

# **Review of groundwater pumping related impacts on Reach 1b of Boundary Creek**

**Boundary Creek, Big Swamp  
and Surrounding Environment  
Remediation and Environmental  
Protection Plan**

**December 2022**

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# Introduction

## Background

In June 2017, Barwon Water acknowledged that the historic management of periodic groundwater pumping activities at the Barwon Downs borefield between 1982 and 2016 had resulted in water level decline and depressurisation of the Lower Tertiary Aquifer (LTA), which in turn was the primary cause of a reduction in groundwater contribution to the lower reaches of Boundary Creek (i.e. baseflow), that helped sustain streamflows during dry periods. When combined with other stressors, such as the modification of the creek, drought conditions and the ineffective regulation of passing flows at a private on-stream dam located on Boundary Creek, the overall reduction in streamflow led to a range of unintended consequences such as: the drying out of Big Swamp, the oxidation of naturally occurring acid sulfate soils and the subsequent decline in water quality within Big Swamp and the lower reaches of Boundary Creek.

In December 2019 Barwon Water submitted the Boundary Creek, Big Swamp and Surrounding Environment Remediation and Environmental Protection Plan (REPP) to Southern Rural Water in response to the requirements outlined in the section 78 Ministerial Notice that was issued to Barwon Water in September 2018, which was subsequently implemented on 1 March 2020.

The Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan (REPP) includes two parallel work packages:

- 1. The Boundary Creek and Big Swamp Remediation Plan** – That outlines the controls and actions that could be practicably carried out to remediate the confirmed area of impact within the Boundary Creek catchment (i.e. where measurable and evidence based scientific methodologies conclude that the historical management of groundwater pumping activities at the Barwon Downs borefield resulted in environmentally significant adverse impacts); and
- 2. The Surrounding Environment Investigation** - To investigate whether other areas within the regional groundwater system have been impacted by historical management of groundwater extraction activities at the Barwon Downs borefield.

In the original REPP, Reach 1 of Boundary Creek was excluded from the 'confirmed area of impact' and the surrounding environment investigation due to the absence of any environmentally significant adverse impacts. However, based on feedback received from Southern Rural Water and the Independent Technical Review Panel (ITRP), this reach was re-classified into two sub-reaches, Reach 1a and Reach 1b.

In 2022, Barwon Water received additional feedback from Southern Rural Water and the ITRP requesting additional justification regarding the exclusion of Reach 1b from the 'confirmed

area of impact’ – i.e. where practicable controls and actions are required to improve environmental outcomes in line with the section 78 notice. Noting that broader management actions, such as the cessation of groundwater pumping activities and Barwon Water’s commitment to develop and implement a decommissioning plan for the Barwon Downs borefield extraction bores are aimed at preventing the potential for any future groundwater pumping related impacts.

## **Objectives**

Drawing from the investigations completed between 2016 and 2019 that were used to determine the ‘confirmed area of impact’ within the Boundary Creek catchment, this document collates the relevant information and multiple lines of evidence as it specifically relates to the exclusion of Reach 1b of Boundary Creek from the confirmed area of impact.

## **Identification of the ‘confirmed areas of impact’ within the Boundary Creek Catchment**

Between 2016 and 2019 Barwon Water undertook significant work within the Boundary Creek catchment to identify where measurable and evidence based scientific methodologies conclude that the historical management of groundwater pumping activities at the Barwon Downs borefield resulted in environmentally significant adverse impacts. Noting that the activities undertaken at the Barwon Downs borefield were undertaken under a licence that included drawdown triggers to mitigate against potential impacts.

Because of this, and in accordance with the section 78 notice and the REPP, the identification of environmentally significant adverse impacts has focused on assessing the unintended consequences that have resulted from borefield related drawdown, which has been monitored since 1986.

The works that informed the development of the original REPP indicated that despite some borefield related drawdown occurring within Reach 1 of Boundary Creek (and subsequently Reach 1b), this had not resulted in any environmentally significant adverse impacts – such as the increased occurrence of cease to flow events, acidification and/or decline in water quality, and significant decline in ecological condition and/or function, that has been identified within Reach 2 and Reach 3 of Boundary Creek.

To help assess this further Barwon Water has established the following evaluation criteria, which have been used to review the potential groundwater pumping related impacts and determine whether the exclusion of Reach 1b from the ‘confirmed area of impact’ remains sound:

1. Whether there is evidence of borefield related drawdown
2. Whether there is evidence of borefield related reductions in groundwater discharge
3. Whether there is evidence of borefield related adverse water quality changes

#### 4. Whether there is evidence of subsequent ecological impacts

When combined, these allow for a multiple lines of evidence approach with which to identify any environmentally significant adverse impacts that directly relate to Barwon Water's groundwater pumping activities at the Barwon Downs borefield.

#### **What has informed this process?**

This work has been informed by the following work:

- The Boundary Creek, Big Swamp and Surrounding Environment Remediation & Environmental Protection Plan (REPP)
- The Barwon Downs Technical Works Program conducted between 2016 and 2017
- Numerical and hydrogeochemical modelling work conducted between 2017 and 2021
- Macroinvertebrate sampling work conducted between 2019 and 2022
- Routine environmental monitoring works, including the real time monitoring and spot sampling data from stream gauges installed along Boundary Creek

# The Boundary Creek Catchment

The different reaches of Boundary Creek have been defined by surface water features, underlying hydrogeology, hydrology and operational considerations as described below and presented in Figure 1:

**Reach 1** – This is the upper reach of Boundary Creek and includes a large private on-stream dam (160 ML capacity) that was constructed in 1979. This reach can be further broken into 2 sub-reaches based on the underlying geological units, as follows:

- **Reach 1a**, represents the section of the creek from Barongarook to ~500 m upstream of the private on-stream dam. The Quaternary Sediments within this reach are predominantly underlain by outcropping bedrock which comprise impermeable Paleozoic sandstone, siltstone and mudstone. The Quaternary Sediments within this reach are expected to receive a minor component of rejected recharge from the outcropping basement rock.
- **Reach 1b**, represents the section from Reach 1a through to the downstream end of the private on-stream dam. Approximately 50% of this reach has been heavily modified by the construction of the private on-stream dam with only the upper ~500 m stretch being consistent with its historic condition. The Quaternary Sediments within this reach are underlain by the Lower Tertiary Aquifer (LTA) system. This reach is within the recharge zone and is classified as a losing stream.

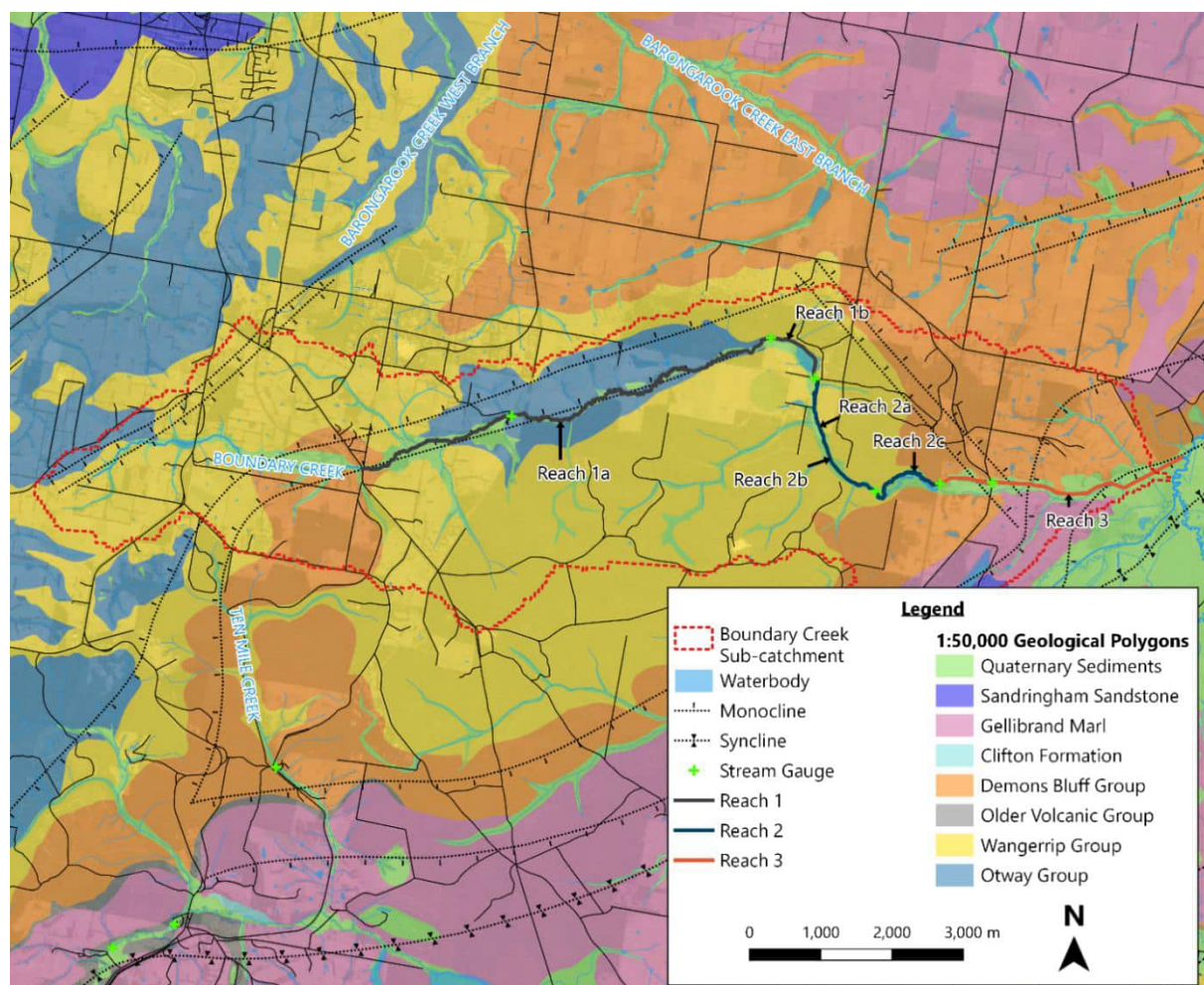
**Reach 2** – Represents the portion of Boundary Creek between the outlet of the private on-stream dam and the downstream end of Big Swamp. This reach can also be further broken down into 3 sub-reaches based on the nature of the streambed, the vegetation classes and underlying geological units, as follows:

- **Reach 2a**, represents a likely artificial channelised section immediately downstream of the private on-stream dam. The Quaternary Sediments within this reach are underlain by the Lower Tertiary Aquifer (LTA) system. Historically, this portion of the stream was likely a gaining stream that received rejected recharge/baseflow from the Lower Tertiary Aquifer system. The hydrogeological regime within this reach is likely to have also been influenced by the presence of the private on-stream dam.
- **Reach 2b**, represents a densely vegetated and marshy low-land area known as the 'damplands', located upstream of Big Swamp. This reach is characterised by highly braided flow pathways and waterlogged conditions. Similar to Reach 2a, the Quaternary Sediments within this reach are underlain by the Lower Tertiary Aquifer (LTA) system. Historically, this portion of the stream was likely a gaining stream that received rejected recharge/baseflow from the Lower Tertiary Aquifer system.



- **Reach 2c**, represents the area from the end of Reach 2b to the downstream end of Big Swamp where the Boundary Creek and Big Swamp flow paths meet. The Alluvial Sediments within this reach are between 1.5 and 6 m thick and are underlain by the Demons Bluff Formation and/or the Narrawaturk Marl that is confined at depth, thus confining the Lower Tertiary Aquifer and minimising the connectivity between the Upper Aquifer and Lower Tertiary Aquifer systems. This reach is considered to have relied on throughflow and groundwater – surface water interaction with the Upper Aquifer system to sustain streamflows during dry periods.

**Reach 3** – Represents the channelised portion of Boundary Creek from the downstream end of Big Swamp to the confluence of Boundary Creek and the Barwon River. This section has been heavily modified to support agricultural activities, with the Quaternary Sediments within this reach being underlain by the Gellibrand Marl, Demons Bluff Formation and/or Narrawaturk Marl that is confined at depth, thus confining the Lower Tertiary Aquifer and minimising the connectivity between the Upper Aquifer and Lower Tertiary Aquifer systems. This reach also receives groundwater discharge from the Upper Aquifer system.



**Figure 1 Simplified geology and hydrology of the Boundary Creek catchment**

# Review of potential impacts to Reach 1b of Boundary Creek

A detailed review of the information against the criteria outlined above is provided in the memorandum contained in Appendix A (Jacobs, 2022) with a summary of the findings provided below.

## **Assessment of borefield related drawdown**

As has been previously acknowledged by Barwon Water, borefield related drawdown has occurred within Reach 1b of Boundary Creek. The limited groundwater monitoring data from bores adjacent to this reach (bores 109139 and 109140) indicate that groundwater levels have declined by up to 5 m within this reach, with bore 109136 located at a higher elevation approximately 400 m south of Reach 1b reporting groundwater level decline in excess of 15 meters.

The outcomes of previous modelling work also indicates that groundwater level declines of approximately 0.6 meters within Reach 1b can be attributed to climate related factors.

It is noted that bore 109130, which has been referenced by Southern Rural Water and the ITRP in previous correspondence, is located downstream of the dam wall within Reach 2a and is within the 'confirmed area of impact'. Any attempt to extrapolate impacts from this bore to those upstream of the dam would need to take into consideration the presence of the dam and dam wall, changes in surface water flows associated with the dam, and the changes in topography.

## **Assessment of borefield related reductions in groundwater discharge**

Historic groundwater levels from bores 109136, 109139 and 109140 indicate that groundwater levels within Reach 1b were generally at or below the streambed elevation. This suggests that it is unlikely that there has been any reduction in groundwater discharge to Reach 1b of Boundary Creek due to borefield related drawdown.

## **Assessment of borefield related adverse water quality changes**

A review of water quality data provided in Appendix A, indicates that there has been no borefield related declines in surface water quality within Reach 1b.

## **Assessment of ecological impacts**

While previous studies focused on characterising the condition of Reach 1 in general, rather than Reach 1b specifically, previous investigations conducted between 2017 and 2018 (after the worst-case conditions) revealed that Reach 1 was in good ecological condition. This is despite parts of this reach being heavily modified from its original condition due to the



construction of the private on-stream dam that also acts as an impassable fish barrier for most fish (Jacobs, 2018).

The ecological condition of Reach 1 is also expected to have been supported by the release of supplementary flows by Barwon Water into the headwaters of Boundary Creek since 2003 in accordance with the groundwater licence.

## Conclusion

As outlined in the memorandum provided in Attachment 1, while groundwater levels in Reach 1b have declined in response to Barwon Water's historical management of groundwater pumping activities at the Barwon Downs borefield, the data and assessments conducted to date indicate that there has been no borefield related reduction in groundwater discharge, surface water quality or ecological condition in Reach 1b of Boundary Creek. As such, it can be concluded that Barwon Water's groundwater pumping activities did not subject Reach 1b of Boundary Creek to any environmentally significant adverse impacts and therefore, in line with the underpinning principles of the REPP (Barwon Water, 2019 as amended 2020), remediation actions are not required to be carried out by Barwon Water within Reach 1b of Boundary Creek.

This is consistent with Barwon Water's decision to exclude Reach 1b of Boundary Creek from the confirmed area of impact in the original REPP and the exclusion of this reach from the surrounding environment investigation.

# References

Barwon Water (2019, as amended 2020) Boundary Creek, Big Swamp and Surrounding Environment – Remediation and Environmental Protection Plan

Jacobs (2018) Low Flow Recommendations for Boundary Creek

Jacobs (2022) Potential impacts to Reach 1b

## Appendix A – Memorandum regarding potential impacts to Reach 1b

## Potential impacts to Reach 1b

<b>Date:</b>	8 November 2022	<b>Jacobs Group (Australia) Pty Limited</b>
<b>Project name:</b>	Boundary Creek and Big Swamp Remediation and environmental protection plan	Floor 13, 452 Flinders Street Melbourne, VIC 3000
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<b>Document no:</b>	03	www.jacobs.com
<b>Copies to:</b>	Will McCance, Jared Scott	

Dear Will,

This memorandum provides technical responses to comments received from Souther Rural Water and members of the Independent Technical Review Panel (ITRP) regarding the Boundary Creek and Big Swamp Remediation and Environmental Protection Plan (REPP).

The comments are focussed on the upper reach of Boundary Creek (Reach 1b) and whether it should be included within confirmed area of impact.

As indicated in the REPP, a practical remediation strategy was to be implemented along Boundary Creek from immediately upstream of Big Swamp to the confluence of Boundary Creek and the Barwon River, as it was confirmed that the historical management of groundwater extraction from the Barwon Downs Borefield caused an environmentally significant adverse impact in these reaches of Boundary Creek. Following a similar logic, this document outlines why Reach 1b was deemed not to have been subject to environmentally significant adverse impacts and hence, why it was not considered part of the confirmed area of impact.

While the ITRP have suggested that borefield related drawdown may have occurred in Reach 1b of Boundary Creek, and this has been previously acknowledged by Barwon Water, it does not inherently mean that environmentally significant adverse impacts have also occurred within this reach. To help demonstrate this more clearly, this document evaluates four criteria in Reach 1b, including:

1. Whether there is evidence of borefield related drawdown
2. Whether there is evidence of borefield related reductions in groundwater discharge
3. Whether there is evidence of borefield related adverse water quality changes
4. Whether there is evidence of ecological impacts

## 1. Reach 1b

### 1.1 Borefield related drawdown

As highlighted in comments provided by the ITRP, the regional groundwater model outputs suggest the potential for borefield related drawdown to have occurred along Boundary Creek in Reach 1b. This is illustrated in Figure 1-1 below which suggests borefield related drawdown increases from 0 m immediately downstream of the basement to ~10 m immediately downstream of McDonalds Dam.

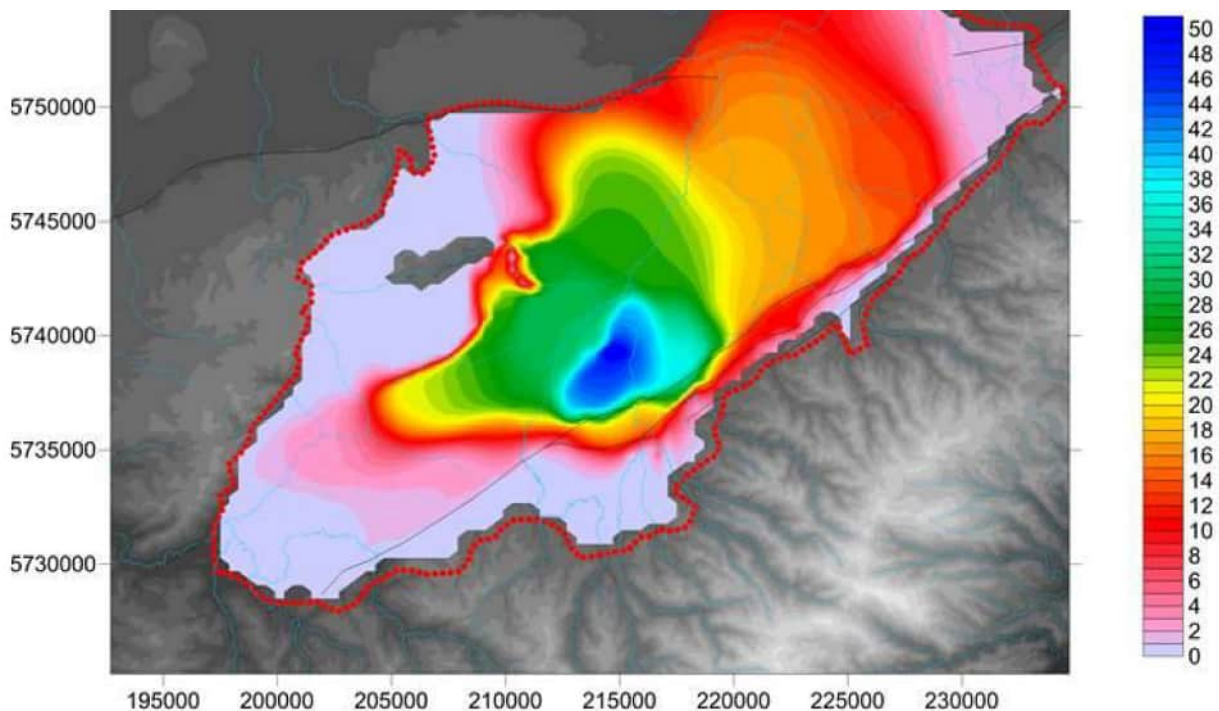


Figure 1-1 Predicted drawdown in the LTA in 2010 in the absence of climate effects (Jacobs, 2018a)

The reach in question is located on the very edge of the predicted drawdown cone. This is driven by the termination of the Pember Mudstone and Pebble Point formation in this region, as well as the thinning of the Dilwyn Formation from 50 m thickness to 1 m thickness (see Figure 1-2 to Figure 1-4 below). Given this, the model results will be dependent on the reliability of the geological surfaces that define the extent and thickness of these units in this area.

The model surfaces were based on the Victorian Aquifer Framework (VAF) and updated following a review of drilling logs at wells installed following the development of the VAF. Accordingly, bore logs adjacent to Reach 1b include bores 109139 and 109140 upstream of McDonalds Dam and bore 109130 downstream of McDonalds Dam. In addition, bore 109136 is located in an up-slope area approximately 400 m south of Boundary Creek.

While drilling logs at bore 109130 indicate sands from 6 to 19 m and logs at bore 109136 indicate quartz sands between approximately 5 and 25 m depth, which are consistent with the Lower Tertiary Aquifer (see Appendix A), those upstream of the dam at bores 109139 and 109140 are less clear due to crude lithological logs which only indicate "clay" as the screened unit at bore 109139 and "sand" as the screened unit at bore 109140.

Given this, while there is high confidence in the occurrence of the LTA along Boundary Creek at bore 109130 and ~400 m to its south at bore 109136, there is less confidence in its occurrence/thickness immediately upstream of McDonalds Dam at bores 109140 and 109139. As such, there is commensurate uncertainty in the magnitude of drawdown predicted by the model in this area.

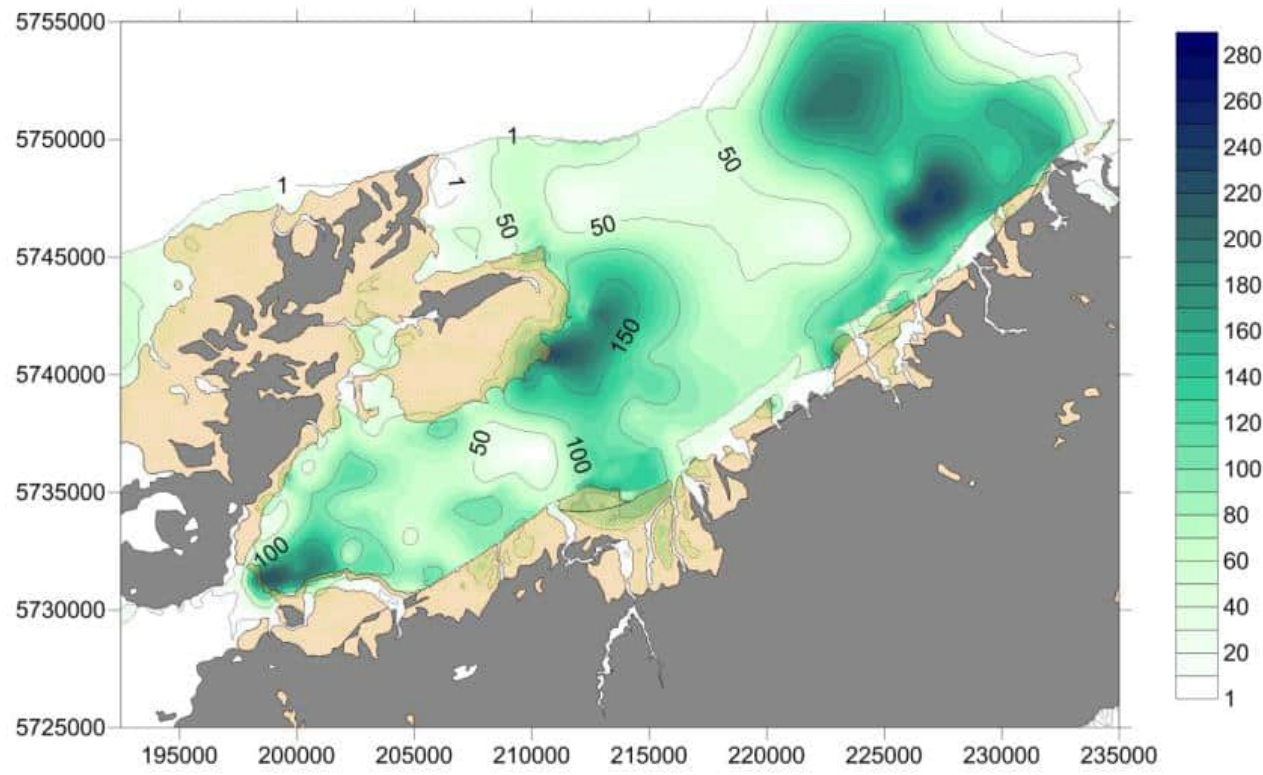


Figure 1-2 Thickness of Dilwyn Formation (Jacobs, 2018a)

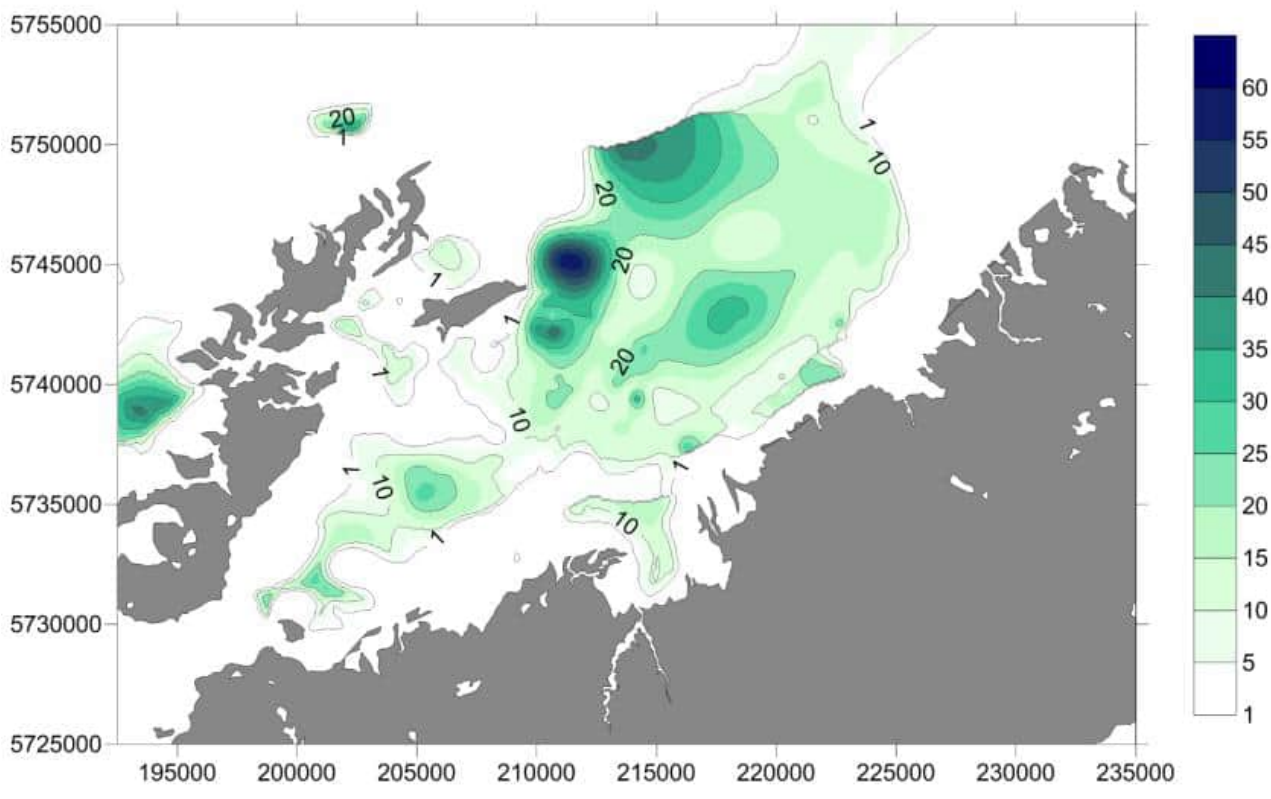
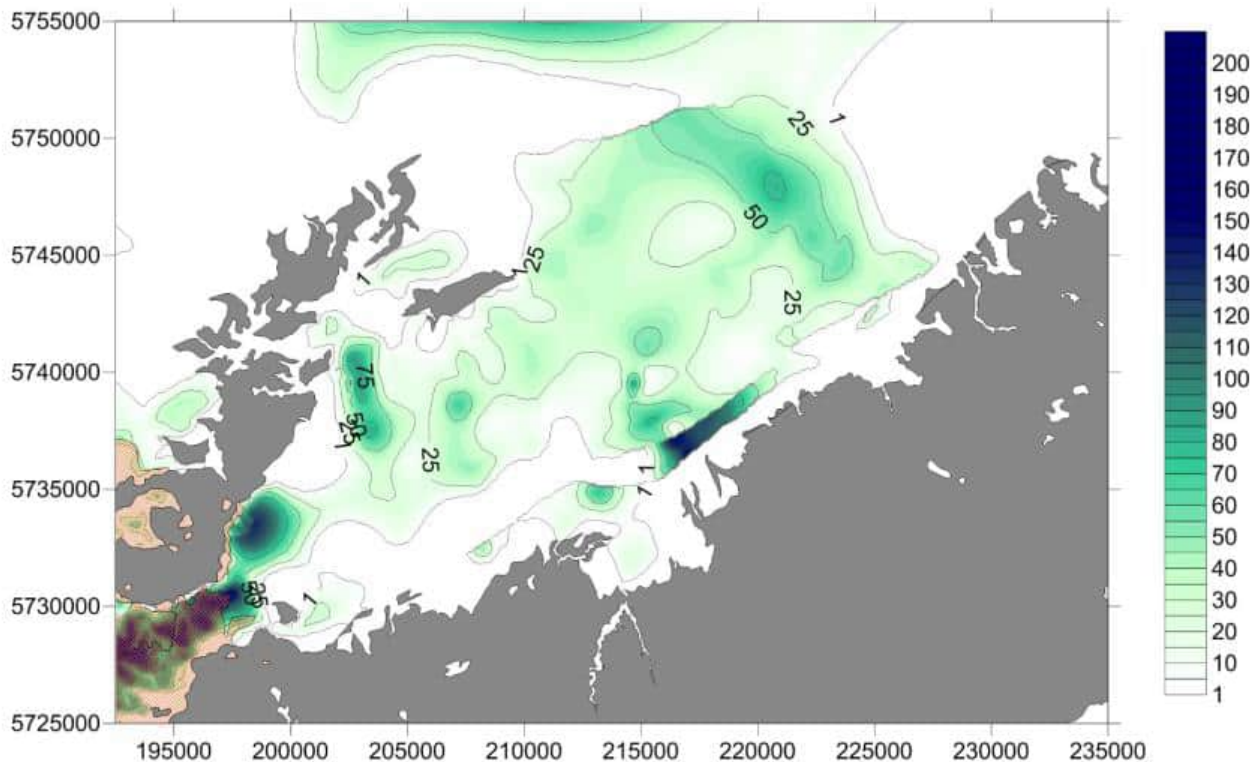


Figure 1-3 Thickness of Pember Mudstone (Jacobs, 2018a)





**Figure 1-4 Thickness of Pebble Point Formation (Jacobs, 2018a)**

While there has been limited groundwater monitoring undertaken in Reach 1b in bores immediately adjacent to Boundary Creek, monitoring was undertaken in 1987-1988 in bores 109139 and 109140. In addition, a groundwater level logger was deployed in bore 109140 in 2014-2015 following development. The average groundwater elevations during these periods is detailed in Table 1-1 below. Assuming that these bores are screened in the LTA based on the crude lithological logs referred to above, monitoring indicates that a decline of approximately 4.5 to 5.0 m has occurred in Reach 1b between 1987 and 2014-2015.

It is also noted that the 2014-15 period is unlikely to represent the maximum drawdown in the LTA in this area, and that some recovery may have occurred between 2012 and 2014. For example, by 2014 there was ~20% recovery observed in bore 109130 adjacent to Reach 2a of Boundary Creek following the 1987-2012 period of drawdown (See Appendix A). While this is downstream of Reach 1b and there have been periods in which supplementary flows have not been passed near bore 109130, if a similar proportion of recovery at bore 109140 is applied, it is possible that the maximum drawdown at bore 109140 may be as high as 6 m.

However, it is also true that groundwater level declines in the LTA can be attributed to climate driven responses. Modelling results indicate that such declines through Reach 1b may have ranged between 0 to 6 m, with 1-2 m of decline most common through the reach (Jacobs 2018a). In addition, potentiometric surface mapping of the LTA (Jacobs, 2017a) suggested approximately 0.6 m of decline could be attributed to climate in unconfined portions of the LTA.

Given the similarity and relative uncertainties in considering the above factors, it is reasonable to assume that a maximum drawdown of approximately 5 m has occurred at 109140 in response to borefield operation.

Groundwater levels were not available at bore 109136 after 2001 and as such, the maximum drawdown in this bore has not been estimated. However, levels in 1987-1988 ranged from 168-170 m AHD and those in 2001 were approximately 154 m AHD, indicating a groundwater level decline of greater than 16 m is likely to have occurred in this bore (Table 1-1). As indicated above, ~0.6 m of this can be attributed to climate responses.

To summarise the above, while there is uncertainty in the predicted drawdown in Reach 1b, and the thickness of the LTA in the reach, the predicted drawdown of 0-10 m and measured drawdown of ~5 m in this area are

reasonably consistent. Given that these figures fit well with previous conceptualisations, they support our understanding that borefield related drawdown has occurred in this area.

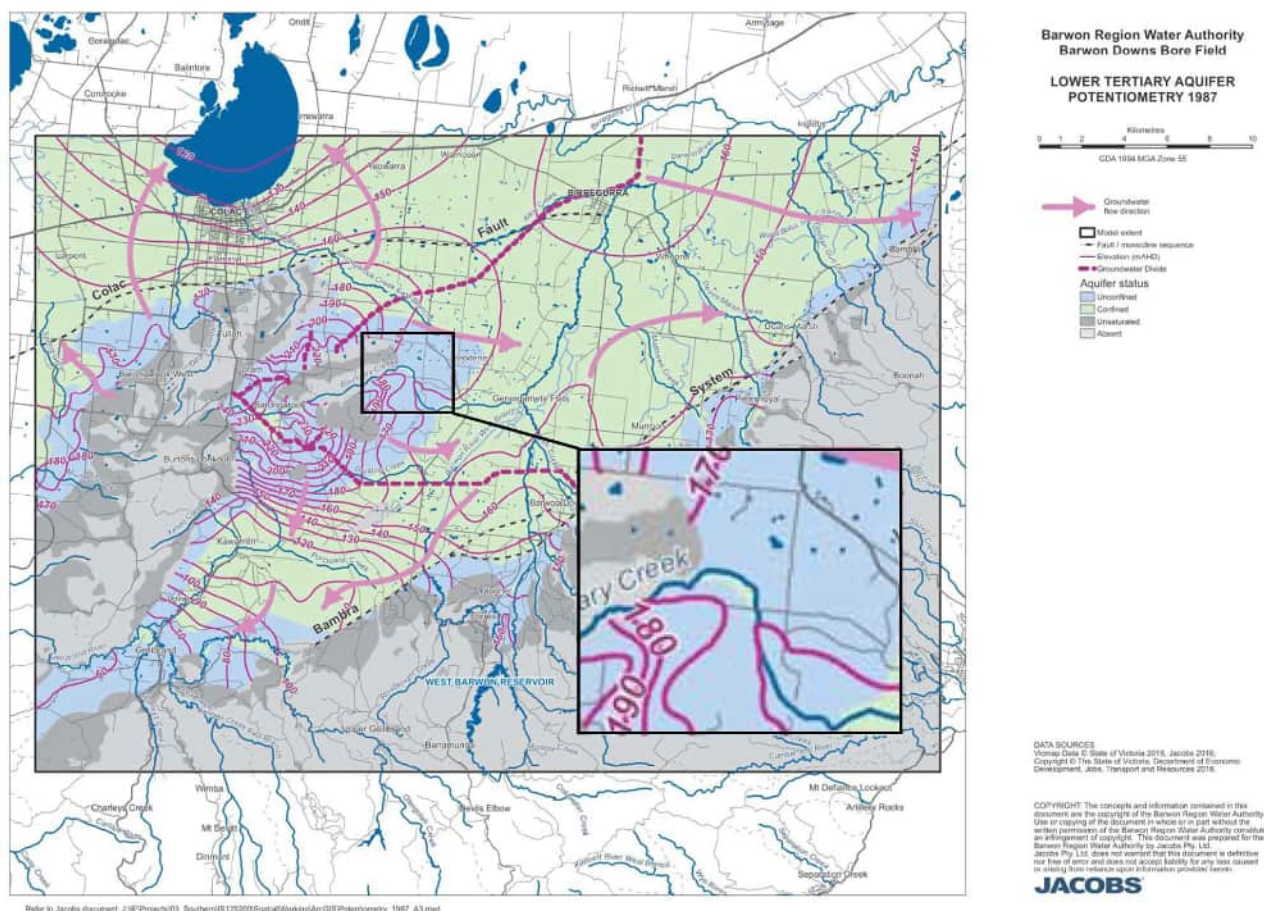
**Table 1-1 Average annual groundwater levels in 109139, 109140 and 109136**

Year	109136	109139	109140
1987	169.95	165.61	166.24
1988	168.76	165.39	165.74
2001	153.92	-	-
2014	-	-	161.52
2015	-	-	161.19

## 1.2 Reduction in groundwater discharge

The ITRP have highlighted that potentiometric surfaces in the LTA show that Reach 1b was previously a gaining stream (i.e. contours 'bent' around the stream alignment and pointing upstream), and that it is not so now. The potentiometric map for 1987 referenced by the ITRP is illustrated in Figure 1-5 below, with an enlargement of Reach 1b provided.

Firstly, and as highlighted above, the potentiometric surfaces generated for Reach1b are subject to the same uncertainty driven by the occurrence/thickness of the LTA upstream of bore109130. Secondly, and as illustrated in the enlargement below, the 160 m AHD contour only crosses Boundary Creek downstream of McDonalds Dam in Reach 2a. As such, the potentiometric surface presented only suggests that Reach 2a of Boundary Creek was gaining in 1987, not Reach 1b.



**Figure 1-5 Potentiometric surfaces in the LTA (Jacobs, 2017)**

Regardless of the above, a review of measured groundwater levels in this area to assess the potential for borefield related drawdown to have impacted groundwater discharge to Reach 1b has also been considered. To do this, groundwater levels from bore 109136 have been used to represent groundwater levels at the upstream end of Reach 1b and groundwater levels in bore 109140 used to represent groundwater levels at the downstream end of Reach 1b. It is noted that bore 109136 is more than 5 m higher in elevation than Boundary Creek ~400 m to its north and as such, are likely to provide an upper estimate of groundwater levels at the upstream end of Reach 1b.

Accordingly, as detailed in Table 1-1, and following the assumptions made above:

- Groundwater levels may have fallen from 169.95 m AHD to <153.92 m AHD at bore 109136 due to borefield related drawdown, though ~0.6 m of this may be related to climate.
- Groundwater levels may have fallen from 166.24 m AHD to 161.24 m AHD at bore 109140 due to borefield related drawdown.

The surface elevation of the streambed in Reach 1b falls from approximately 170 m AHD at the upstream end of Reach 1b to approximately 168 m AHD upstream of McDonalds Dam, while the elevation of the dam itself is between 167 and 168 m AHD (Figure 1-6).

Groundwater levels in bore 109136 were at or below creek bed elevation in 1987-1988. Given that (1) these levels are likely to reflect an upper estimate of groundwater levels at the upstream end of Reach 1b and that (2) climate related reductions in groundwater levels of ~0.6 m are likely to have occurred in this area, it is likely that the upstream end of Reach 1b has been neutral/losing historically, and almost certainly would have become losing following climate driven reductions in groundwater levels.

Groundwater levels in bore 109140 were more than 1.5 m below creek bed elevation in 1987-88 and as such, the downstream end of Reach 1b is likely to have been historically losing.

A schematic representation of streambed and groundwater elevations in Reach 1b have been provided in Figure 1-7 for illustrative purposes.

Given the above, it is unlikely that there has been any reduction in groundwater discharge to Reach 1b due to borefield related drawdown.



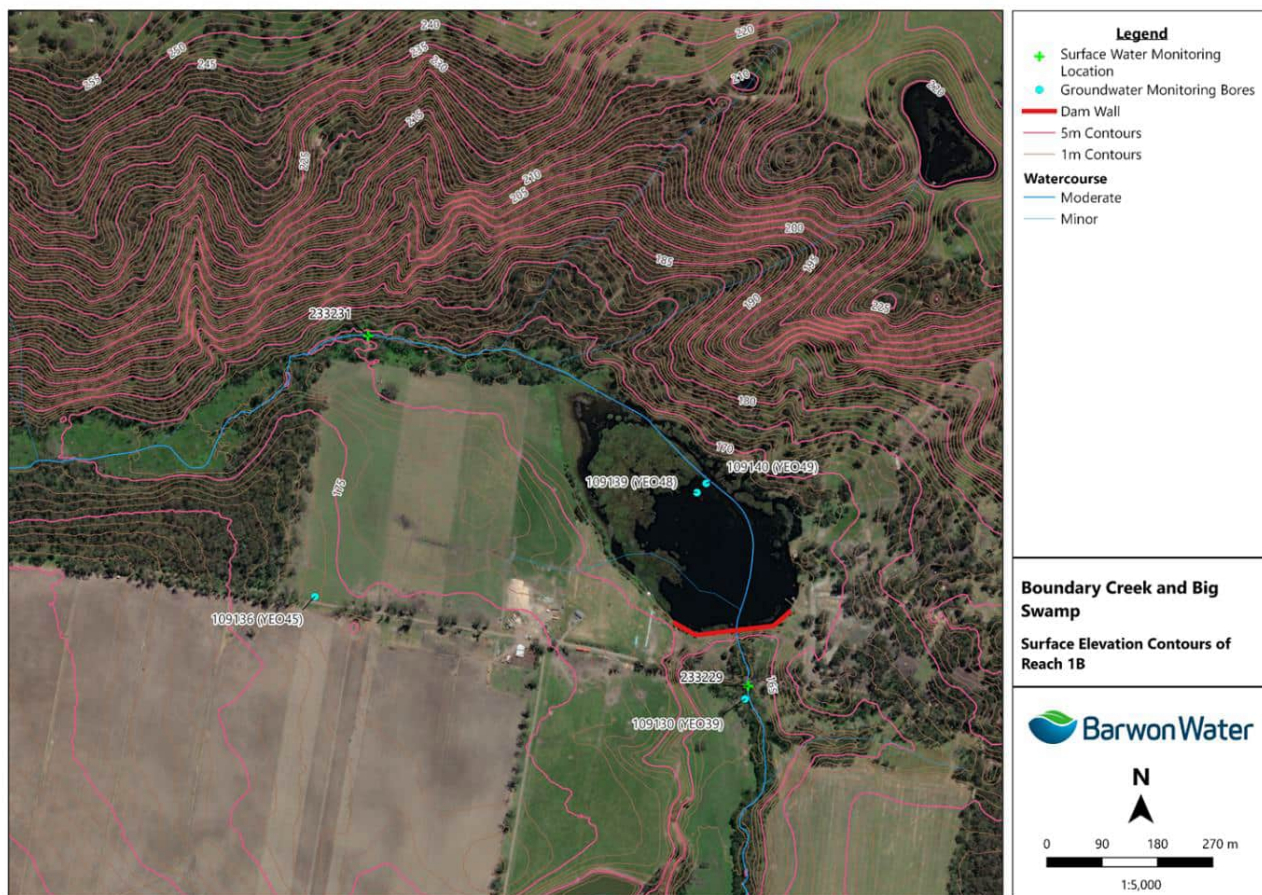


Figure 1-6 Surface elevation contours of Reach 1b

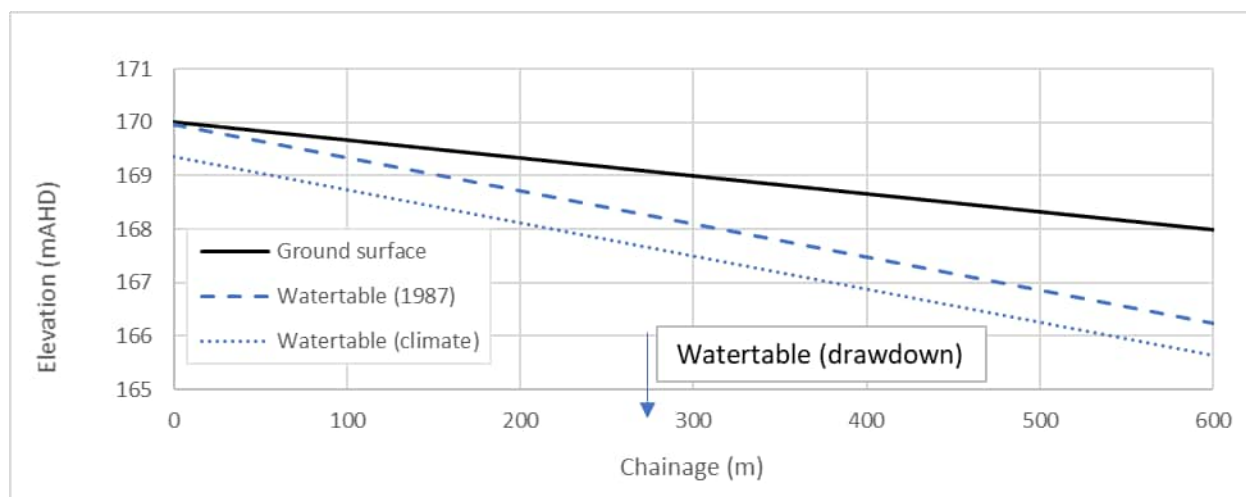


Figure 1-7 Schematic representation of streambed elevation and groundwater elevations in Reach 1b in 1987 and following a 0.6 m reduction due climate impact (borefield related drawdown off scale)

### 1.3 Adverse water quality changes

This section presents surface water quality monitoring downstream of Reach 1b to assess any potential adverse water quality impacts to the reach which may have occurred in response to borefield operation. During the development of the REPP, timeseries pH and EC data at gauge 233229 was available, along with

more detailed water chemistry provided during sampling in 2017. This section builds on the pre-existing data with subsequent timeseries monitoring and an additional sampling event undertaken in 2022.

Surface water quality monitoring has been undertaken between 2014 and 2022 at stream gauge 233229 downstream of Reach 1b (WMIS, 2022). Surface water pH data at this gauge is illustrated in Figure 1-8 for good quality data records. It is noted that there are periods in April and June 2019 when pH readings ranged between 5 and 9. These were preceded by flow gauging error codes which indicate a combination of “site dry” and “data lost due to natural causes” which were not recorded in the pH data set. As such, it is likely that these pH readings in April and June reflect logger drift.

Regardless, the data show that surface water pH generally ranges between 6 and 8. The Environment Reference Standard (ERS) for rivers and streams in the lowlands of the Barwon River catchment (EPA, 2017) prescribes a pH range of 6.8 to 8.0 at the 25<sup>th</sup> to 75<sup>th</sup> percentiles. The data indicate a range of 6.7-7.0 at these percentiles and is broadly consistent with the ERS.

Surface water electrical conductivity (EC) has also been illustrated for this gauge in Figure 1-9. This indicates that surface water electrical conductivity is approximately 400  $\mu\text{S}/\text{cm}$  on average over the monitoring period, though an increase in EC to  $\sim 2,000$   $\mu\text{S}/\text{cm}$  was recorded during November 2021. The recorded average annual flow in November 2021 was 0.05 ML/day, indicating extremely low flow or flow cessation. This may have resulted in sediment build up on the logger resulting in erroneous readings or perhaps the evapo-concentration of stagnant water at the gauging station. Regardless, the 75<sup>th</sup> percentile of EC at the gauge is 454  $\mu\text{S}/\text{cm}$  and below that of the ERS value of 2,000  $\mu\text{S}/\text{cm}$ .

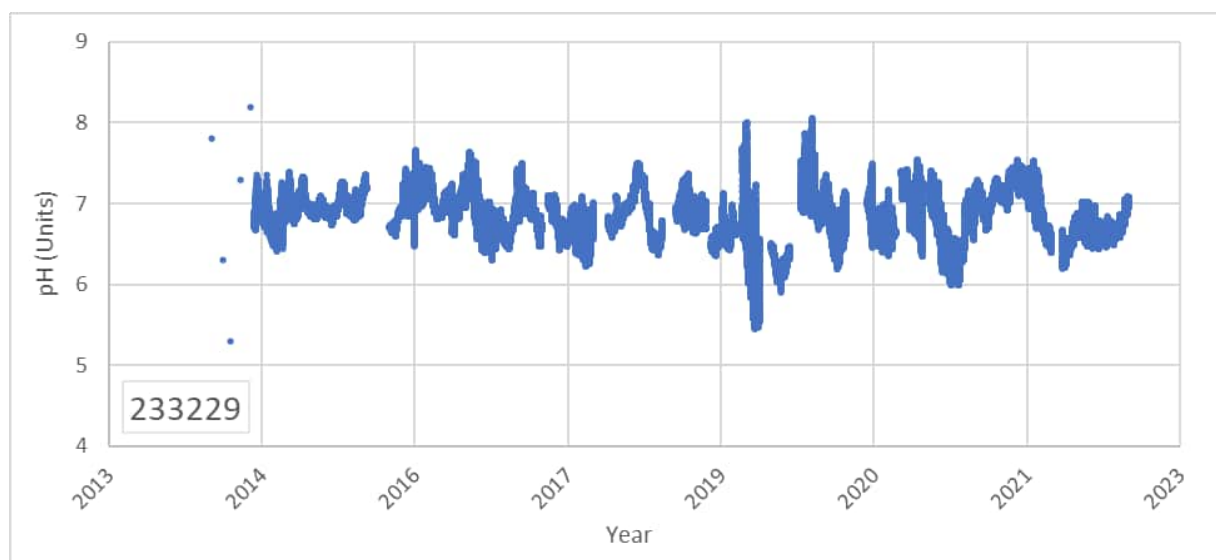


Figure 1-8 Surface water pH at stream gauge 233229

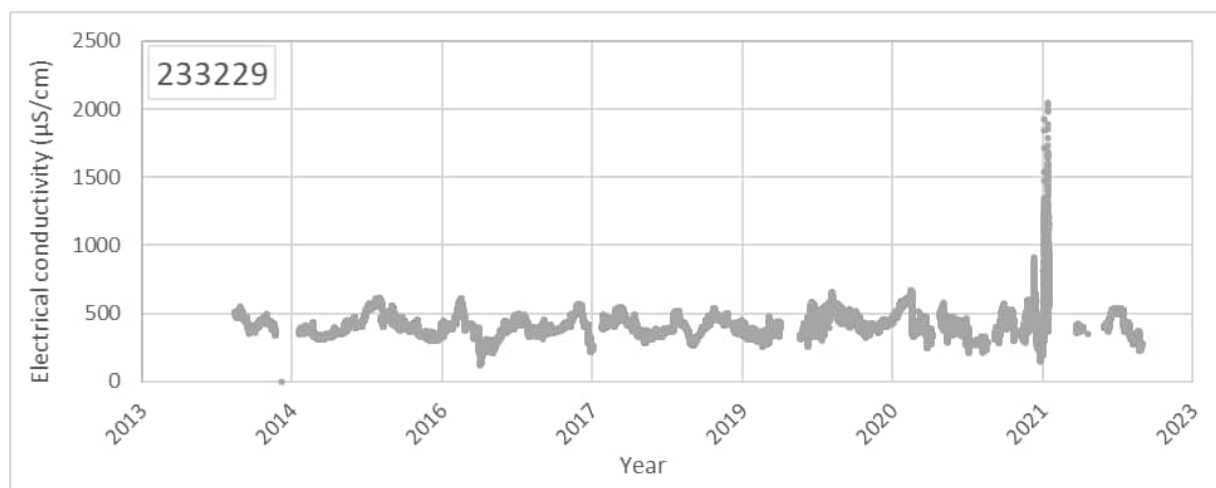


Figure 1-9 Surface water EC at stream gauge 233229

Detailed surface water chemistry analysis was undertaken downstream of Reach 1b as part of the Yeodene Swamp Study (Jacobs, 2017b) at McDonalds Dam, in Reach 2b (the damp lands) and upstream of Big Swamp. This was used to help inform the exclusion of Reach 1b from the confirmed area of impact in the REPP. Subsequent sampling undertaken by Austral (2022) at McDonalds Dam and upstream of Big Swamp has been used in this section to support this data. The results of these sampling events has been detailed in Table 1-2.

The results indicate that relevant WQGV were exceeded in selected samples for:

- Nitrogen and phosphate
- Aluminium
- Zinc

Exceedances in Nitrogen and Phosphate are likely to be related to runoff from local agricultural land and not related to borefield operation.

Exceedances in Aluminium were only recorded in August 2017 under high flow conditions. These are likely to reflect particulate Aluminium under high flow conditions when turbidity was elevated. This has been discussed in the Boundary Creek system previously (Jacobs, 2021).

The exceedance for Zinc only occurred on one occasion at one location and was not recorded immediately downstream of Reach 1b. It is noted that Zinc exceedances have been recorded in other upland areas of the Barwon Downs region (Austral, 2019) and appear unrelated to borefield operation.

In summary, the above data do not suggest borefield related declines in surface water quality in Reach 1b. The pH and EC of water in the reach is consistent with the ERS. Exceedances in metal concentrations have occurred with respect to aluminium and zinc, however these are likely to reflect a combination of analytical error and natural conditions. Exceedances with respect to nutrients (Total N and Phosphate) are likely to be related to runoff from local agricultural land and not borefield operation.

**Table 1-2 Detailed water quality analysis downstream of Reach 1b (WQGV exceedance highlighted in blue)**

Analyte	WQGV <sup>1</sup>	D/S McDona lds Dam	Damp lands	U/S Big Swamp	Damp lands	U/S Big Swamp	D/S McDona lds Dam	U/S Big Swamp
		Aug-17	Aug-17	Aug-17	May-17	May-17	May-22	May-22
<b>Nutrients</b>								
Ammonia (as N)	0.9	0.12	0.09	0.18	0.32	0.02		
Nitrate (as N)	-	0.16	0.15	< 0.02	1.3	0.06		
Total Nitrogen (as N)	1.1	0.28	0.24	0.18	2.1	0.4		
Phosphate total (as P)	0.06	0.07	0.07	0.08	0.05	0.05		
<b>Major ions</b>								
Calcium	-	5.9	5.8	27	5.3	5.2		
Magnesium	-	7.7	7.7	17	8.1	8.3		
Potassium	-	4.1	4.1	3.4	3.5	3.4		
Sodium	-	59	57	66	46	46		
Chloride	-	120	140	160	97	96		
Fluoride	-	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5		
Sulphate (as SO <sub>4</sub> )	-	7.2	7.8	16	6.2	5.8		
<b>Alkalinity (speciated)</b>								
Bicarbonate Alk. (CaCO <sub>3</sub> )	-	< 20	< 20	72	30	31	35	30
Carbonate Alk. (CaCO <sub>3</sub> )	-	< 10	< 10	< 10	< 10	< 10		
Hydroxide Alk. (CaCO <sub>3</sub> )	-	< 10	< 10	< 10	< 10	< 10		



Analyte	WQGV <sup>1</sup>	D/S McDona lds Dam	Damp lands	U/S Big Swamp	Damp lands	U/S Big Swamp	D/S McDona lds Dam	U/S Big Swamp
Total Alk. (CaCO <sub>3</sub> )	-	< 20	< 20	72	30	31		
<b>Heavy Metals</b>								
Aluminium	0.055	0.17	0.16	0.23	< 0.05	< 0.05	< 0.01	0.01
Arsenic	0.013	< 0.001	< 0.001	0.002	< 0.001	< 0.001	< 0.001	0.001
Cadmium	0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Chromium	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Copper	0.0014	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Iron	-	0.92	0.91	3.4	0.5	0.37	0.39	0.59
Lead	0.0034	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Manganese	1.9	0.05	0.065	0.098	0.026	0.015	0.015	0.019
Mercury	0.0000 6	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Nickel	0.011	< 0.001	< 0.001	0.007	< 0.001	< 0.001		
Zinc	0.008	0.005	0.008	0.008	0.01	0.005	0.007	0.007
Ferric Iron - Fe <sup>3+</sup>	-	0.35	0.41	0.2	0.48	0.17		
Ferrous Iron - Fe <sup>2+</sup>	-	0.57	0.51	3.2	0.25	0.3		

<sup>1</sup> WQGV as indicated for slightly disturbed freshwater ecosystems as indicated at <https://www.waterquality.gov.au/anz-guidelines/guideline-values>

## 1.4 Impacts on ecology

While there haven't been any specific studies focussed specifically on Reach 1b of Boundary Creek, previous work has characterised the ecological condition of Reach 1 in general (Jacobs, 2018b).

The major findings of these investigations concluded that Reach 1 was in good ecological condition. Much of the natural channel form has been maintained with long runs and intermittent pools likely providing habitat for small native fish and frogs. Large sections of native riparian, fringing and aquatic vegetation are intact, however, Blackberry dominates the understorey in many locations. It was also found that Reach 1 is likely to have been made more suitable for fish, macroinvertebrates and frogs by the supplementary flow released by Barwon Water, though significant improvement in vegetative communities is unlikely to have occurred in response to supplementary flows.

Given this, it was concluded that the ecological condition of Reach 1 remained good and therefore, negative impacts as a result of historical management of groundwater extraction from the Barwon Downs borefield were unlikely.

## 1.5 Summary

In summary, the above indicates that:

- As previously acknowledged and predicted, borefield related drawdown has occurred in Reach 1b, as evidence by drawdowns predicated in the groundwater model and a drawdown of ~5 m recorded at bore 109140.
- Monitoring indicates that this reach was losing prior to borefield operation, as evidence by historical groundwater levels prior to drawdown being below creek bed elevation at bores 109139 and 109140 and levels slightly below creek elevation at bore 109136. This indicates that borefield operation would not have reduced groundwater discharge to Reach 1b.
- Water quality in Reach 1b is generally good and within relevant WQGV's. Isolated exceedances of WQGV's do not appear to be related to borefield operation and instead, appear to be related to a

combination of nearby agricultural land use (resulting in N and P exceedance), monitoring error (resulting in Al exceedance) and natural conditions in the catchment (resulting in Zn exceedance).

- The ecological condition of Reach 1 remains good and made more suitable for fish, macroinvertebrates and frogs by the supplementary flow release. As such, it is unlikely that borefield operation has had a negative impact on its ecological health.

These findings have been summarised in Table 1-3 below. Accordingly, while it can be confirmed that groundwater levels in Reach 1b have declined in response to borefield operation, there has been no reduction in groundwater discharge, surface water quality or ecological condition. As such, it can be concluded that Reach 1b has not been subject to environmentally significant adverse impacts related to borefield operation and hence, supports the decision not to include reach 1b of Boundary Creek in the area of confirmed impact requiring remediation.

**Table 1-3 Summary of potential impacts to Reach 1b associated with borefield related drawdown**

<b>Consideration</b>	<b>Impact</b>	<b>Comment</b>
Borefield related drawdown	Confirmed	Model suggests drawdown, monitoring suggests ~5 m of borefield related drawdown.
Groundwater discharge	Nil	Reach confirmed to be losing prior to borefield operation or would have become losing due to climate, nil impacts confirmed.
Water quality	Nil	Water quality downstream is generally within WQGV's. Isolated exceedances (Al, Zn, N and P) are unrelated to borefield operation.
Ecological condition	Unlikely	Ecological condition of Reach 1 remains good

**Figure 2-1 Drilling Log for 109130**

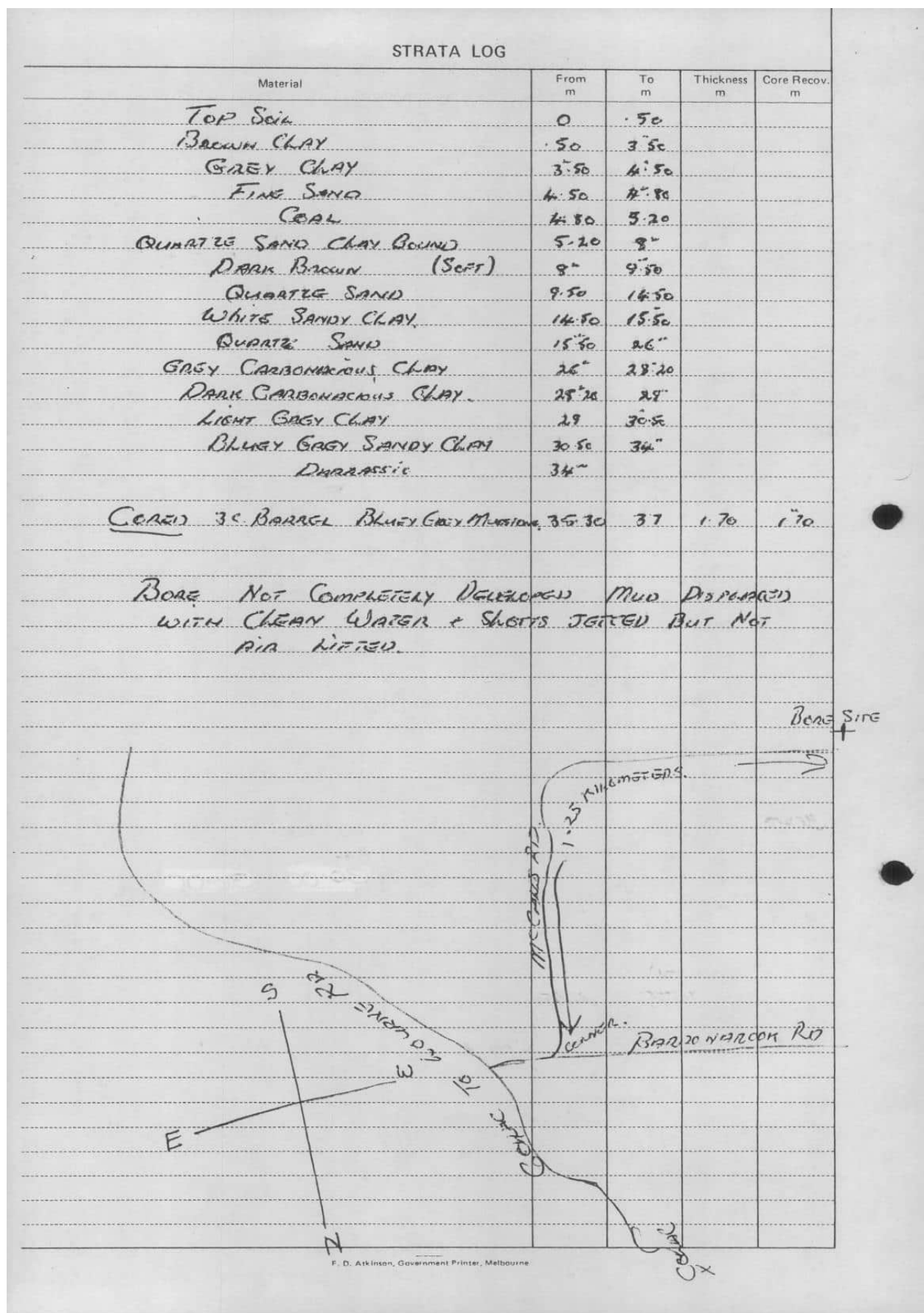


Figure 2-2 Drilling Log for 109136

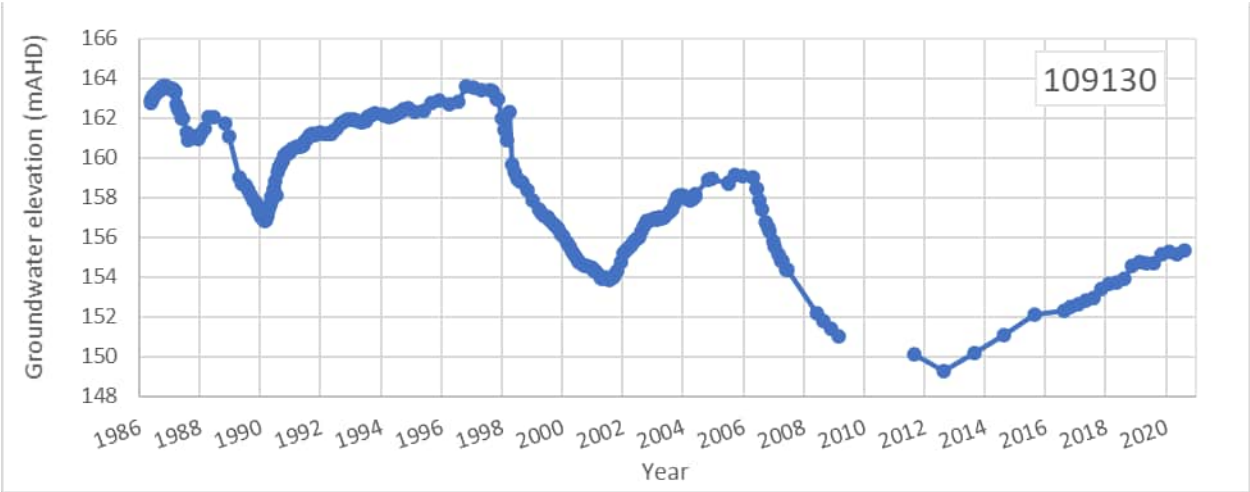


Figure 2-3 Groundwater hydrograph at 109130

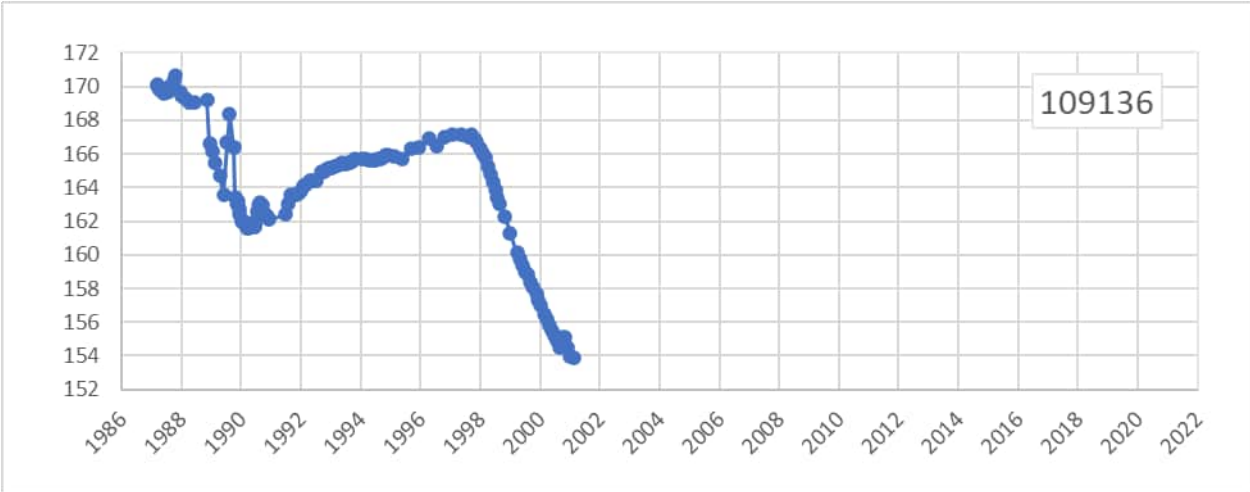


Figure 2-4 Groundwater hydrograph at 109136

### 3. References

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