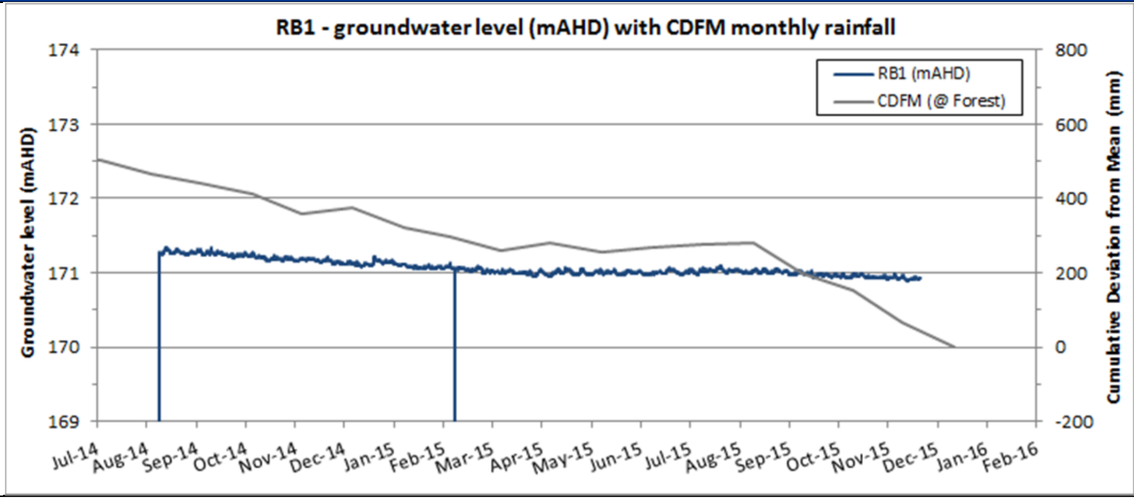
Bore 109143 (bottom hydrograph) is located further downstream of 109130 and shows a slight rising trend, but not as pronounced as 109130.</td>
<td>






</td>
</tr>
</table>

Bore ID	Aquifer & Depth	Description	Hydrograph
109136	(40.0m)	Bore 109136 is located at some distance from Boundary Creek (0.5 – 1km) and a logger was installed	
Other			
UDvCk	LTA (61.0m)	UDvCk is located near the Barongarook High and screens the LTA where it outcrops. The bore shows a relatively stable groundwater trend with a very slight declining trend consistent with rainfall.	

Bore ID	Aquifer & Depth	Description	Hydrograph
RB1	BSE (92.3m)	RB1 is located to the east of UDvCk and is screened in the basement aquifer. Similar to UDvCk, the waterlevel trend is relatively stable with a slight decline consistent with rainfall.	

Appendix B. Overview of hydrology in Boundary Creek

Figure B.1 : Stream flow in Boundary Creek at the Barongarook release and the Barongarook gauge. Note Barongarook release data is not a complete data record

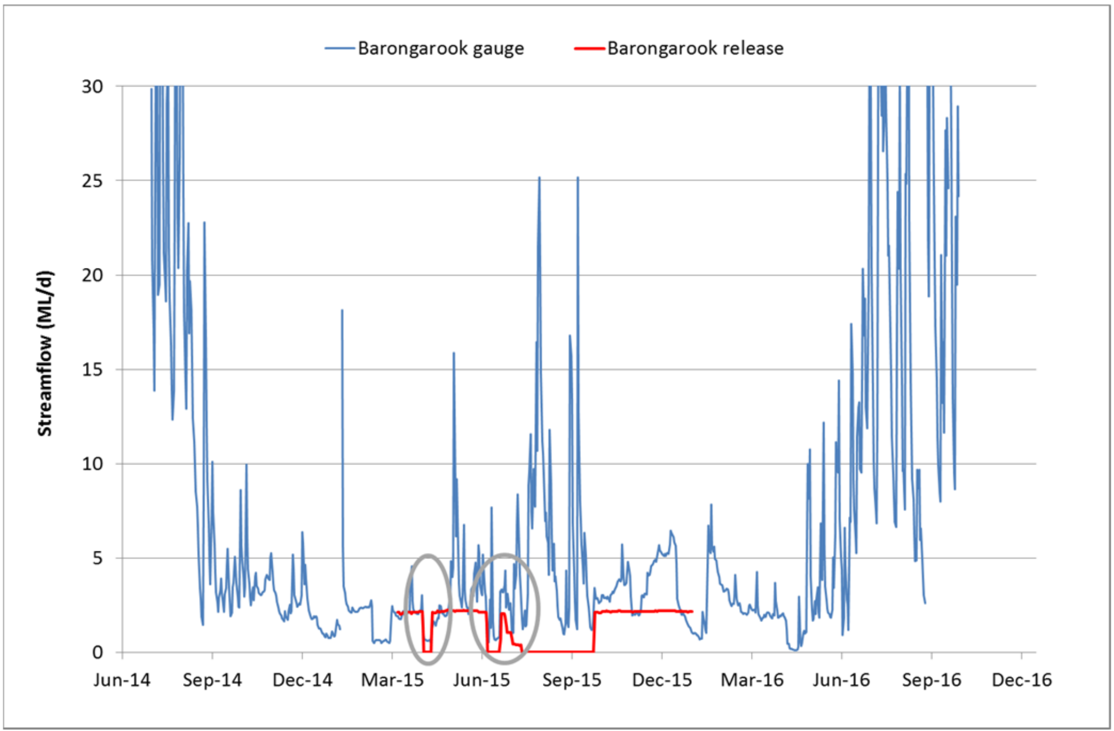


Figure B.2 : Stream flow in Boundary Creek upstream and downstream of McDonalds Dam 1989-2016

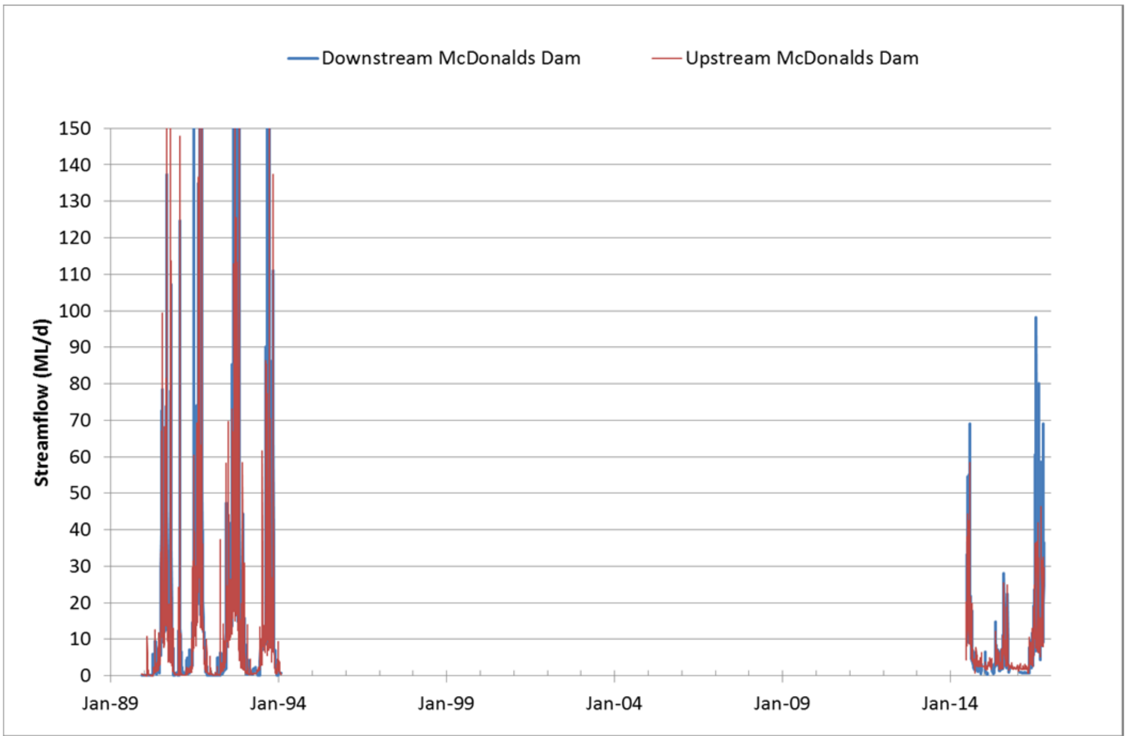


Figure B.3 : Stream flow in Boundary Creek upstream and downstream of McDonalds Dam 2014-2016

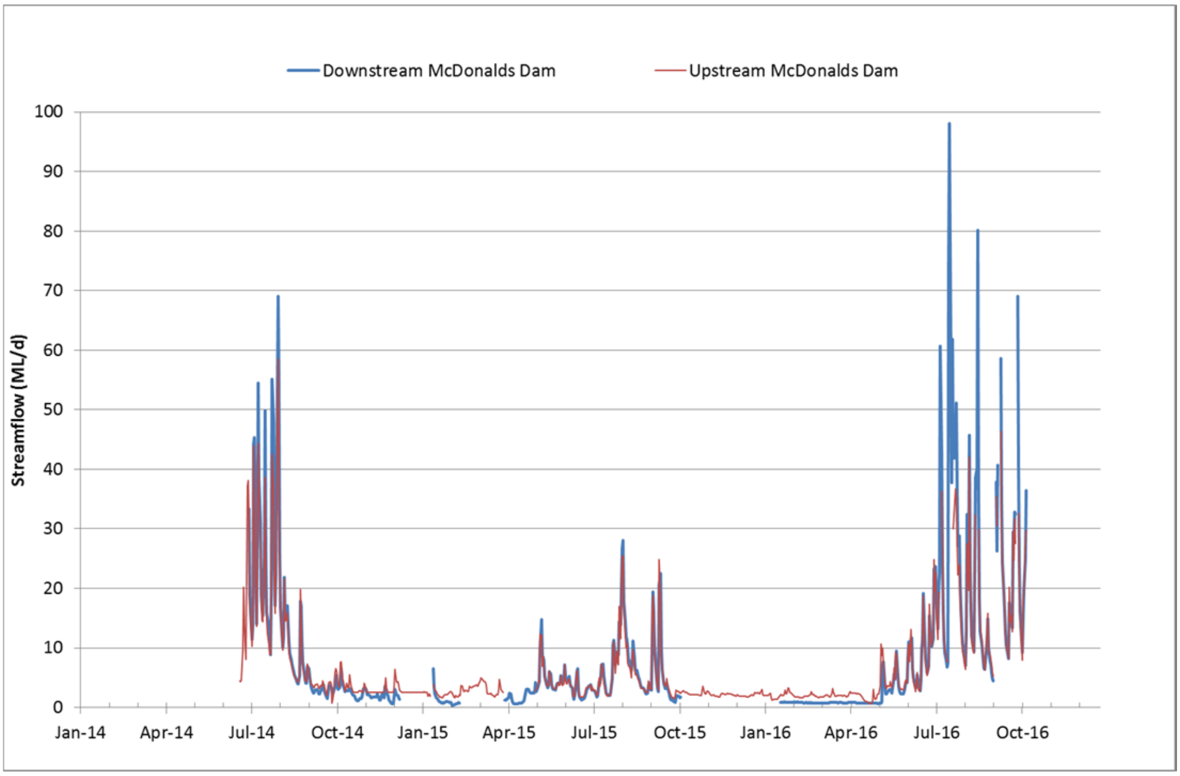


Figure B.4 : Stream flow in Boundary Creek downstream of McDonalds Dam and at Yeodene 1985-2016

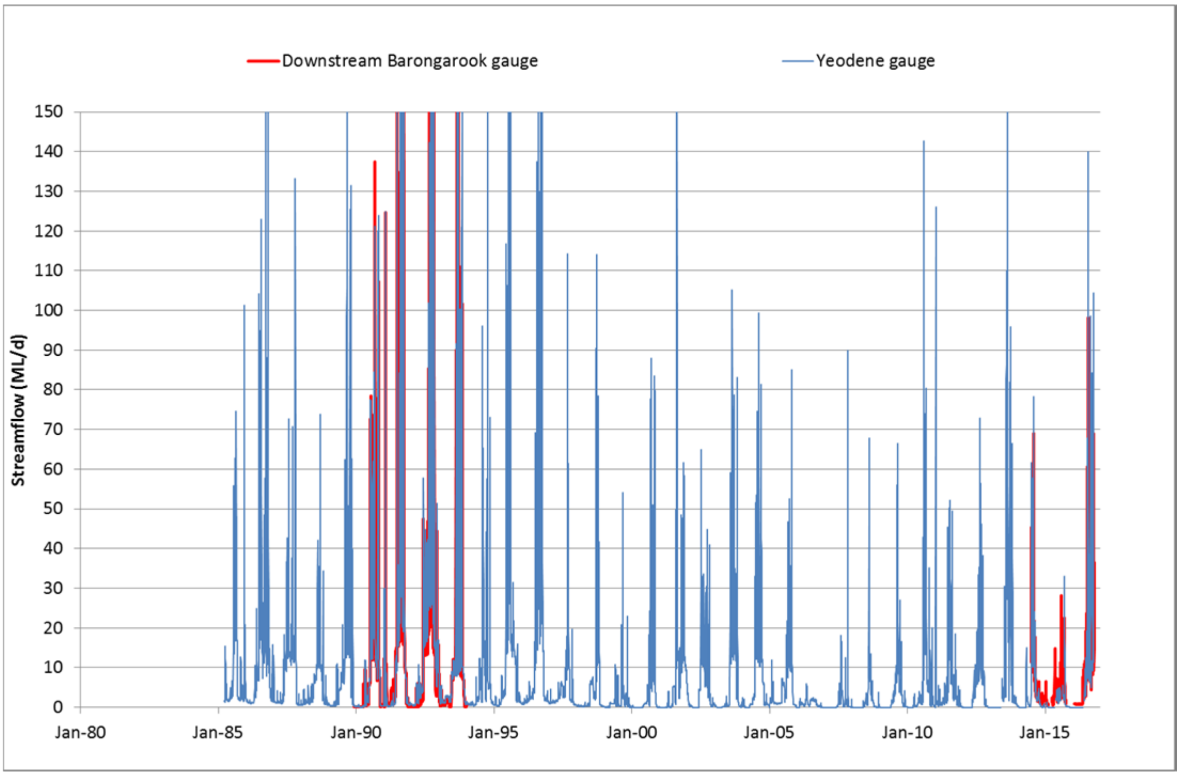
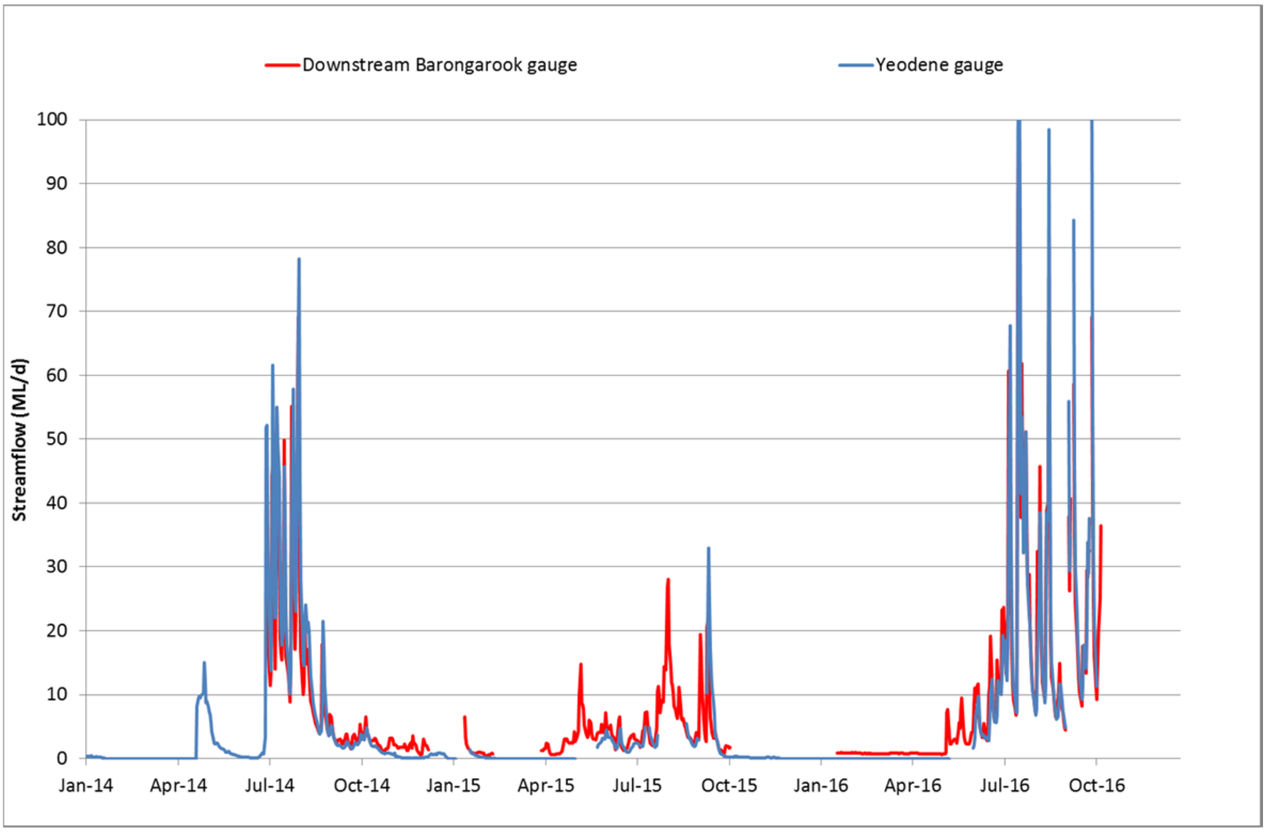


Figure B.5 : Stream flow in Boundary Creek downstream of McDonalds Dam and at Yeodene 2014-2016



Appendix C. Summary of Ecological Values in Boundary Creek

Ecological value	High probability	Medium probability	Low probability	Extremely low probability
Reach 1				
Vegetation	Overstorey consisting of *Eucalyptus* and *Acacia.* Weedy ground layer with occasional sedges and herbs. Frequent beds of Water Ribbon in the channel.			
Fish	Short-finned Eel	Flathead Gudgeon, Mountain Galaxias	River Blackfish, Southern Pygmy Perch, Yarra Pygmy Perch, Dwarf Galaxias	
Macroinvertebrates and crustaceans	Macroinvertebrates communities in excellent condition (AURIVAS Band A – Reference condition)			
Platypus			Platypus	
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog			
Reach 2				
Vegetation	'Dampland' with a dense canopy of *Melaleuca squarrosa* and *Leptospermum lanigerum* and a wetland ground-layer of diverse sedges, rushes and reeds (likely reliant on permanently waterlogged soils).			
Fish		Flathead Gudgeon	Southern Pygmy Perch, Dwarf Galaxias	
Macroinvertebrates and crustaceans	Macroinvertebrates communities in moderate condition (AURIVAS Band B – Significantly impaired). Otway Busy Yabby			
Platypus				Platypus
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog			

Ecological value	High probability	Medium probability	Low probability	Extremely low probability
Reach 3				
Vegetation	Largely cleared of native vegetation, although the riparian zone upstream of the road crossing was re-vegetated 10-15 years ago. It has a mature eucalypt overstorey and a dense mid storey layer.			
Fish				Fish unlikely to be supported at all by Reach 3.
Macroinvertebrates and crustaceans	Macroinvertebrates communities in poor condition (AURIVAS Band C – Severely impaired)			
Platypus				Platypus
Frogs			Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog	

Appendix D. Groundwater Flow Directions

Figure D.1 : Potentiometry and groundwater flow directions in the LTA in 1987

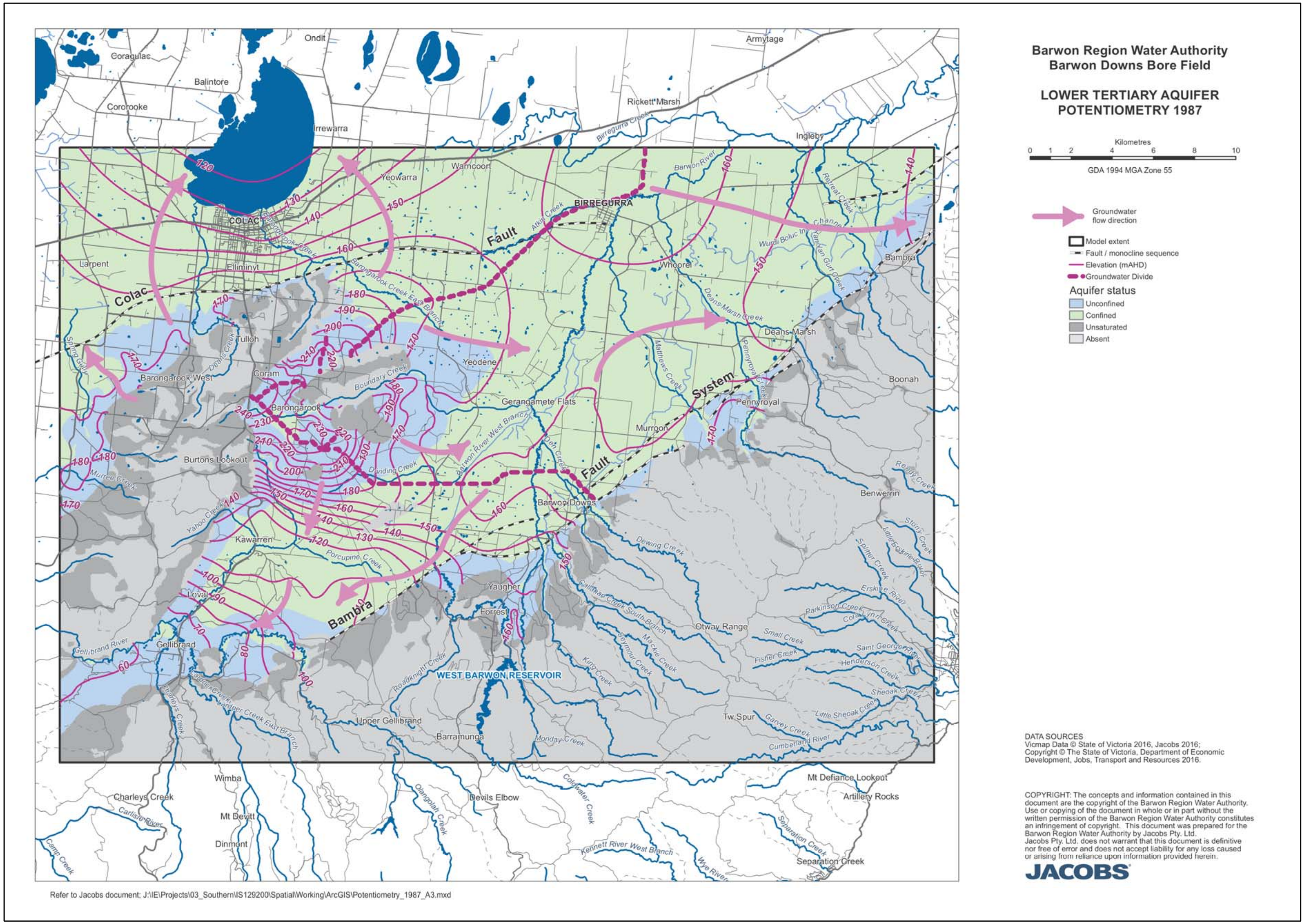


Figure D.2 : Potentiometry and groundwater flow directions in the LTA in 2012

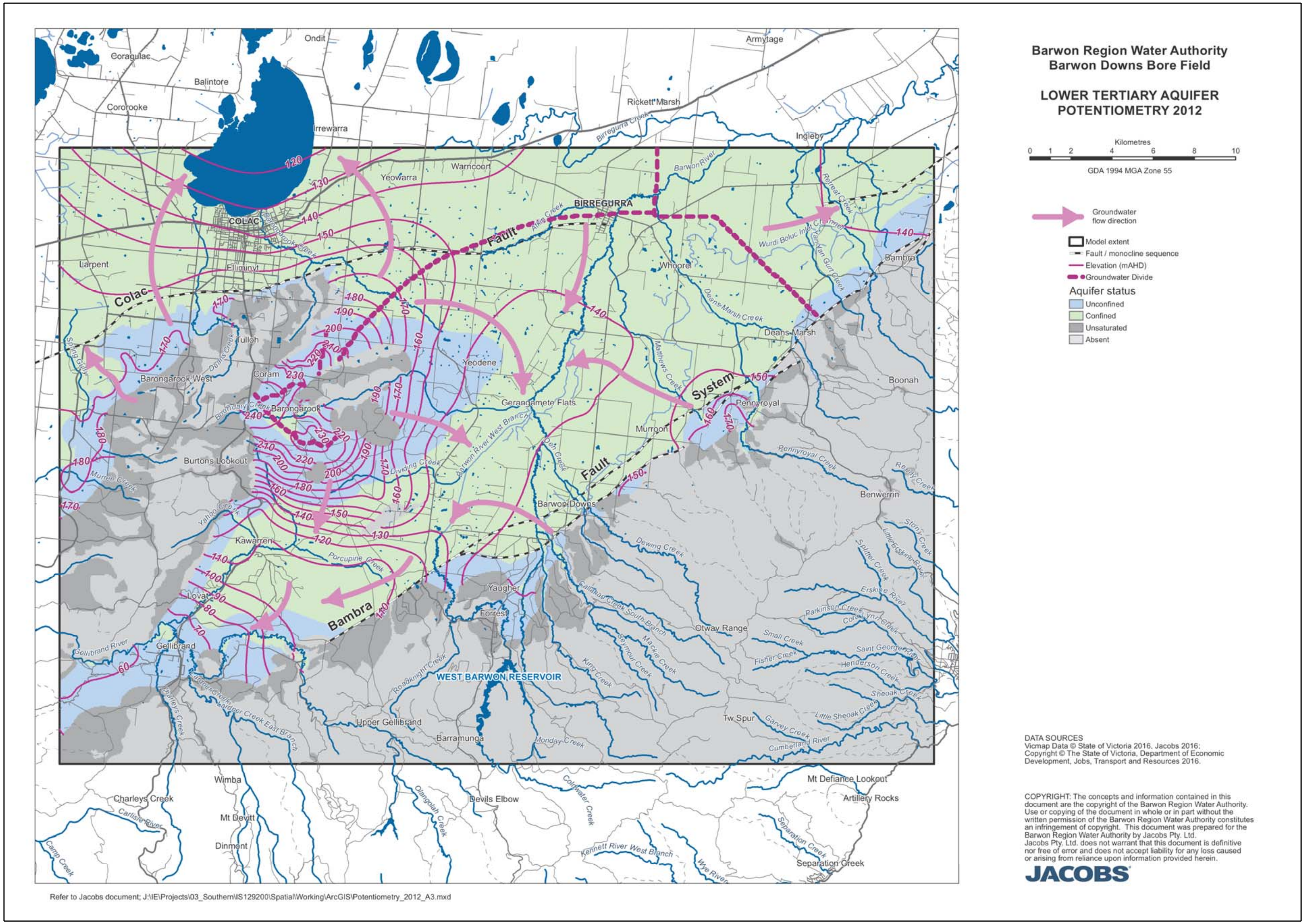


Figure D.3 : Potentiometry and groundwater flow directions in the LTA in 2014