Low Flow Recommendations for Boundary Creek

Barwon Water

Final Draft - 04

11 July 2018

Low Flow Recommendations for Boundary Creek

Project No:	IS191000
Document Title:	Low Flow Recommendations for Boundary Creek
Revision:	Final Draft - 04
Date:	11 July 2018
Client Name:	Barwon Water
Client No:	000695
Project Manager:	Louise Lennon
Author:	Dr Joshua Hale, Professor Paul Boon, Josh Griffiths, Amanda Woodman, Dr Simon Treadwell, Dr Andrew Sharpe

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

Contents

Executive Summary

Key Findings

- Boundary Creek can be divided into three reaches which exhibit broadly uniform geomorphology, hydrology, hydrogeology and system operation. The three reaches are
  - Reach 1 - Upstream of “McDonalds Dam”
  - Reach 2 – “McDonalds Dam” outlet to the downstream end of Yeodene Swamp. *Reach 2 consists of three distinct habitats and has therefore been further divided into three sub-reaches - Reach 2a (channelised section immediately downstream of McDonalds Dam), Reach 2b (the “dampland”, a densely vegetated, floristically diverse marsh and Reach 2c (Yeodene Swamp).*
  - Reach 3 - Downstream of Yeodene Swamp to the confluence with the Barwon River.
- The lower reach of Boundary Creek rarely stopped flowing at the Yeodene gauge prior to 1999, but since then, flow has ceased for long periods in summer and autumn in most years. The pH recorded in the creek at the Yeodene gauge shows a step-change decrease over a similar timescale: the median pH measured at Yeodene prior to 1999 was 6.1, but from 1999 onwards it has been 3.8.
- Under the conditions of the current groundwater extraction licence, Barwon Water is required to provide supplementary flow (currently 2 ML/day) to Boundary Creek to mitigate potential impacts on stock and domestic users (primarily in Reach 3) from extraction from the Barwon Downs borefield. Review of data from the surface water gauges along the creek shows that since monitoring commenced in 2015, the entirety of the supplementary flow (which is usually 2 ML/day and is released into a tributary of Reach 1 of Boundary Creek) has not been passed through “McDonalds Dam” during the summer months (contrary to the conditions of its operation). Flow downstream of the dam is typically less than 1 ML/day during the summer months. There are no monitoring data available prior to 2015 suitable to assess whether the supplementary flow was released downstream of the dam before this time.
- Management objectives for the Boundary Creek catchment have been defined per reach and sub-reach and are to:
  - **Maintain** current ecological condition in Reach 1 (upstream of McDonalds Dam), Reach 2a (channelized section downstream of dam) and Reach 2b (the “damplands”).
  - **Improve** the current ecological condition in Reaches 2c (Yeodene Swamp) and Reach 3.
- The objective of this study is to quantify the minimum low flow volume required to support the current ecological values in Boundary Creek. Due to their varying ecological and hydraulic characteristics, the minimum low flows required to support the ecological values of each reach have been identified independently from each of the other reaches, without consideration of the operational constraints of the system and are outlined in the table below. If a higher flow is required through an upstream reach in order to deliver the recommended flow in a downstream reach, this would not be detrimental to the values or objectives of the upstream reach. The low flow recommendations represent the **minimum** flow required to achieve objectives. The minimum low flows for each reach and sub-reach are summarised in Table 0-1.

Table 0-1 Summary of the minimum low flow volume required to support the ecological values of each reach of Boundary Creek. The compliance point identifies the flow gauge where flow of the relevant volume needs to be recorded to meet the **ecological objectives of that reach. For example, 1.5 ML/day needs to be recorded at the gauge downstream of "McDonalds Dam" to meet the objectives of Reach 2b, while 3 ML/day needs to be recorded at that gauge to meet the objectives of** Reach 2c.

Boundary Creek reach	Management objective	Minimum low flow volume recommendation	Compliance point for the minimum low flow recommendation
Reach 1	Maintain	0.5 ML/day	Gauge upstream of "McDonalds Dam"
Reach 2a Reach 2b Reach 2c	Maintain Maintain Improve	0.5 ML/day 1.5 ML/day 3 ML/day	Gauge downstream of "McDonalds Dam"
Reach 3	Improve	0.5 ML/day	Gauge at Yeodene

- The current study considers the volume of low flow required to support the ecological values of Boundary Creek. While the flow volumes recommended are sufficient to mix the pools in Boundary Creek, this study assumes that the ambient water is of suitable quality (particularly pH) to support the targeted species and communities. The provision of suitable quality water in Reach 3 will require remediation of the Yeodene Swamp, which is discussed in detail in the *Yeodene Swamp Study* (Jacobs 2017c).

Background

The Barwon Downs borefield is operated under licence from Southern Rural Water and provides a drought resilient water source for greater Geelong. At the height of the worst drought on record (2006-10), Geelong's water storages dropped to 14 per cent with the borefield brought online to supplement the shortfall. This licence is due for renewal in mid-2019.

Using groundwater has generated community concern about impact to the local environment. In response to these concerns, Barwon Water has carried out a program of technical studies and increased monitoring activities.

As part of these technical studies, the ecological values (e.g. species, communities) in the Boundary Creek catchment were reviewed (Jacobs 2017a). Informed by the outcomes of Jacobs (2017a) the current study quantifies the low flow volume that would be necessary in each reach and sub-reach of the creek to support the key ecological values.

Objectives

The objective of this study is to quantify the minimum low flow volume required to support the current ecological values in Boundary Creek. The flow recommendations for the "damplands" and Yeodene (Big) Swamp, have been considered in detail as part of a separate study, the *Yeodene Swamp Study* (Jacobs 2017c), and the results are incorporated into the current study. The purpose of the *Yeodene Swamp Study* is to characterise the chemical and physical processes affecting the volume and quality of water which will be used to inform potential strategies to help manage current water quality issues in the lower reaches of Boundary Creek.

This study considers only the volume of low flow required to support the ecological values of Boundary Creek and assumes that the water is of suitable quality (particularly pH) to support the species and communities of Boundary Creek. The provision of suitable quality water in Reach 3 will require remediation of the Yeodene Swamp, which is discussed in detail in the *Yeodene Swamp Study* (Jacobs 2017c).

Approach

The low flow volume required to support the aquatic values of Boundary Creek has been determined using an approach adapted from the FLOWS method, which is the standard method used to define environmental flow requirements for Victorian waterways (DEPI 2013). The most significant adaptation is that the current study focusses on low flows, as this is the flow component most likely to be affected by changes to groundwater-surface interactions due to the operation of the Barwon Downs borefield.

The FLOWS method assembles a panel of technical specialists, who in consultation with a range of stakeholders, including local residents, define a set of management objectives for a waterway. The targeted physical and ecological outcomes in the creek required to achieve the management objectives are also defined. The flows required to provide the physical and ecological outcomes are then determined with the use of hydraulic models of the waterway to link flow volume with water level, hydrological information of the catchment and literature which describes the flow requirements of the key species or communities.

Summary of Findings

Table 0-2 provides a consolidated summary of the ecological condition assessment of each reach and sub-reach (i.e. good, moderate or poor ecological condition), the management objective (i.e. maintain or improve) and associated targeted outcomes and the low flows required to meet the management objectives. A map indicating the minimum low flow recommendations for the creek is presented Figure 0-1.

Table 0-2 Ecological condition (i.e. good, moderate, poor), management objectives (i.e. to maintain or improve), targeted physical and ecological outcomes and associated minimum low flow requirements for Boundary Creek.

Reach	Ecological condition	Management objective	Targeted physical and ecological outcome	Flow volume	Description
1	Good	Maintain	• Provide pool habitats for fish, frogs, vegetation. • Allow fish to move between pools. • Mix pools.	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
				Minimum low flow of 0.5 ML/day (measured at the gauge upstream of "McDonalds Dam")	• A flow of 0.5 ML/day corresponds with a water depth of between 30 and 70 cm in pools and 3 cm of water over riffles. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch, Mountain Galaxias), macroinvertebrates and frogs and allow movement of fish between pools.
2a	Moderate	Maintain	• Provide pool habitats for fish, frogs, vegetation. • Allow fish to move between pools. • Mix pools.	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
				Minimum low flow of 0.5 ML/day (measured at the gauge downstream of "McDonalds Dam")	• A flow of 0.5 ML/day corresponds with a water depth of between 70 and 80 cm in pools and 12 cm of water over riffles. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch, Mountain Galaxias) macroinvertebrates and frogs and allow movement of fish between pools.

Reach	Ecological condition	Management objective	Targeted physical and ecological outcome	Flow volume	Description
2b	Good	Maintain	• Maintain waterlogged soils to continue to support Swampy Riparian Vegetation, macro-invertebrates and Otway Bush Yabby.	Cease to flow	• Cease to flow conditions are not required to maintain the condition of the reach, however, he soil in the "damplands" would stay waterlogged for short periods (less than 2 weeks) without inflow with minimal impact on the ecology of the area.
				Minimum low flow of 1.5 ML/day (measured at the gauge downstream of "McDonalds Dam")	• The water balance analysis and volume of water released historically from "McDonalds Dam" indicates that 1.5 ML/day measured at the gauge immediately downstream of "McDonalds Dam" is sufficient to maintain waterlogged soils in the "dampland".
2c	Poor	Improve	• Flow (of any magnitude) recorded at the Yeodene flow gauge throughout the year • Improve the water quality as indicated by pH. Water quality in Boundary Creek is discussed in detail in Jacobs (2017c).	Cease to flow	• Must be prevented. The main objective for this reach is to maintain inundation of the swamp to prevent oxidation of soils and improve water quality in Reach 3.
				Minimum low flow of 1.5 ML/day (to provide 1.5 ML/day in Reach 2c, 3 ML/day needs to be measured at the gauge downstream of "McDonalds Dam")	• Maintain waterlogged soils in the swamp, reducing the oxidation potential of the acid sulphate soils, with the objective of decreasing the incidence of very low pH water in Reach 3. Adaptive management may lead to the refining of the low flow recommendation to ensure flow at the Yeodene gauge is maintained throughout the year. • The water balance analysis and volume of water released historically from "McDonalds Dam" indicates 3 ML/day is required (measured at the flow gauge immediately downstream of "McDonalds Dam") from a volumetric perspective (e.g. independent of the pH of the water) to achieve a flow of 1.5 ML/d at the "damplands" and hence achieve the ecological objectives of the "damplands" and the Yeodene Swamp.
3	Poor	Improve	• Provide pool habitats for fish, frogs, vegetation and possibly occasional use by Platypus. • Provide opportunity for	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).

Reach	Ecological condition	Management objective	Targeted physical and ecological outcome	Flow volume	Description
			fish movement between pools • Minimise frequency and duration of cease to flow events. • Improve the water quality as indicated by pH. Water quality in Boundary Creek is discussed in detail in Jacobs (2017c).	Minimum low flow of 0.5 ML/day (measured at the Yeodene flow gauge)	• A low flow of 0.5 ML/day in Reach 3 corresponds to pools up to 40 cm deep and shallow runs of approximately 6 cm depth. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch), macroinvertebrates and frogs and allow movement of fish between pools. Flow of that depth may also allow occasional use by Platypus that enter the creek from the Barwon River to forage, however, the structural habitat (clear banks) are unsuitable for resident individuals.

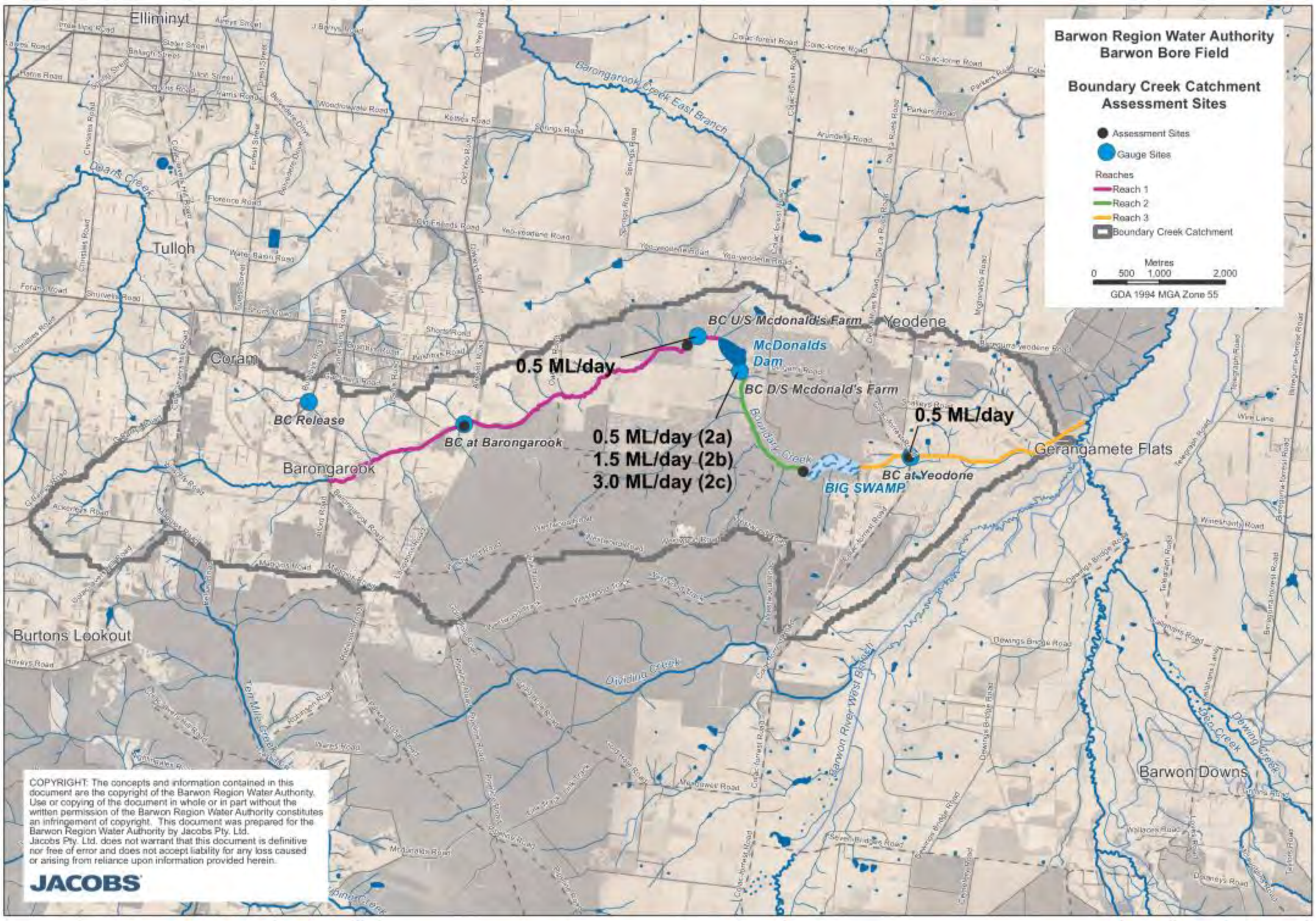

Figure 0-1 Minimum low flow volume recommendations for Boundary Creek.

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.

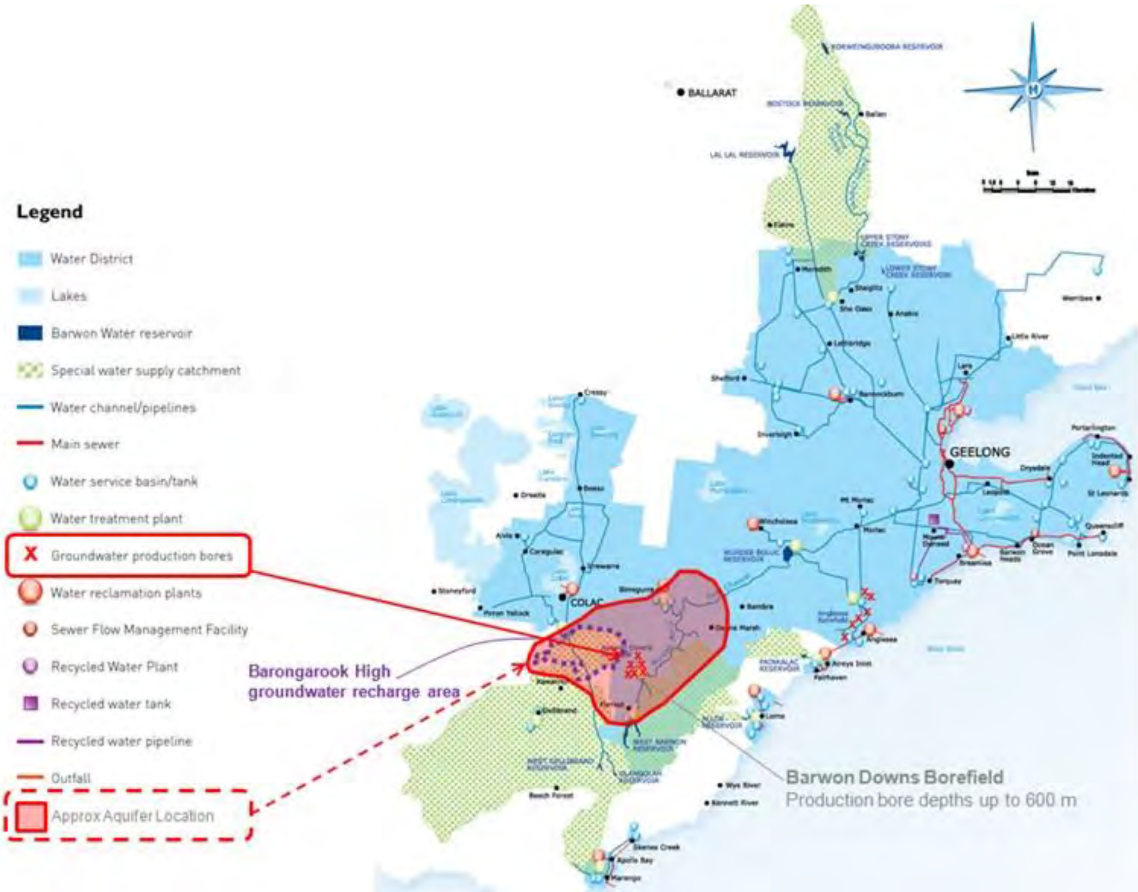

Figure 1-1 Map of the Barwon Downs region including the aquifer extent and the primary groundwater recharge area.

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 (see Figure 1-2). The aquifer covers an area of approximately 500 km2 below the surface and is connected to the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment near Gellibrand. Barongarook High is the main recharge area of the aquifer because of its unconfined nature.

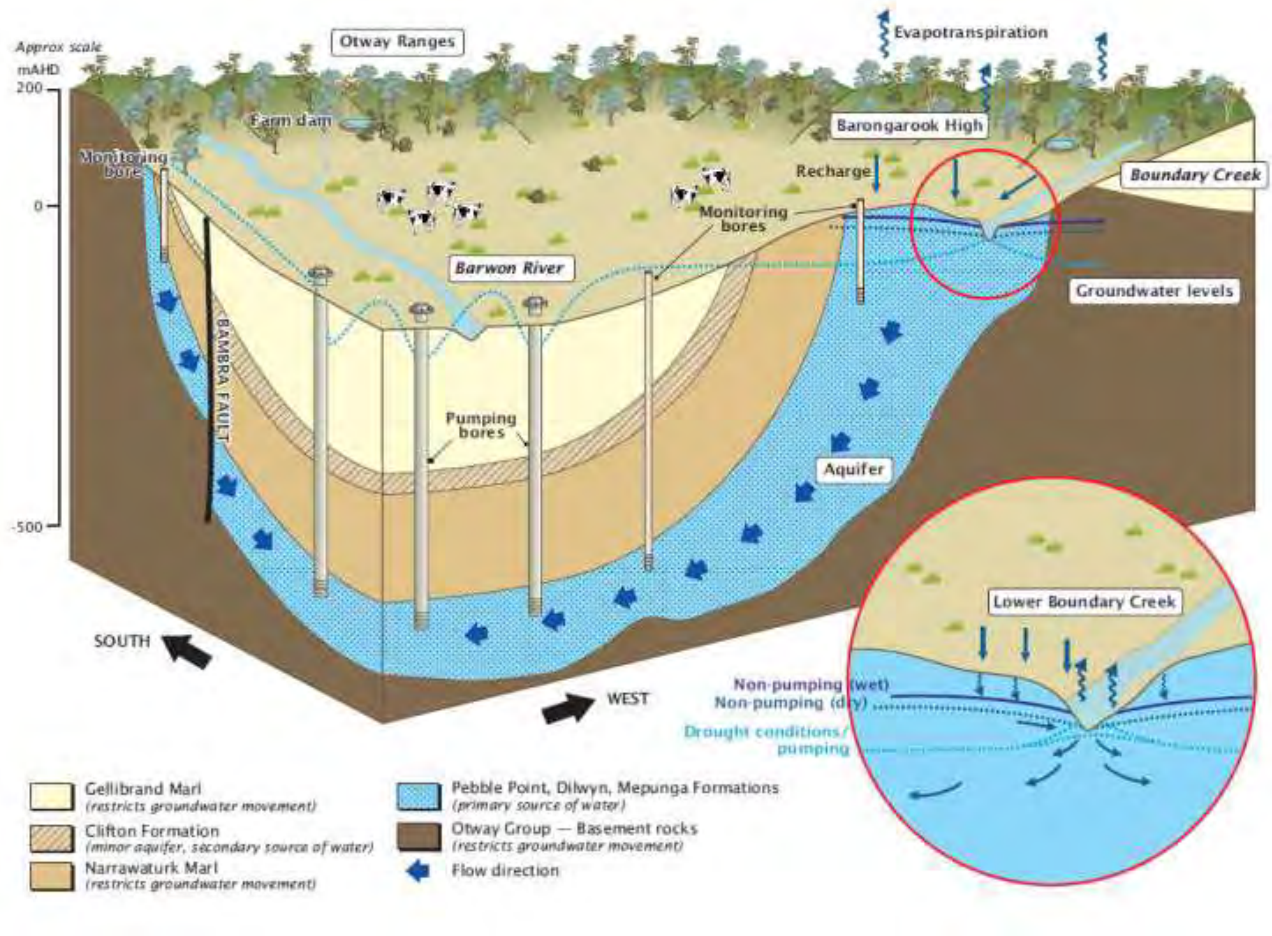

Figure 1-2 Schematic of the Lower Tertiary Aquifer and where it outcrops at the surface.

1.2 History of the Barwon Downs borefield

1.2.1 Borefield history

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

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

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

1.2.2 Groundwater extraction

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

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

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

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

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

1.2.3 Licence history

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

- Extraction for the purpose of urban water supply;
- Maximum daily extraction rate of 42.5 ML;
- Maximum annual extraction rate of 12,600 ML;
- Maximum ten-year extraction 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;

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

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

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

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

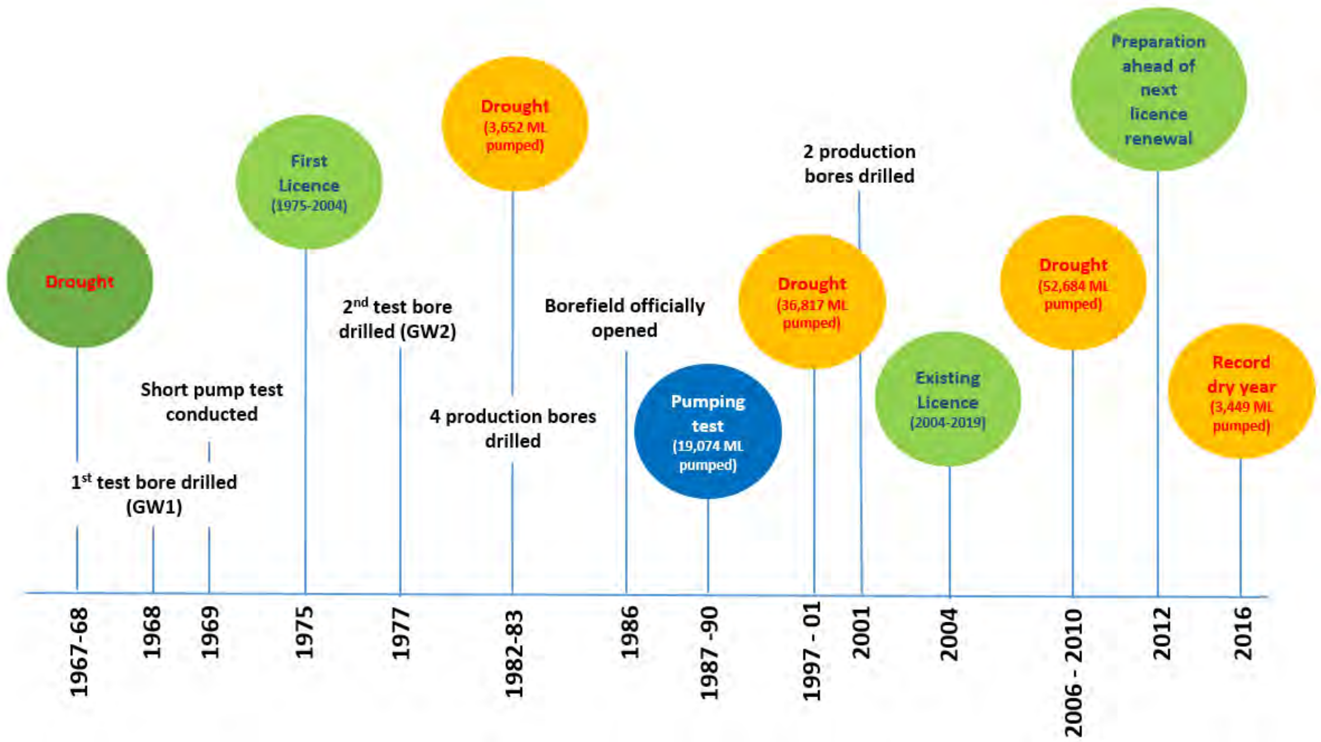

Figure 1-3 Timeline of events that surround the development and use of the Borefield.

1.3 Current groundwater licence

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

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

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

1.4 Strategic drivers for the Barwon Downs technical works monitoring program

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

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

1.4.1 Water security

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

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

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

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

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

1.4.2 Community issues

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

Areas of community interest recently have included the:

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

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

1.4.3 Informing the licence renewal

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

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

1.5 Overview of the technical works monitoring program

1.5.1 Monitoring program development

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

Stage 1: Review of the existing monitoring program

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

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

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

Stage 2: Technical works monitoring program scope refinement

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

- differentiating between groundwater extraction and climate effects on the regional groundwater system,
- understanding the potential risks of acid 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 supplementary flow is effective,
- characterising groundwater dynamics in the aquitard to improve hydrogeological understanding of groundwater flow and quantity, and
- better understanding of groundwater and surface water interaction, particularly along Boundary Creek where groundwater contributes to base flow.

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

Stage 3: Construction of additional monitoring assets

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

- 33 new groundwater monitoring bores drilled, including the replacement of one existing bore,
- 3 existing bores refurbished,
- 4 new potential acid 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.

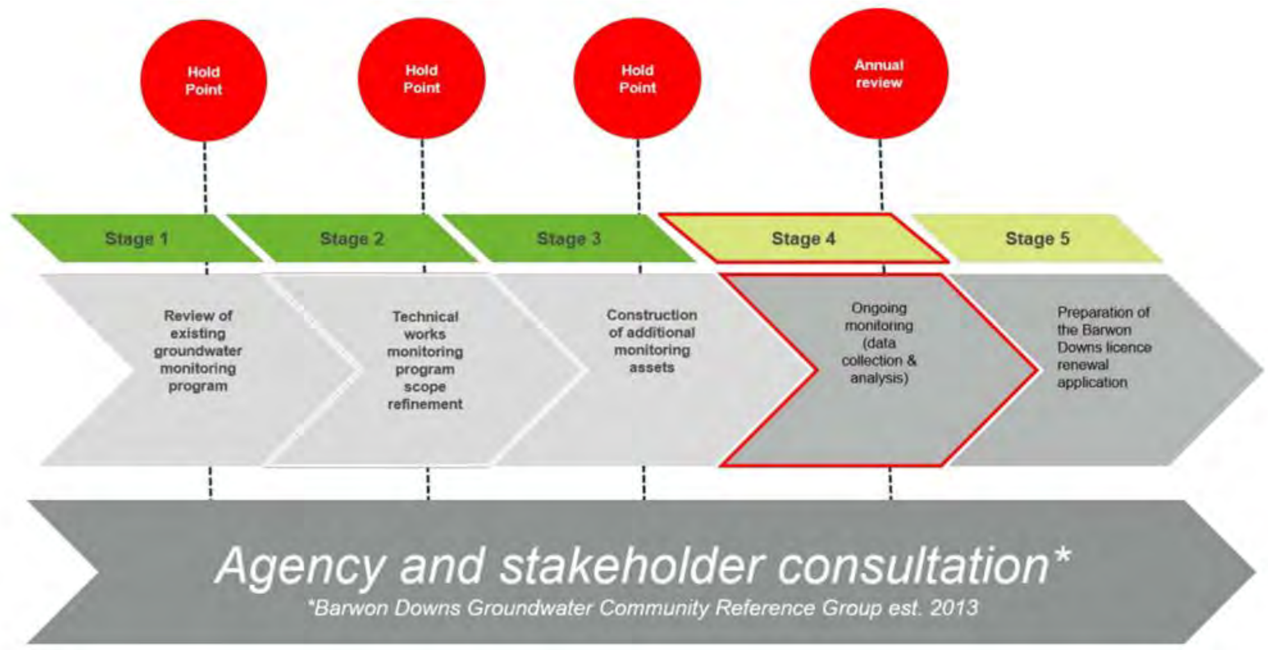

Figure 1-4 Development of the technical works monitoring program.

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.

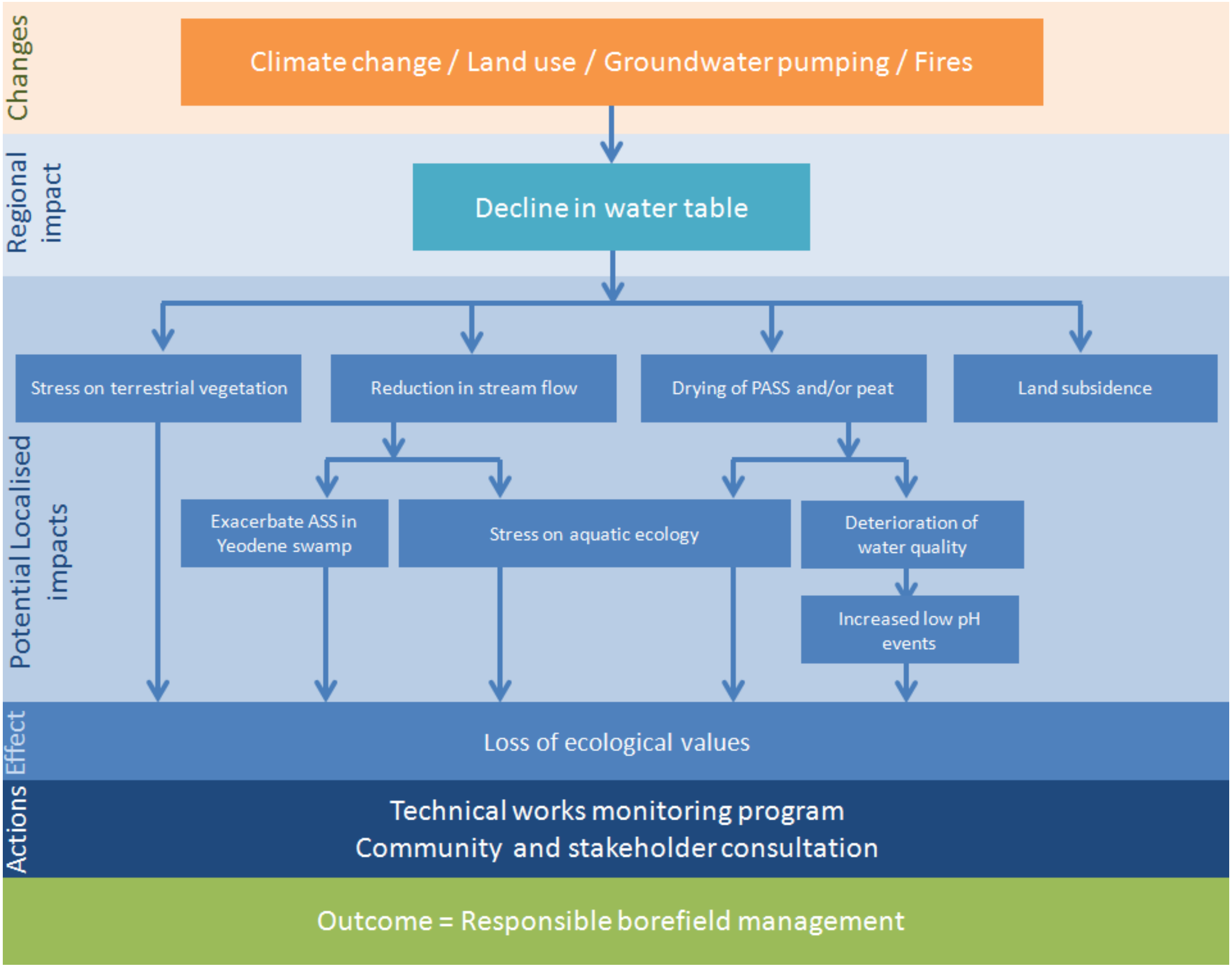

Figure 1-5 Potential impacts in the catchment from changes in the catchment.

1.6 This report

The objective of this study is to quantify the low flow volume that would be necessary in each reach and sub-reach of Boundary Creek to support the key ecological values.

The structure of this report is as follows:

- Chapter 2 outlines a description of the ecological values in Boundary Creek
- Chapter 3 describes the method used to determine the flow requirements
- Chapter 4 outlines the management objectives of Boundary Creek
- Chapter 5 quantifies the low flow volume that would be necessary to achieve the management objectives for the creek.

2. Ecological values supported by Boundary Creek

2.1 Chapter overview

The purpose of this chapter is to provide a brief description of the Boundary Creek catchment, the major changes that have taken place in the catchment since European settlement, the important aspects of the surface water hydrology of the creek and the current ecological values as defined in Jacobs (2017a). This section also presents updates where relevant to the findings of Jacobs 2017a.

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

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

The location of these reaches is shown in Figure 2-1.

Reach 2 consists of three distinct habitats and has therefore been further divided into three sub-reaches (Reaches 2a, 2b and 2c). The three sub-reaches are defined as;

- Reach 2a – Channelised section immediately downstream of McDonalds Dam
- Reach 2b – The “dampland” (a densely vegetated, floristically diverse marsh)
- Reach 2c – Yeodene Swamp

An overview of each reach and the ecological condition is provided in Table 2-1 and more detail is provided in the following sections.

Table 2-1 Overview of the reaches in Boundary Creek.

Reach	Hydrology	Ecological Condition	GW-SW interaction
1	• Enhanced by supplementary flow, which makes up most of the baseflow during summer months.	Good	Gaining from basement aquifer
2a	• "McDonalds Dam" is a major feature of the catchment that impacts flows • Although there is a passing flow requirement for the dam, recorded data (since 2015) demonstrates that not all of the supplementary flow entering the dam is being released.	Moderate	Losing to pumped aquifer
2b	• Contains the "dampland" • No surface water gauging, highly divided flow paths	Good	Losing to pumped aquifer
2c	• Contains Yeodene (Big) Swamp and has been acidified in recent years. • No long term surface water gauging. Comprises highly braided and complex flow paths through centre of the swamp and a channel along the northern boundary, which appears to flow with moderate to high flows.	Moderate to poor	Variable gaining and losing with surficial aquifer
3	• Longest surface water monitoring record (from 1979) • Step change in flow data since 1999, the Yeodene gauge has recorded cease to flow events most years since 1999. • pH recorded in the creek at Yeodene shows a similar step change pattern. The median pH measured at Yeodene prior to 1999 was 6.1 - ranging from 5.2 (25^{th} %ile) to 6.5 (75^{th} %ile), but from 1999 onwards the median has been 3.8 – 3.6 (25^{th} %ile) to 4.4 (75^{th} %ile). See Section 2.3.4.	Poor	Variable gaining and losing with surficial aquifer

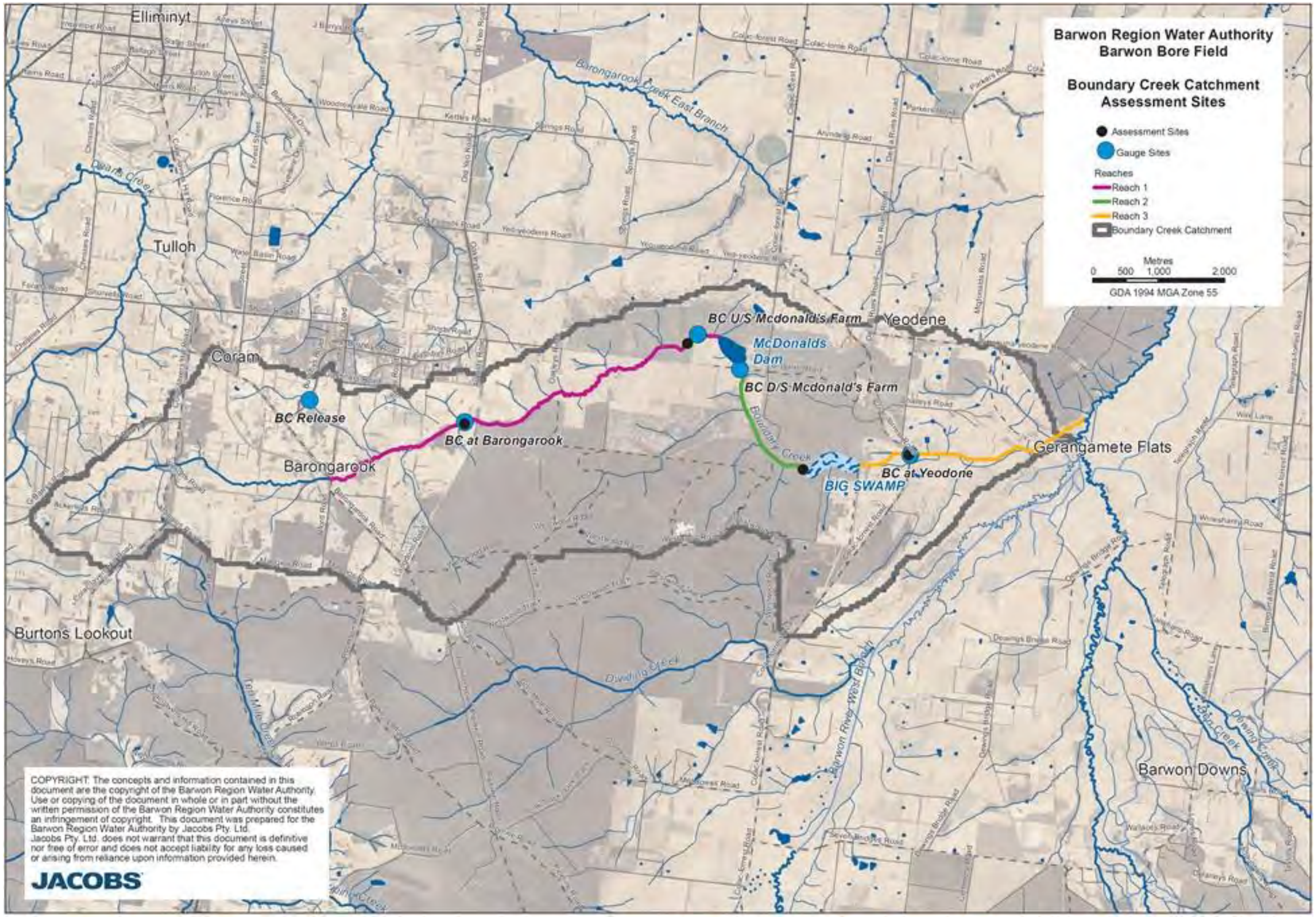

Figure 2-1 Location of Reaches 1, 2 and 3 in Boundary Creek.

2.2 Boundary Creek catchment

2.2.1 Summary of changes in the catchment

Boundary Creek rises south of Colac, near Barongarook West in southern Victoria, and flows in an easterly direction for approximately 18 km, before joining the Barwon River east of Yeodene.

The Boundary Creek catchment has been highly modified over the last century. The changes to the catchment, some of which are permanent and irreversible, have significantly altered the natural hydrological flow regime of Boundary Creek. These changes include a range of natural and human factors which are outlined below;

- Much of the lower part of the catchment has been cleared to support agriculture and grazing, likely changing runoff patterns and therefore streamflow.
- An on-stream water storage was constructed in approximately 1979 about halfway down the catchment (referred to as “McDonalds Dam” after the original landholder). All the flow in the creek is captured by this dam and downstream flow requires releases from the dam or overtopping. The dam has the following conditions on its operation (note that the ‘Authority’ refers to Southern Rural Water):
    - ***Passing flows:*** *The licence holder must, at all times that there is natural inflow into the on-waterway storage, maintain a flow in the waterway downstream of the storage, to the satisfaction of the Authority.*
    - ***Take period:*** *Unless otherwise directed by the Authority, water may only be harvested into the on-waterway dam during the period from 1 July to 31 October inclusive; at all other times, the entire stream flow must be passed downstream of the dam.*
- Under the conditions of the dam operation, all inflow must be passed downstream of the dam between 1 September and 30 June.
- It should be noted that “McDonalds Dam” is the commonly used and accepted name for the dam locally, and references a previous owner of the area, Michael McDonald. The use of the name “McDonalds Dam” in this report is to allow easy reference and does not insinuate that the dam is in any way owned or operated by Michael McDonald.
- The catchment has a number of private diverters and farm dams which collect rainfall before it reaches the creek (private diverters make up 91 ML, of which 86 ML are winterfill licences and 5 ML are for stock and domestic uses; SKM 2006).
- Groundwater has been extracted from the Barwon Downs borefield to augment potable supply during low rainfall conditions.
- Like the rest of south-eastern Australia, the Boundary Creek catchment was impacted by the Millennium Drought. Less rainfall and runoff caused declining stream flows and groundwater levels throughout the state.
- Yeodene (Big) Swamp is a peat swamp located in the middle of the Boundary Creek catchment (downstream of “McDonalds Dam”). A peat fire was first reported in 1997 and again in 2006. In 2010, the Country Fire Authority (CFA) dug trenches along the southern and eastern boundaries of the swamp in an attempt to control the fire.
- Under the conditions of the current groundwater extraction licence, Barwon Water is required to provide supplementary flow (currently 2 ML/day) to Boundary Creek to mitigate potential impacts on stock and domestic users (primarily in Reach 3) from extraction from the Barwon Downs borefield. The supplementary flow is released except when the groundwater level in bore Yeo 40 recovers above a level of 158.5 m AHD following the cessation of pumping or at any time between 1 June and 30

November that the natural flow at Yeodene exceeds 1 ML/day (Southern Rural Water 2006). The supplementary flow has been provided since at least 2003 (Barwon Water 2004) and is delivered to a tributary of Boundary Creek near Bushby Road. The tributary joins Boundary Creek approximately 1 km downstream of Barongarook Road.

These changes are discussed in the context of each reach in the following sections.

2.2.2 Description of the catchment

The following section describes in detail the reaches and sub reaches in Boundary Creek. For the purposes of quantifying the low flow volume that would be necessary in each reach and sub-reach of the creek to support the key ecological values, one representative site in each reach and sub-reach has been assessed in detail for this study (see Section 3). These representative sites are also described below.

2.2.2.1 Reach 1

The most upstream reach (Reach 1) retains much of its natural form with the creek flowing through an area of intact remnant riparian vegetation in Otway State Park. Reach 1 has a mix of broad channel covered in grasses and reeds and sections of more defined channel with fringing and aquatic vegetation and woody snags. The 2 ML/day supplementary flow released by Barwon Water to compensate stock and domestic users in Boundary Creek is released into a small tributary that joins Boundary Creek in Reach 1. The downstream end of Reach 1 is defined by “McDonalds Dam”, a large on-stream water storage with a concrete weir wall. In addition to “McDonalds Dam”, there are a number of farm dams in the catchment as well as private diverters.

For Reach 1, the representative site is downstream of Langdons Road, just upstream of “McDonalds Dam”. The channel in this area is deeply incised in parts and flows over a number of shallow rocky riffles with pool/run sections up to approximately 50 cm deep during low flow. The channel also supports overhanging vegetation and has undercut banks in parts (Figure 2-2). A conceptual model of Boundary Creek at the assessed representative site in Reach 1 is provided in Figure 2-3.

The site is broadly representative of the habitat found in Reach 1. There are some sections of the creek in Reach 1 that have been cleared for agriculture, but most of the reach has a continuous and vegetated riparian zone.

Figure 2-2 Boundary Creek upstream of “McDonalds Dam” at the representative site in Reach 1.

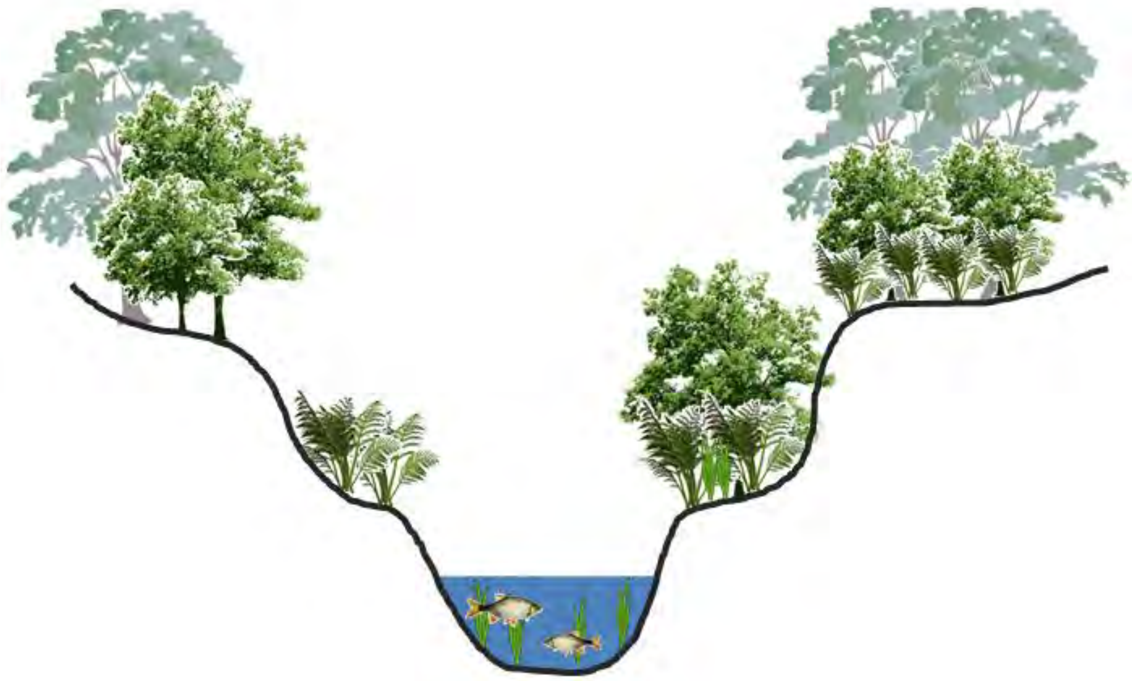

Figure 2-3 Conceptual model of Boundary Creek at the representative site in Reach 1. Note that the communities and species depicted are for illustrative purposes and are not intended to represent the actual species present at Boundary Creek.

2.2.2.2 Reach 2a

Reach 2 extends from downstream of “McDonalds Dam” to the outlet of Yeodene Swamp, and comprises three distinct habitats. Reach 2 has therefore been further divided into three sub-reaches; the channelised section immediately downstream of “McDonalds Dam” (Reach 2a), the “damplands” (Reach 2b) and Yeodene Swamp (Reach 2c).

The creek immediately downstream of “McDonalds Dam” (Reach 2a) flows in a defined, mostly straight and likely artificial channel through land cleared of native vegetation to support agriculture. Imagery from the 1940s suggests that this area was historically a broad floodplain with a number of dispersed flow paths, with the channelisation likely to have occurred after the construction of “McDonalds Dam” (which was approximately 1979).

Over the summer months, much of the inflow to the dam consists of the 2 ML/day supplementary flow which is released by Barwon Water to a tributary which joins Boundary Creek in Reach 1. As outlined in Section 2.2.1, the conditions of the operation of the dam stipulate that all of the inflow from September to June is passed, however, it appears that the flow downstream of the dam is considerably less at some times of the year than the inflow to the dam. This is discussed further in Section 2.3.2.

The representative site for Reach 2a is at the downstream extent of the section of defined channel, before Boundary Creek fans out into a broad marsh and following that, into the “dampland” (Reach 2b). This area has limited intact large native riparian vegetation, however, some beds of submerged and emergent native aquatic plant species are present, which may provide habitat to aquatic animals like frogs and fish (Figure 2-4).

A conceptual representation of the channel in Reach 2a is shown in Figure 2-5.

Figure 2-4 Boundary Creek downstream of McDonalds Dam at the representative assessment site in Reach 2a.

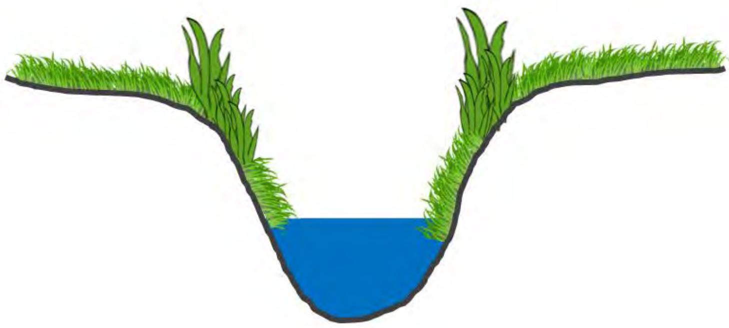

Figure 2-5 Conceptual model of Boundary Creek at the representative site in Reach 2. Note that the communities and species depicted are for illustrative purposes and are not intended to represent the actual species present at Boundary Creek.

2.2.2.3 Reach 2b

Reach 2b is defined as downstream of the open marsh to the upstream end of Yeodene Swamp. The flow channels in Reach 2b are highly braided, resulting in diffuse pathways for water flow through the area. The reach is characterised by waterlogged, marshy habitat and is best described as a “dampland”.

The representative site is typical of the broad, dispersed, marshy nature of Boundary Creek in this area. The stream channel and riparian zone are free of weeds. There is a relatively large amount of large wood (i.e. fallen trees) and leaf litter in the channel and overhanging and submerged vegetation. The area was dotted with burrows, likely of the Otway Bush Yabby.

Photos of the representative site in Reach 2b are shown in Figure 2-6. A conceptual model illustrating the aquatic habitats at this site is shown in Figure 2-7.

Figure 2-6 Boundary Creek at the "dampland" in Reach 2.

Figure 2-7 Conceptual model of Boundary Creek at the "dampland". Note that the communities and species depicted are for illustrative purposes and are not intended to represent the actual species present at Boundary Creek.

2.2.2.4 Reach 2c

Downstream of the “dampland” is Yeodene Swamp (Reach 2c), a large peat swamp approximately 1 km in length. There is a deep, defined channel running along the northern side of the swamp (i.e. Boundary Creek), but observations made during the current study indicated that this channel may only convey water under moderate to high flows. This was because despite flow into and out of the swamp, and a large volume of surface water in the swamp proper, the channel near the location of the middle of the swamp was dry.

A fire was reported in the swamp on October 10 1997 (Colac Otway Fire Management Plan 2015), which suggests that the swamp dried prior to this time. The fire continued to burn underground with smoke sightings in 1998 and 2010 (Colac Otway Fire Management Plan 2015). Trenches up to 3 m deep were dug in 2010 by the Country Fire Authority (CFA) in an attempt to control the spread of the fire (Himmelreich 2010). There is one trench along most of the southern margin of the swamp and another that is oriented east-west near the downstream extent of the swamp. The drying of the swamp, the subsequent fire and digging of the trenches is likely to have had considerable impacts on the hydraulic functioning of the swamp and therefore the hydrology of Boundary Creek more broadly (see Section 2.3.4).

The extensive drying and oxidation of sulphate-rich soils in the swamp and their subsequent re-wetting has led to the mobilisation of acidic water. Based on measurements taken as part of this, and related studies (Jacobs 2017c), between 2014 and 2017, when Boundary Creek downstream of the swamp is flowing the pH is usually very low (median pH of 3.8 at the Yeodene flow gauge in contrast to a median pH of ~7.0 upstream of the swamp, see Section 2.3.4).

The swamp was assessed at a site near the middle (Site T1 from the *Barwon Downs Vegetation Survey* Jacobs 2016). The groundcover was dense *Sphagnum* moss and Bracken Fern (*Pteridium escultentum*), with a canopy layer formed by occasional Swamp Gum (Figure 2-8). The dominance of bracken, a pioneering fern species, is evidence of the recent disturbance of the area. The plant species were assessed to be a mixture of terrestrial species requiring readily available water, including opportunistic users of groundwater, and highly water-dependent mosses.

A conceptual model of Boundary Creek from “McDonalds Dam” to the confluence with the Barwon River and including the “damplands” and Yeodene Swamp is shown in Figure 2-9. This diagram illustrates the approximate location and extent of the fire trenches in Yeodene Swamp and the location of the incised channel along the northern extent of the swamp. It also shows a conceptual understanding of the groundwater-surface water interactions in the creek. See Section 2.3.5 for a brief description of the groundwater-surface water interactions of the creek.

Figure 2-8 Vegetation in Yeodene Swamp.

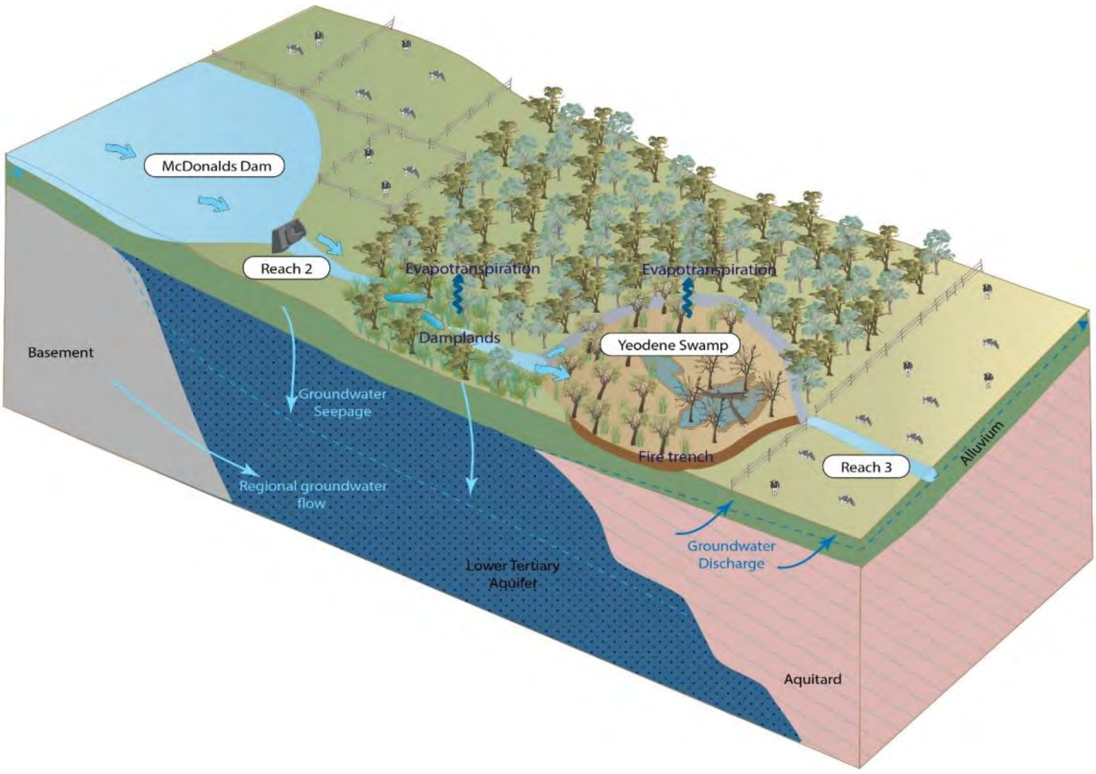

Figure 2-9 **Conceptual model of Boundary Creek from "McDonalds Dam" to the confluence** with the Barwon River, showing the **"damplands" and Yeodene Swamp. Diagram not to scale and for illustrative purposes only.**

2.2.2.5 Reach 3

The final distinct section of Boundary Creek extends from Yeodene Swamp to the confluence with the Barwon River (Reach 3). This reach has been heavily modified to support agricultural activity; the channel has been straightened and excavated and the majority of the native riparian vegetation has been cleared. The surrounding land use is almost entirely agricultural or pastoral. Some landholders along this stretch of the creek have replanted riparian vegetation (N. Shalley, pers. comm.) and in these areas the aquatic habitat (snags, aquatic vegetation) is improved (Tunbridge 1988; Lloyd *et al.* 2005).

The representative site in Reach 3 was assessed approximately 250 m upstream of the confluence with the Barwon River. Much like the rest of Reach 3, the channel at this site has been straightened and excavated and all the pre-European large riparian vegetation has been cleared (Figure 2-10).

Conceptual models of the typical habitat in Reach 3 are presented in Figure 2-11. One diagram shows the habitat in the section of the creek that no longer supports any riparian vegetation, such as the location of the representative assessment site. The other diagram shows the habitats that are likely to be provided in sections of the creek in Reach 3 that have replanted riparian vegetation.

Figure 2-10 Aquatic habitat in Reach 3 of Boundary Creek. Left: Channel just downstream of the Colac-Forrest Road showing revegetation. Right: Boundary Creek just upstream of the confluence with the Barwon River at the detailed FLOWS assessment site.

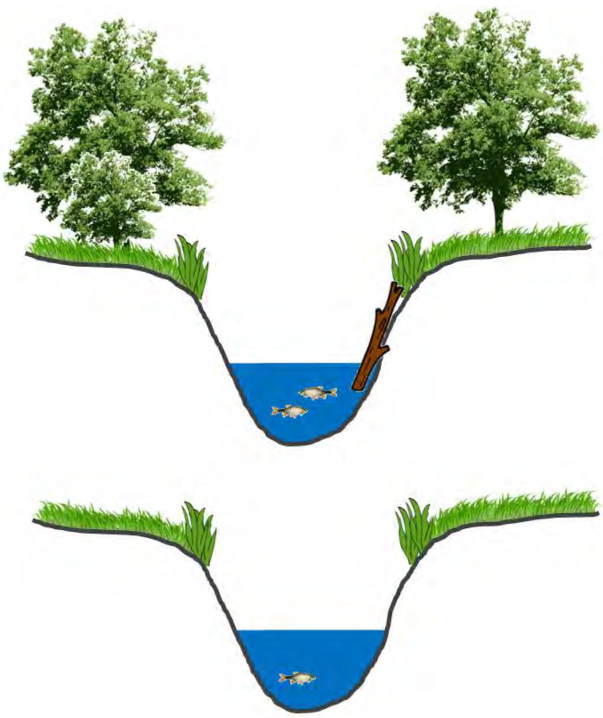

Figure 2-11 Conceptual model of Boundary Creek at the representative assessment sites in Reach 3. The top image shows the habitats that would likely be provided in areas of the creek that have replanted riparian vegetation. The bottom image shows the creek in areas that have been cleared of riparian vegetation. Note that the communities and species depicted are for illustrative purposes and are not intended to represent the actual species present at Boundary Creek.

2.3 Hydrology of Boundary Creek

The surface water hydrology of Boundary Creek was reviewed as part of Jacobs (2017a) and has been updated to reflect data that has been collected since that report. The following is a summary of the hydrological components of Boundary Creek that are important for characterising the functioning of the creek, with respect to the ecological values that are supported. More detail, including data to support the observations, is provided in the sections that follow.

- The creek in Reach 1 flows across outcropping basement geology and is gaining marginally, that is, groundwater from the basement aquifer discharges to the creek. The basement aquifer in this location has not been influenced by operation of the Barwon Downs borefield (Jacobs 2017b). See Section 2.3.5 for a description of the groundwater-surface water interactions at Boundary Creek.

- The 2 ML/day supplementary flow released by Barwon Water makes up a significant portion of the flow in the summer months upstream of Yeodene Swamp (Reaches 1, 2a and 2b). The borefield licence dictates that the supplementary flow is provided throughout the year, except when the flow at Yeodene (Gauge 223228) is recorded to be greater than 1 ML/day between 30 November and 1 June. Historically Boundary Creek in Reach 1 would likely have been ephemeral, ceasing to flow in the summer months (Gardiner 2017) and drying completely during low-rainfall conditions, an observation supported by accounts from local residents (S. Alford, pers. comm.).

- As part of the surface water licence associated with “McDonalds Dam”, all inflow must be passed downstream of the dam between 1 September and 30 June. Over the summer months, much of the inflow to the dam consists of the 2 ML/day supplementary flow released by Barwon Water to a tributary which joins Boundary Creek in Reach 1. Evidence from 2015 to 2017 indicates that the flow downstream of the dam is considerably less than the inflow to the dam at some times of the year.

- Reach 2 is in an area where the underlying aquifer that is pumped by Barwon Water outcrops at the surface. The creek in Reach 2 gained from groundwater historically, but as a result of operation of the Barwon Downs borefield and climate variability, the creek now loses to groundwater (Jacobs, 2017b).

- Reach 2b, the “damplands” is characterised by waterlogged soils, which are likely maintained by the supplementary flow.

- In summer, surface water flow is not apparent downstream of the “damplands” and there is no inflow to Yeodene Swamp (Reach 2c). The swamp is therefore significantly drier than it would have been historically.

- The flow data available for Boundary Creek (measured at Yeodene gauge from 1986 to 2017) indicates that the creek downstream of Yeodene Swamp (Reach 3) rarely stopped flowing at any time of year prior to 1999, but since then, flow has stopped for long periods in summer and autumn in most years.

- When the creek does flow (usually from late autumn to spring) the water in Reach 3 of Boundary Creek is highly acidic as a result of the extensive oxidation of sulphuric soils in Yeodene (Big) Swamp.

2.3.1 Flow gauging in Boundary Creek

Boundary Creek is now heavily gauged (Figure 2-12), although historically, that was not the case. Available gauge data are listed from upstream to downstream in Table 2-2.

Figure 2-12 Schematic of Boundary Creek.

Table 2-2 Available gauge data for Boundary Creek.

Gauge Number	Gauge Name	Period of record	Periods of missing data
233273	Barongarook	July 2014 - current	Minimal
233231	upstream "McDonalds Dam"	Dec 1989 – Current	Feb 1994-June 2014. Data for 2014 may be unreliable due to a leak under the gauge control structure.
233230	"McDonalds Dam"	Dec 1989 – Feb 1994 and June 2014 to Current	No periods of missing data. Level only, no stream flow data
233229	downstream "McDonalds Dam"	Dec 1989 – Feb 1994 and June 2014 to Current	None; however, some of the data obtained prior to 2015 has quality codes that indicate data of uncertain quality. High quality data is available from 2015 onwards, which has been the data used for this study.
233228	Yeodene	Mar 1985 - current	Minimal

2.3.2 Reach 1

It is difficult to determine the natural flow regime in Reach 1 of Boundary Creek due to the influence of the supplementary flow. The 2 ML/day supplementary flow has been released into Boundary Creek since at least 2003 (Barwon Water 2004).

To investigate the contribution of this flow on the hydrology of the upper part of Boundary Creek, the flow record from the release site (bw763) and at Barongarook (233273) was reviewed. The flow measured at these gauges is plotted in Figure 2-13.

As shown in Figure 2-13 the 2 ML/day release contributes significantly to the baseflow in Reach 1 during the summer months. This is most clearly seen in April 2015, when the supplementary flow was ceased for maintenance of the gauge upstream of "McDonalds Dam" during which Boundary Creek at Barongarook ceased to flow. The influence of the supplementary flow is also seen from December 2016 to March 2017 when the flow in the creek at Barongarook was consistently 2ML/day with only small, likely rainfall driven flow events above 2 ML/day.

The evidence from these gauge sites suggests that the supplementary flow makes up a reasonably large proportion of the baseflow in Boundary Creek in the summer months.

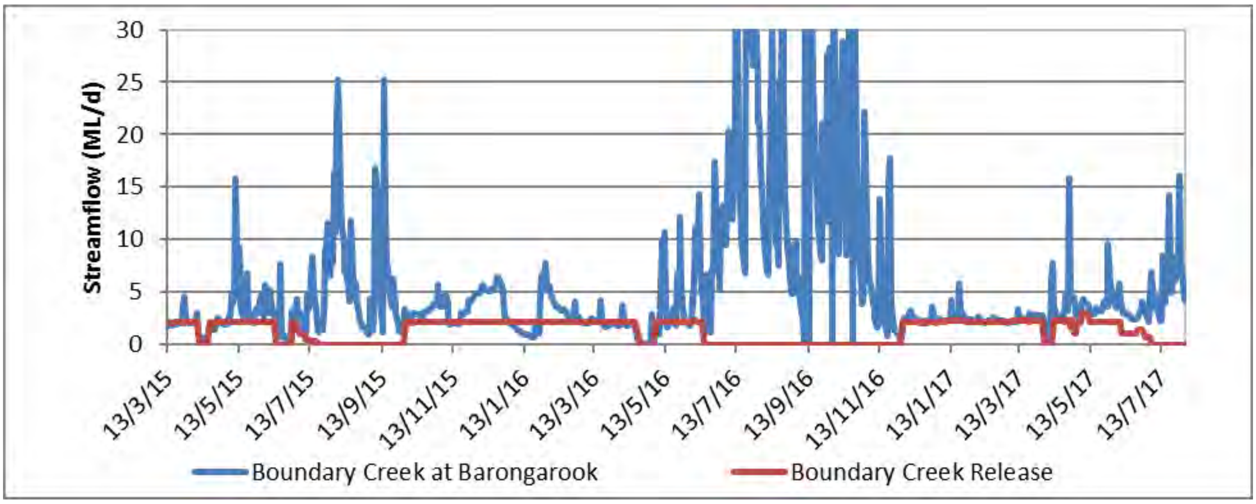

Figure 2-13 Streamflow at the Barongarook gauge compared to the Release site (Reach 1).

2.3.3 Reach 2a

The major physical feature impacting flow in Reach 2a of Boundary Creek is "McDonalds Dam". There are no historical flow records from before "McDonalds Dam" was constructed in approximately 1979. However, there are two gauges that have been installed recently, one located upstream and one located downstream of the dam.

Over the summer months, much of the inflow to the dam is made up of the 2 ML/day supplementary flow which is released by Barwon Water to a tributary which joins Boundary Creek in Reach 1. As outlined in Section 2.2.1, the conditions of the operation of the dam stipulate that all of the inflow from September to June is passed, however, summer flows at the gauge downstream of the dam are consistently less than half the flows at the gauge upstream of "McDonalds Dam" (Figure 2-14). This is especially relevant where non-peak flows are passing through the system. This trend is verified by high quality data between February and May 2016, which show upstream flows of between 1.6 ML/d and 3 ML/d, while flows downstream range between 0.7 and 0.9 ML/d.

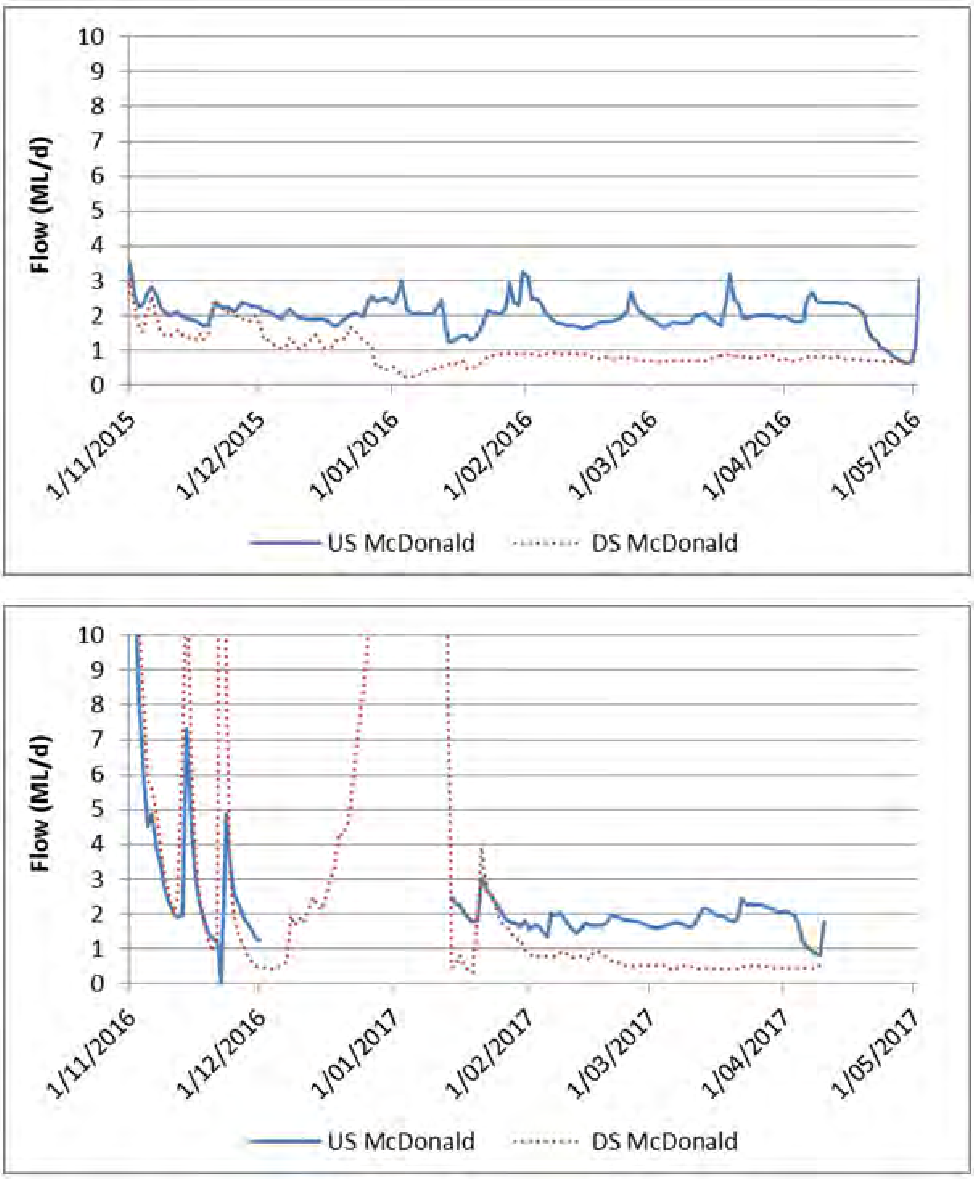

Figure 2-14 Flow upstream and downstream of "McDonalds Dam" during summer periods. Top: Summer 2015-2016 Bottom: Summer 2016-2017. Note the gap in data from the upstream gauge between December 2016 and January 2017.

Table 2-3 Difference in flows **into and out of "McDonalds Dam"**.

Period		Barwon Water Flow Release (ML)	Flow "McDonalds Dam" upstream (ML)	Flow "McDonalds Dam" downstream (ML)	Difference: U/S vs D/S (ML)	Average daily difference (ML/Day)
From	To					
1 Nov 2014	10 Dec 2014	85	121	77	44	1.1
16 Jan 2015	16 Feb 2015	67	73	34	39	1.2
1 Nov 2015	1 Apr 2016	329	315	159	156	1.0
14 Jan 2017	10 Apr 2017	175	188	66	122	1.4

2.3.4 Reach 3

The flow record from the Yeodene gauge is the most complete in the catchment, beginning in 1979 and extending continuously to the present. The flow data show a noticeable step change from 1999, with days where the creek did not flow increasing significantly (Figure 2-15). These data show that surface water flow has ceased for long periods nearly every summer and autumn since 1999, however, before that time (1979-1998), Boundary Creek rarely stopped flowing (the only extended period being 1984/85 and 1990).

The pH recorded in the creek at Yeodene shows a similar step change pattern. The median pH measured at Yeodene prior to 1999 was 6.1, but from 1999 onwards it has been 3.8 The range of pH recorded in the creek over this period is shown in Figure 2-16.

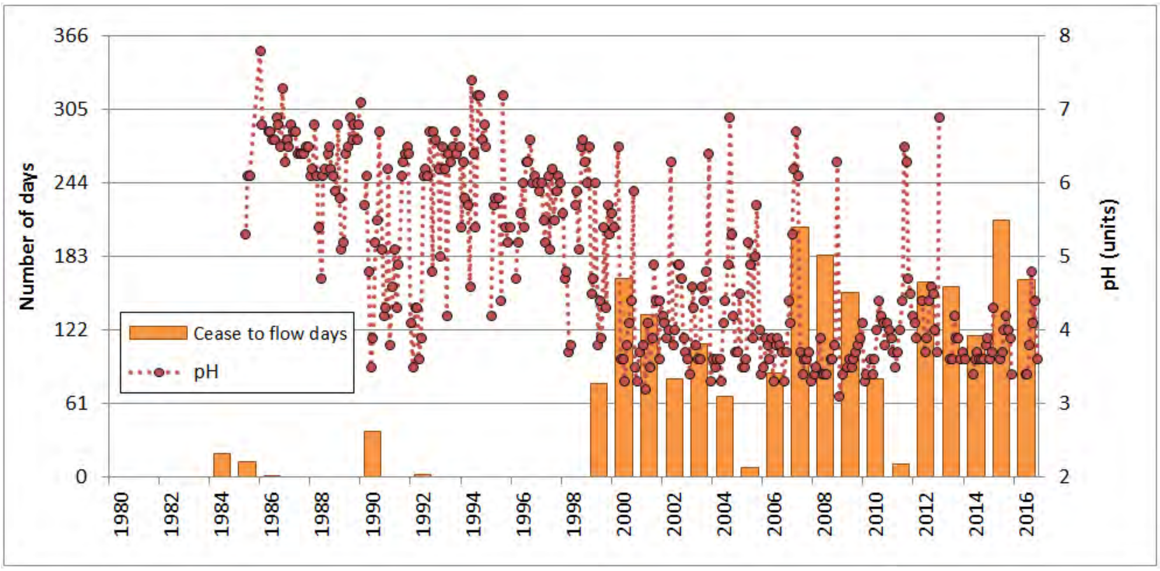

Figure 2-15 Number of cease to flow days and pH recorded at the Yeodene gauge from 1979 to present.

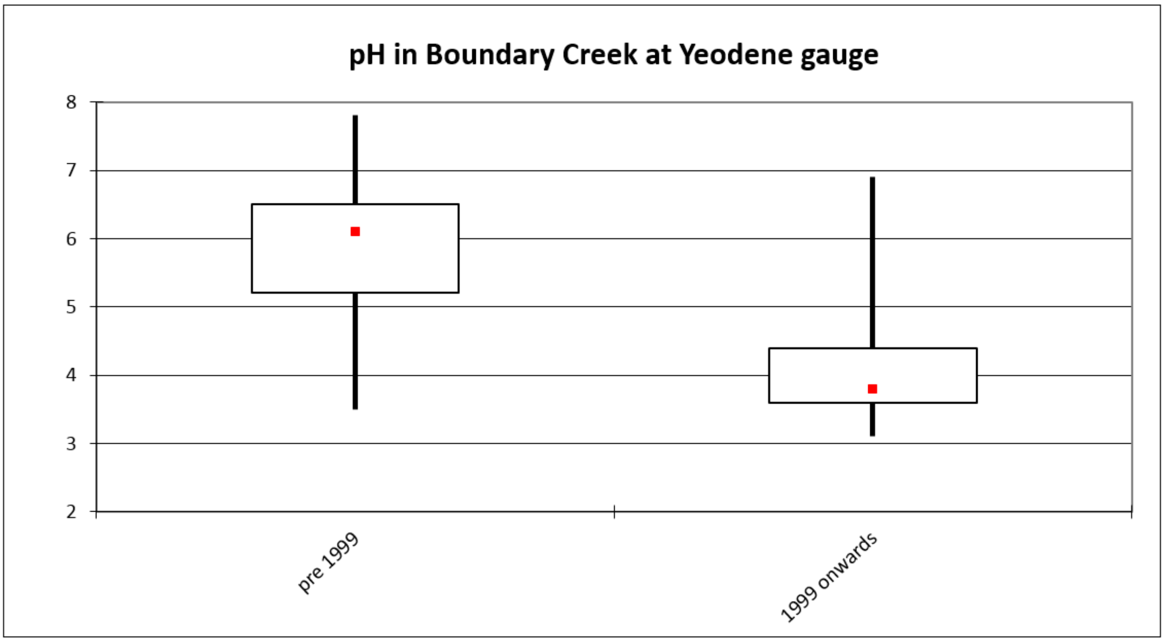

Figure 2-16 pH in Boundary Creek measured at the Yeodene flow gauge pre 1999 and 1999 onwards. The whiskers represent the minimum and maximum recorded pH over the two time periods. The bottom and top of the box represents the 25th and 75th percentile record respectively. The red square denotes the median pH recorded over the two time periods.

2.3.5 Groundwater surface water interactions along Boundary Creek

Boundary Creek flows across the Barongarook High over a mixture of Lower Tertiary Aquifer, Basement and Quaternary Alluvium and surface water within Boundary Creek interacts with groundwater in all aquifers. A long section of the hydrogeology changes along Boundary Creek is shown in Figure 2-17.

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

Downstream of "McDonalds Dam" (Reach 2), the creek flows across outcropping Lower Tertiary Aquifer. 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 Swamp.

In Reach 3, downstream of Yeodene 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.

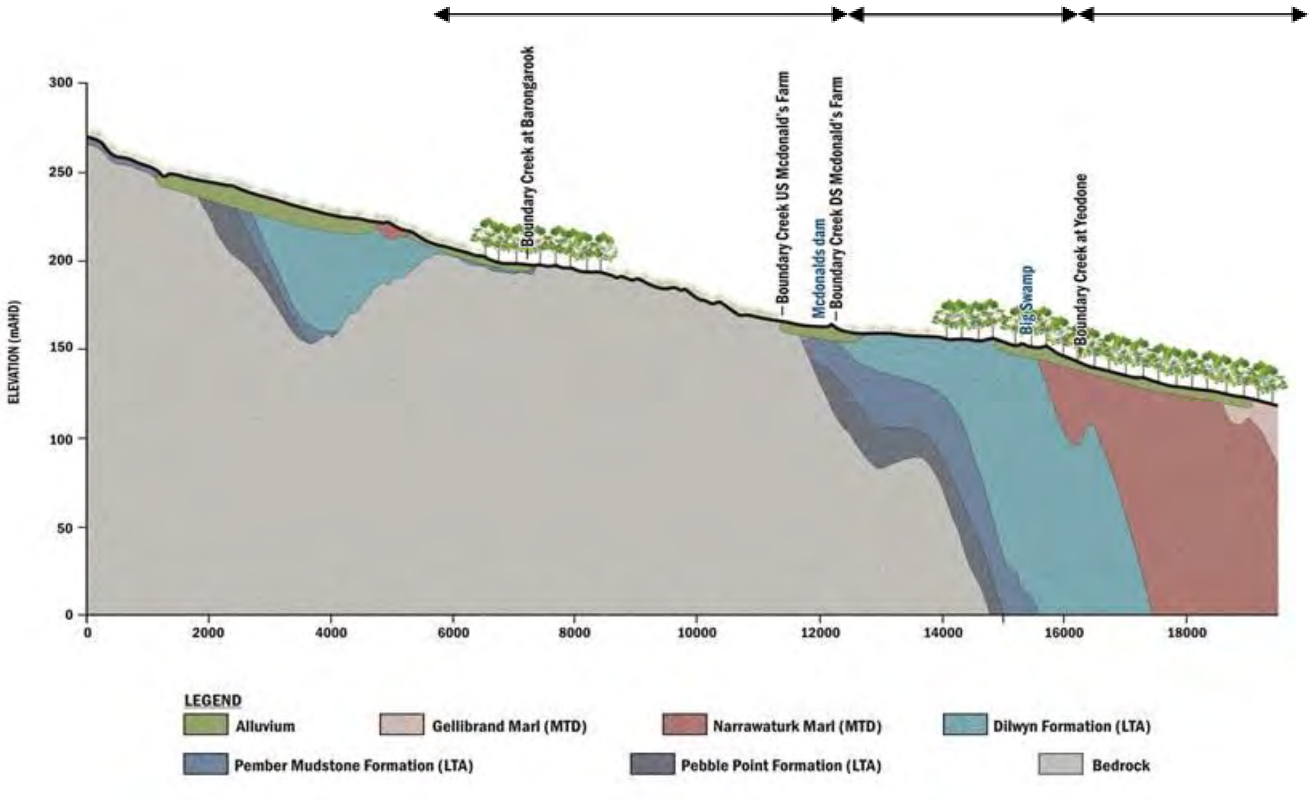

Figure 2-17 Hydrogeological long section along Boundary Creek.

2.4 Ecological values supported by Boundary Creek

The ecological values currently supported by Boundary Creek were described in detail in Jacobs (2017a) and a summary is provided in the following section. Where information has been obtained by the authors since the 2017 study, which has revised understanding of the catchment, this has also been discussed in the following section.

2.4.1 Overview of the approach

The aquatic values supported by Boundary Creek were described by a panel of specialist ecologists (see Section 3) using a range of direct and indirect techniques, including direct survey, reviews of historic records, direct observations and reports from local residents, predicted species distributions, habitat assessments and hydrological characterisations of the creek.

Based on the methods outlined above the specialist ecologists made a broad qualitative assessment of the current ecological condition of each reach and sub-reach (i.e. good, moderate or poor quality). This qualitative assessment has been made to inform the ecological objectives for each reach and sub-reach (i.e. to either maintain or improve the ecological condition).

2.4.2 Updates and corrections to the *Boundary Creek aquatic ecology investigation* (Jacobs 2017a)

Since the completion of the *Boundary Creek aquatic ecology investigation* (Jacobs 2017a) understanding of the catchment has been improved by additional surveys and the contributions of long term residents. These updates, and corrections to the 2017 study where relevant, are described below.

As part of the 2017 study (Jacobs 2017a), the probability of Platypus occurrence in Boundary Creek was determined by assessing the habitat and relying on specialist opinion. Since the 2017 study, DNA technology has advanced to a stage where Platypus can be detected with a high degree of sensitivity and confidence by amplifying genetic material from water samples (Weeks *et al.* 2015). Data from recent studies indicate that 6-10 net surveys achieve a 95% detection probability (if the species is present, there is a 95% chance of detecting them), while two water samples with two PCRs (Polymerase Chain Reaction, the method for amplifying DNA) achieves a detection probability of 97% (Weeks *et al.* 2015).

Platypus monitoring using eDNA (“environmental DNA”) has been pioneered by Josh Griffiths from cesar consulting and he was engaged as part of the current study to survey Boundary Creek (and nearby locations in the Barwon River). Water samples were obtained from five sites along Boundary Creek in April 2017; the representative sites in Reach 1, Reach 2a and Reach 2b as well as within “McDonalds Dam” and the outfall of the supplementary flow at Bushby Road (to ensure that any positive results in Boundary Creek were not due to trace amounts of DNA from the source of the supplementary flow). Samples were also collected from two sites in the nearby Barwon River: upstream of the confluence with Boundary Creek at Dewings Bridge Road (in the Barwon River East Branch) and downstream of the confluence at Colac-Lorne Road. The water samples were analysed using standard eDNA techniques and assessed for the presence of Platypus DNA using species specific DNA primers (see Weeks *et al.* 2015 for details of the survey method). The eDNA analysis failed to detect Platypus genetic material at any of the sites monitored in either Boundary Creek or the sites in the upper Barwon River.

It was mistakenly stated in Jacobs (2017a) that only one fish survey had been undertaken in Boundary Creek (that being Tunbridge’s 1988 survey). In fact, a series of surveys were undertaken throughout Boundary Creek by the Arthur Rylah Institute, in May 1992, Oct 1992, June 1993 and Oct-Dec 2001 (ARI 2001). Six sites were surveyed, three in Reach 1 (the headwaters near Barongarook, just upstream at Colac-Lavers Hill Road and just upstream of “McDonalds Dam”), two sites in Reach 2 (downstream of “McDonalds Dam”, near the downstream extent of the “damplands”) and a site in Reach 3 (near Colac-Forrest Road). Three native species were recorded as part of these surveys, Short-fin Eel (*Anguilla australis*), Mountain Galaxias (*Galaxias olidus*) and Southern Pygmy Perch (*Nannoperca australis*). One introduced species, Redfin Perch (*Perca fluviatilis*) was also caught. Freshwater Yabbies (identified as *Engaeus sp.*) and Freshwater Shrimp (*Parataya australiensis*) were also recorded as part of the ARI surveys. The ARI surveys provide valuable information about the distribution of fish species at the time the surveys were undertaken. Table 2-4 presents a consolidated review of the four surveys, indicating in which reach each species was recorded in at least one of the surveys. This information has been used to update the assessment of ecological values supported by Boundary Creek (Section 2.4.3).

Table 2-4 Fish and crustacean species recorded in Boundary Creek during a series of surveys undertaken by ARI between 1992 and 2001.

Reach/sub-reach	ARI survey sites	Fish species recorded	Crustacean species recorded
Reach 1	1, 2 and 3	• Short-finned Eel • Mountain Galaxias • Southern Pygmy Perch	• *Engaeus sp.* • *Parataya*
Reach 2a (channelised section downstream **"McDonalds Dam")**	4	• Short-finned Eel • Mountain Galaxias • Redfin Perch	• *Parataya*
Reach 2b ("damplands")	5	• Short-finned Eel • Mountain Galaxias • Redfin Perch	• *Engaeus sp.*
Reach 2c (Yeodene Swamp)	Not surveyed		
Reach 3	6	• Short-finned Eel • Mountain Galaxias	• *Engaeus sp.*

In the conclusion section of the 2001 survey report (ARI 2001), the authors were careful to acknowledge that there was not at that time sufficient data to suggest that the population structure or density of aquatic species had altered significantly since 1992. However, the authors also noted "some anomalies (such as the absence of *G. olidus* at site 6 and also the reduction in density at site 1) which should be further investigated to ensure that any environmental conditions are not deteriorating" (ARI 2001, p 10).

In Jacobs (2017a) it was incorrectly stated that Dwarf Galaxias (*Galaxiella pusilla*) was recorded from the Boundary Creek near the Colac-Forrest Road by Tunbridge (1988). Rather, Mountain Galaxias (*Galaxias olidus*) was recorded as part of Tunbridge's survey. Lloyd *et al.* (2005) did, however, estimate that Dwarf Galaxias could potentially occur in Boundary Creek. The probability that Dwarf Galaxias currently occurs in Boundary Creek has been revised to account for the lack of direct observations of the species.

As part of the 2017 report, it was estimated that there was only a low probability that Southern Pygmy Perch would be supported by Reach 2, an inference based on the relatively low water depth and lack of observed pools in that part of Boundary Creek by the specialist ecologists. Observations from 1997 or 1998 described in Gardiner (2017), however, confirm that Southern Pygmy Perch were supported by habitat in Yeodene Swamp. This evidence has been used to update the predicted distribution of Southern Pygmy Perch and other small bodied native fish species in the catchment.

It was inferred as part of the 2017 study that the endangered Otway Bush Yabby, or Otway Cray (*Geocharax gracilis*), was supported in Reach 2 based on the indirect observations of numerous yabby burrows in the "damplands" (Reach 2a). ARI (2001) directly recorded Yabbies in Boundary Creek - in Reach 1, Reach 2b ("the damplands") and Reach 3 – but identified them as Land Yabbies (*Engaeus sp.*). As individuals were not directly surveyed as part of the 2017 study, the burrows observed in Reach 2 may be those of Land Yabbies, not the Otway Bush Yabby, which is listed as endangered by the Victorian government (DSE 2009). The two species water requirements are broadly similar (e.g. moist burrows and reliable flow, DPIPWE 2010; Johnston and Schultz 2010) and therefore have been considered together.

In the 2017 study (Jacobs 2017a) Reach 3 was not assessed to provide suitable habitat, for Yabbies, however, direct observations of Yabbies have been made in Reach 3 by long term landholder John Day (Gardiner 2017). John observed numerous Yabbies in Reach 3, particularly in the paddocks adjacent to the creek, prior to the creek first drying out (from the late 1990s onwards). Yabbies are still present at John's property, but at significantly lower abundance than in the past, and are generally located further upland, away from the creek (Gardiner 2017). Gardiner (2017) also recorded that John observed large numbers of crayfish, eels and fish in Reach 3 prior to the creek drying up, but very little species diversity at all in the time since.

There are records of the Southern Victorian Spiny Crayfish (*Euastacus yarreansis*) from Boundary Creek on the Victorian Biodiversity Atlas (DELWP 2018). The species is not listed as threatened by the Victorian government, but is considered vulnerable on the IUCN Red List (Coughran and Furse 2010). Boundary Creek is near the predicted species range (Coughran and Furse 2010). Spiny Crayfish rarely grow larger than 90 mm and requires cool, flowing streams for persistence. Although the 2017 study did acknowledge the records of the species from the creek, their current distribution was not explicitly estimated.

Finally, the ecological character and condition of the Yeodene Swamp was not considered in detail for the 2017 study. However, the swamp is included as part of the current study.

2.4.3 Summary of ecological values currently supported by Boundary Creek

In **Reach 1**, the majority of the riparian zone is made up of an overstorey of *Eucalyptus* and *Acacia*, with a ground layer of weeds and occasional sedges and herbs. The channel supports Water Ribbons (*Triglochin procerum*). As Reach 1 is upstream of "McDonalds Dam", which would act as an impassable fish barrier for most fish, the only species that could be supported are those that could find refuge habitat in "McDonalds Dam" when the creek upstream dries out (which may have occurred a number of times since the dam was constructed in 1979) or those species that can skirt fish barriers. Short-finned Eels can move overland and therefore could move into Reach 1 readily by passing upstream over "McDonalds Dam". Small bodied fish species, such as Southern Pygmy Perch and Mountain Galaxias, would have been supported by refuge habitat in "McDonalds Dam" and are therefore likely to be present. These species were recorded in Reach 1 during the last of the ARI series of surveys (ARI 2001). The macroinvertebrate communities of Reach 1 are in excellent condition (AUSRIVAS Band A) (Jacobs 2017a). ARI (2001) also recorded Land Yabbies and Freshwater Shrimp and the cool, flowing water would be suitable for Victorian Spiny Crayfish. A range of common frog species are likely to be supported by the well vegetated banks and usually slow flowing water.

The current habitat quality of the creek in general is considered poor to moderate for Platypus, however, the best available habitat (e.g. deep pools and densely vegetated and steep banks suitable for burrow construction) is in Reach 1. Despite the presence of moderate quality Platypus habitat in Reach 1 and reports from long term residents that Platypus were historically supported in a number of places in Boundary Creek (P. C. Shalley and G. J. Potter, Statutory Declarations published in Gardiner 2017) the eDNA surveys indicate that there is no evidence of Platypus genetic material in Reach 1.

Overall, the ecological condition of **Reach 1** is rated as **good.**

Immediately downstream of "McDonalds Dam" (**Reach 2a**), Boundary Creek flows through a defined, channelised creek mostly cleared of large native vegetation. The areas immediately next to the channel support dense beds of submerged and emergent native aquatic plant species, including spike-rushes (*Eleocharis* spp.), Water Ribbons, saw-sedges, and knotweeds (*Persicaria* spp.). These plants would provide habitat to aquatic animals such as small bodied fish, frogs and crustaceans. Surrounding this aquatic vegetation is a patchy array of Tea-tree (*Leptospermum* spp.) which add ecological value to the riparian zone. The extensive clearing and channelisation of the stream, however, decreases the ecological value of this sub-reach. The ecological condition of Reach 2a is rated as **moderate.**

Reach 2b, the "dampland", contains a dense shrub-layer canopy of Scented Paperbark (*Melaleuca squarrosa*) and Woolly Tea-tree (*Leptospermum lanigerum*), both inundation-tolerant species, and a wetland ground-layer of diverse sedges, rushes and reeds (e.g. *Carex*, *Gahnia* and *Phragmites* spp.) that are likely reliant on permanently waterlogged soils. A tree-layer of Swamp Gum (*Eucalyptus ovata*), is also present, and this too is an inundation-tolerant species. The highly braided flow paths through this section of the creek would contribute greatly to the sustenance of the vegetation in the "dampland". Small bodied native fish (e.g. Southern Pygmy Perch, Mountain Galaxias) and Short-fin Eel could be supported as well as a range of frog species. Otway Bush

Yabby/*Engaeus sp.* burrows were observed throughout the area. The “dampland” section of Boundary Creek is considered to be in **good** ecological condition.

Yeodene Swamp (**Reach 2c**) supports a complex mosaic of fully terrestrial, inundation-tolerant and inundation-requiring plant species. These include a tree layer provided by Swamp Gum (a species tolerant of waterlogged conditions for large parts of the year), diverse suites of water-dependent sedges, saw-sedges, sword-sedges and club-sedges (e.g. *Carex appressa*, *Gahnia sieberiana*, *Lepidosperma elatius* and *Isolepis inundata*) with a requirement for at least waterlogged, and sometimes inundated, land, and large areas of *Sphagnum* moss, which is partly responsible for the formation of the peaty substratum that lies under Yeodene Swamp. Some sections have also regenerated with a dense shrub layer of *Leptospermum continentale* and *Meleuca squarrosa* with little understorey. The dominance of bracken over most of the area, a pioneering fern species, is evidence of the recent disturbances of the area. A small section near the eastern end of the swamp is regularly inundated with little aquatic vegetation, likely as a result of sub-optimal pH. The dead tree-ferns and trees present at this location indicate that this is a result of relatively recent changes in hydrological conditions.

The lack of surface water in much of the swamp for large parts of the year reduces its suitability for fish species, although the habitat is known to be, or has been, suitable for small bodied species such as the Southern Pygmy Perch (Gardiner 2017). Therefore, if at times of the year the pH became suitable for fish, then colonisation from other parts of the creek could occur. The swamp consists of dense vegetation and large areas of slow flowing water, which when inundated (and with suitable pH) would support frog breeding and recruitment. The macroinvertebrates of the swamp were not assessed directly, but are likely to be in moderate to poor condition due to the lack of regular surface flow and low pH.

A rating of the ecological condition of Yeodene Swamp must be done in the context of the range of impacts that have occurred since European settlement and the impact that the swamp has on Reach 3. The vegetation supported currently by the swamp is recovering following the range of disturbances, however, it is a profoundly different community to that which would have been present prior to the disturbances in the catchment (which would have been characterised by a greater prevalence of inundation reliant and tolerant species than currently present) and is not yet at an equilibrium with the current hydrological regime. Therefore, in isolation of the rest of the catchment, the ecological condition would be rated as poor to moderate. However, the impact the current functioning of the swamp has on the volume and quality of water in Reach 3 means that the ecological condition in this broader context is **poor.**

Reach 3 ceases to flow and dries in most summers, has highly acidic water when it is flowing (which is usually from late autumn/early winter) and has relatively poor aquatic and riparian habitat for much of its length due to the cleared riparian zone and excavated banks. Despite this, Water Ribbons were observed in parts of Reach 3 during the site inspection for this study. The frequent drying and low pH of the water when it is flowing means that Reach 3 is unlikely to support many resident aquatic species although some common fish species may use the reach occasionally. One Southern Brown Tree Frog (*Litoria ewingii*) was observed in Reach 3 during site inspections completed as part of this study and therefore it is likely that other common frog species can use habitat in this reach. The macroinvertebrate community is in poor condition (AUSRIVAS Band C) (Jacobs 2017a). Yabbies and crays were common in this reach historically, but are now observed predominantly upland from the creek (Gardiner 2017).

Reach 3 contains poor Platypus habitat due to the lack of vegetation cover or banks suitable for burrow construction, lack of permanent flow and frequent low pH when the reach is flowing. Genetic analysis found no evidence that Platypus are supported currently by Boundary Creek, however, Platypus could use the lower reaches of Boundary Creek for occasional foraging when it is flowing and if the water quality was suitable. The excavated banks and lack of vegetation cover means it is highly unlikely that resident Platypus could be supported, even provided that the flow and water quality was suitable. Overall, the current ecological condition of Reach 3 was rated as **poor** by the ecological specialist panel.

2.4.4 Summary of aquatic ecological values in the three reaches of Boundary Creek

Table 2-5 summarises the probability that the various aquatic species and communities currently occur in each of the three reaches of Boundary Creek as estimated by the specialist ecologists and described in the *Boundary Creek aquatic ecology investigation* (Jacobs 2017a). The estimates have been updated where new information has become available since the 2017 assessment. In addition, explanatory notes for each species distribution estimate has now been included.

Table 2-5 Summary of ecological values in the three reaches of Boundary Creek.

Ecological value	High probability	Medium probability	Low probability	Extremely low probability	Ecological condition
Reach 1					
Vegetation	Overstorey consisting of terrestrial *Eucalyptus* and *Acacia* spp. Weedy ground layer with occasional sedges and herbs. Frequent beds of Water Ribbon in the channel (direct observations during site inspections).				Good
Fish	Short-finned Eel, Southern Pygmy Perch, Mountain Galaxias (all recorded in this reach by ARI 2001)		River Blackfish (recorded by Tunbridge in 1988 in Reach 3, but not recorded as part of ARI surveys)	Flathead Gudgeon, Yarra Pygmy Perch (both known from the broader Barwon River catchment and suitable habitat exists in Reach 1, but not previously recorded in Boundary Creek). Dwarf Galaxias (predicted to potentially occur in Boundary by Lloyd *et al.* but not directly recorded from Boundary Creek)	
Macroinvertebrates and crustaceans	Macroinvertebrates communities in excellent condition - AURIVAS Band A – Reference condition (direct survey for this study, Jacobs 2017a), *Engaeus sp*. (Otway Bush Yabby*), *Parataya* (recorded by ARI 2001 in this reach).		Spiny Crayfish (not directly recorded by ARI 2001, but suitable habitat present)		
Platypus				Platypus (eDNA analysis found no evidence of Platypus genetic material)	
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog (assessed based on species preferences and distributions)				

Ecological value	High probability	Medium probability	Low probability	Extremely low probability	Ecological condition
Reach 2a					
Vegetation	Limited riparian vegetation in Reach 2a, submerged and emergent native aquatic plant species, including spike-rushes (*Eleocharis* spp.), Water Ribbons, saw-sedges, and knotweeds (*Persicaria* spp.) (direct observations during site inspections).				Moderate
Fish	Short-finned Eel, Mountain Galaxias (recorded in this reach by ARI 2001), Southern Pygmy Perch (recorded by Gardiner 2017 in 1997/1998 from just downstream)		Flathead Gudgeon, Yarra Pygmy Perch (both known from the broader Barwon River catchment, suitable habitat exists and could migrate into reach, but not previously recorded in Boundary Creek). River Blackfish (recorded by Tunbridge in 1988 in Reach 3, but not recorded as part of ARI surveys)	Dwarf Galaxias (predicted to potentially occur in Boundary by Lloyd *et al.* 2005 and could migrate into this reach but not directly recorded from Boundary Creek)	
Macroinvertebrates and crustaceans	Not directly assessed – likely to be in moderate condition - AURIVAS Band B – Significantly impaired. *Engaeus sp*. (Otway Bush Yabby*), *Parataya* (recorded by ARI 2001 and observations of burrows in Reach 2b).		Spiny Crayfish (not directly recorded by ARI 2001, but suitable habitat present)		
Platypus				Platypus (eDNA analysis found no evidence of Platypus genetic material)	
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog (assessed based on species preferences and distributions)				

Ecological value	High probability	Medium probability	Low probability	Extremely low probability	Ecological condition
Reach 2b (the **"damplands")**					
Vegetation	Complex "dampland" with a dense canopy of Scented Paperbark and Woolly Tea-tree and a wetland ground-layer of diverse sedges, rushes and reeds (direct observations during site inspections).				Good
Fish	Short-finned Eel, Mountain Galaxias (recorded in this reach by ARI 2001), Southern Pygmy Perch (recorded by Gardiner 2017 in 1997/1998 from just downstream)		Flathead Gudgeon, Yarra Pygmy Perch (both known from the broader Barwon River catchment, suitable habitat exists and could migrate into reach, but not previously recorded in Boundary Creek). River Blackfish (recorded by Tunbridge in 1988 in Reach 3, but not recorded as part of ARI surveys).	Dwarf Galaxias (predicted to potentially occur in Boundary Creek by Lloyd *et al.* 2005 and could migrate into this reach but not directly recorded from Boundary Creek)	
Macroinvertebrates and crustaceans	Macroinvertebrates communities in moderate condition - AURIVAS Band B – Significantly impaired (directly surveyed for this study, Jacobs 2017a). *Engaeus sp*. (Otway Bush Yabby*), *Parataya* (recorded by ARI 2001 and observations of burrows in this reach).		Spiny Crayfish (not directly recorded by ARI 2001, but suitable habitat present)		
Platypus				Platypus (eDNA analysis found no evidence of Platypus genetic material)	
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog (assessed based on species preferences and distributions)				

Ecological value	High probability	Medium probability	Low probability	Extremely low probability	Ecological condition
Reach 2c (Yeodene Swamp)					
Vegetation	Overstorey of Swamp Gum, a shrub layer of Scented Paperbark and Woolly Tea-tree, and a very spatially complex ground layer mosaic of terrestrial taxa (e.g. Bracken), water-tolerant sedges, and water-requiring Sphagnum moss (direct observations during site inspections).				Poor (at a catchment scale but moderate in isolation of the rest of the catchment, reflecting that some recovery of the swamp following changes in the water regime have occurred but the community has transitioned towards less water reliance than historically.)
Fish				Resident fish unlikely to be supported due to the lack of surface flow at some times of the year and low pH water when inundated. Species supported in Reach 2b could use habitat under suitable flow and water quality conditions.	
Macroinvertebrates and crustaceans	Likely to be in poor to moderate condition - AURIVAS Band B – Significantly impaired (Not directly assessed)			Unlikely to support resident crustaceans due to limited flow and unsuitable pH. Should conditions improve, crustaceans supported in Reach 2b could be supported by habitat in Reach 2c.	
Platypus				Platypus (eDNA analysis found no evidence Platypus genetic material)	
Frogs		Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog (assessed based on species preferences and distributions and direct observations of frogs using extremely low pH water in Reach 3)			

Ecological value	High probability	Medium probability	Low probability	Extremely low probability	Ecological condition
Reach 3					
Vegetation	Largely cleared of native vegetation, although the riparian zone upstream of the Colac-Forrest Road crossing was re-vegetated 10-15 years ago. It has a mature eucalypt overstorey and a dense mid storey layer. Some sections of the riparian zone downstream of the road has also been re-vegetated (direct observations during site inspections).				Poor
Fish				Resident fish unlikely to be supported due to the lack of surface flow at some times of the year and low pH water when flowing. However, reach could provide habitat (provided flow and pH is suitable)	
Macroinvertebrates and crustaceans	Macroinvertebrates communities in poor condition - AURIVAS Band C – Severely impaired (directly assessed for this study, Jacobs 2017a).	Otway Bush Yabby/*Engaeus sp.* (long term resident accounts indicate that individuals predominantly observed upland, no longer adjacent to the creek, Gardiner 2017, recorded by ARI 2001), *Parataya* (ARI 2001)		Southern Victorian Spiny Crayfish could use habitat in Reach 3 when pools of suitable quality are present.	
Platypus				Platypus (eDNA analysis found no evidence Platypus genetic material), however, reach could provide foraging habitat (provided flow and pH is suitable)	
Frogs	Victorian Smooth Froglet, Common Froglet, Pobblebonk, Striped Marsh Frog, Spotted Marsh Frog, Southern Brown Tree Frog (assessed based on species preferences and distributions)				

3. Approach for determining the minimum low flow volume requirements for aquatic values in Boundary Creek

3.1 Chapter overview

The purpose of this chapter is to briefly describe the approach used to quantify the minimum low flow volume requirements for the current ecological values in Boundary Creek.

The low flow requirements for the aquatic values of Boundary Creek have been determined for this study using a process adapted from the FLOWS method, which is the standard method used to define environmental flow requirements for Victorian waterways (DEPI 2013). Briefly, the FLOWS method involves the assembly of a panel of technical specialists, who in consultation with a range of stakeholders including local residents, define a set of management objectives for a waterway. The flows required to meet these objectives are then determined by the technical panel with the use of hydraulic models of the waterway to link flow volume with water level, hydrological information of the catchment and literature which outlines the flow requirements of the important species or communities.

While the current study has broadly followed the FLOWS approach, it has been adapted. The most significant adaptation is that the current study focusses on low flows, as this is the flow component most likely to be affected by changes to groundwater-surface interactions due to the operation of the Barwon Downs borefield. Furthermore, this is the flow component that can potentially be managed through controlled releases in the catchment. A standard, holistic FLOWS study would consider the full flow complement (e.g. rainfall driven high flows, such as summer and winter freshes and bankfull flows) which are also important to the health of the system.

A FLOWS study was completed by a consortium led by Lloyd Environmental and including Fluvial Systems and Ecological Associates in 2005. This assessment looked at nine reaches throughout the upper Barwon Catchment, including Boundary Creek (Lloyd *et al.* 2005). The 2005 study did recommend the flows required to support environmental values in Boundary Creek, but only assessed downstream of Colac-Forrest Road and did not consider the values, functioning or requirements of the creek upstream.

The following section provides more detail of the adapted FLOWS approach as it was applied to determine the low flow requirements of the key aquatic species and communities of Boundary Creek.

3.2 The application of the adapted FLOWS method for this study

In accordance with the FLOWS method, an Environmental Flows Technical Panel (EFTP) was assembled with specialist skills in aquatic fauna, aquatic and riparian flora, ecological processes, water quality, hydrology and hydrogeology. The members of the EFTP are shown in Table 3-1.

Table 3-1: Members of the Boundary Creek Environmental Flows Technical Panel (EFTP).

Name	Discipline
Dr Simon Treadwell (Jacobs – Jan 2017 onwards) / Dr Andrew Sharpe (Jacobs - up to Dec 2016)	Macroinvertebrate and fish ecology
Dr Paul Boon (Dodo Environmental)	Aquatic and riparian vegetation
Josh Griffiths (cesar)	Platypus
Dr Josh Hale (Jacobs)	Frogs
Amanda Woodman (Jacobs)	Hydrology and hydraulic modelling
Lou Lennon (Jacobs)	Hydrogeology

A traditional FLOWS study also makes use of local knowledge where possible, usually through the formation of a Project Advisory Group (PAG) (DEPI 2013). For the current study, the Community Reference Group (CRG) formed by Barwon Water as part of the licence renewal process fulfilled the role of the PAG. In addition, a number of other local landholders and people with direct experience of the creek contributed observations and knowledge.

The first step of a standard FLOWS study is to complete a desktop study to review available information to determine the aquatic species and communities (the ‘values’) likely to be supported by the waterway. For the current study, the members of the EFTP reviewed verbal reports provided by members of the CRG (at a meeting on 19-11-14) and the community more broadly, relevant literature, reports and accounts from local landholders (referred by the CRG), historic surveys and questionnaires, databases, maps and photographs to describe the aquatic values that are supported by Boundary Creek. The desktop assessment is described in detail in the *Boundary Creek aquatic ecology investigation* (Jacobs 2017a) and has been summarised and updated where relevant in **Section 2** of this report.

The findings of the desktop study were ‘ground truthed’ during field assessments by the EFTP in December 2014 and again in April 2017 during which time the available aquatic and riparian habitat in the different reaches and sub-reaches of Boundary Creek was qualitatively evaluated. Members of the CRG were invited to attend the field visit in December 2014. The field assessment focussed on a set of sites representative of the habitat found in each of the reaches and sub-reaches. The representative sites are described in **Section 2.2.2.**

A crucial step of a standard FLOWS study is the setting of **management objectives** for the waterway. Following the initial desktop and site assessments, the CRG were consulted regarding the management objectives at a meeting on 17-02-2015. The EFTP also participated in a project workshop with representatives from Barwon Water on 25-05-2017 to determine updated management objectives for each reach. These management objectives define the high level management aspirations for each reach and sub-reach; to **improve** upon, or to **maintain**, the current ecological condition of each reach or sub-reach.

Also identified as part of the workshop were the **targeted ecological and physical outcomes** required from a flow perspective in the creek to meet the management objectives. Examples of these targeted objectives include suitable pool habitat for fish or to support frog breeding and tadpole development. The management objectives and associated targeted ecological and physical outcomes required to meet the objectives are described for each reach and sub-reach in **Section 4.**

To assist the EFTP to determine specific, quantitative flow requirements to achieve the targeted ecological and physical outcomes, a standard feature of FLOWS studies is the use of **hydraulic models**. These hydraulic models relate flow volume (in ML/day) to water depth and wetted width in the channel.

For the current study, hydraulic models were developed for the representative sites in Reaches 1, 2a and 3. To develop these models, physical surveys of the representative sites were undertaken by licenced surveyors to the Australian Height Datum (AHD). The one dimensional hydraulic models were developed in the modelling program HEC-RAS.

The “damplands” (Reach 2b) and the Yeodene Swamp (Reach 2c) are characterised by waterlogged soils, rather than surface flow in a defined channel like the other reaches. The standard hydraulic models developed in HEC-RAS assume an impermeable creek bed and are therefore unsuitable to characterise the low flow requirements of these sections of Boundary Creek.

To assess the low flow requirements for the “damplands” and the Yeodene Swamp, a **water balance** approach has instead been adopted. Details of this approach are described in the Yeodene Swamp report (Jacobs 2017c). Briefly, the water balance for the system estimates all the inflows and outflows of the swamp hydrology. This was informed by a range of information including spot flow velocity gauging, groundwater levels, surface water levels, groundwater permeability analysis and online evaporation data from the Bureau of Meteorology.

Spot flow velocity gauging was undertaken at five locations; the upstream (location 1) and downstream (2) extents of Reach 2a and the downstream extents of Reach 2b (3), Reach 2c (4) and Reach 3 (5) using an impeller style velocity gauge. These locations were chosen so as to allow estimation of the water flowing in and out of a given reach. Evaporative losses were estimated using evaporation rates measured at Colac (station

090035). As there was no apparent flow lag during gauging, and both rainfall and evaporation was negligible, the change in flow in a given reach can be attributed to groundwater inflows or outflows (see Jacobs 2017c). By quantifying this exchange under low flow conditions, a low flow recommendation can be made that accounts for such exchanges.

The hydraulic models and the water balance calculations were used by the EFTP to determine **quantitative flow requirements** to meet the targeted ecological and physical outcomes and therefore, the defined management objective for each reach and sub-reach. The outputs of the hydraulic model and water balance, and their use in defining the low flow requirements of the values of Boundary Creek are shown in **Section 5.**

4. Management objectives and targeted physical and ecological outcomes

4.1 Chapter overview

The EFTP, informed by the input from the CRG and in conjunction with representatives from Barwon Water, determined the management objectives for Boundary Creek and the associated physical and ecological outcomes (with regard to flow) required to meet these objectives.

Table 4-1 summarises the qualitative determination of ecological condition (i.e. good, moderate, poor), the management objective (i.e. maintain or improve) and the targeted ecological and physical outcome for each reach. More detail is provided in the following sections which describe the objectives and targeted physical and ecological outcomes for each of the distinct reaches and sub-reaches of Boundary Creek.

Table 4-1 Ecological condition (i.e. good, moderate, poor) management objective (i.e. maintain or improve) and targeted physical and ecological outcome for each reach of Boundary Creek.

Reach	Current ecological condition	Management objective	Targeted physical and ecological outcome
Reach 1	Good	Maintain	• Provide pool habitats for fish, frogs, vegetation • Allow fish to move between pools • Mix pools
Reach 2a	Moderate	Maintain	• Provide pool habitats for fish, frogs, vegetation • Allow fish to move between pools • Mix pools
Reach 2b	Good	Maintain	• Maintain waterlogged soils to continue to support Swampy Riparian Vegetation, macroinvertebrates and Otway Bush Yabby.
Reach 2c	Moderate (vegetation)	Improve (to provide water of a suitable volume and quality to meet the objectives of Reach 3).	• Maintain inundation of the swamp to prevent oxidation of acid sulphate soils, and in the process, preserve the flow and water quality in Reach 3.
Reach 3	Poor	Improve	• Provide pool habitats for fish, frogs, vegetation • Provide opportunity for fish passage • Minimise frequency and duration of cease to flow events • Mix pools

4.2 Reach 1 (upstream of McDonalds Dam)

Reach 1 is currently 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, including the detailed assessment site. Reach 1 is likely to have been made more suitable for fish, macroinvertebrates and frogs by the supplementary flow released by Barwon Water but this flow is unlikely to have improved the vegetation values of this reach significantly.

Management objective: The flow management objective for Reach 1 is to **maintain** the currently good ecological condition of the reach.

Targeted physical and ecological outcome: To maintain the ecological condition or Reach 1, the low flow must provide pool habitats for fish (e.g. Southern Pygmy Perch, Mountain Galaxias), frogs, crustaceans and aquatic vegetation. The volume must also be sufficient to mix pools to ensure that they do not stagnate. The aquatic values of Reach 1 could likely tolerate short duration cease to flow periods (up to approximately two weeks), provided that the pools do not stagnate or drawdown significantly, but they are not required to maintain the ecological condition of the reach.

4.3 Reach 2a (channel immediately downstream of McDonalds Dam)

The ecological condition of Reach 2a is moderate. The area has limited intact large native riparian vegetation and while fish, frogs and crustaceans may use this reach, the channel shape is uniform and therefore does not provide much diversity of habitat.

Management objective: The flow management objective for Reach 2a is to **maintain** the current moderate ecological condition of the reach. The current condition assessment reflects the channelised nature of the creek and the surrounding landuse, primarily the absence of habitat forming riparian and emergent vegetation. As condition could not be improved by changing the flow regime from current, the objective in the context of setting low flow recommendations for the reach is therefore to maintain the condition, rather than to improve it.

Targeted physical and ecological outcome: To maintain the condition of Reach 2a, flow is required to maintain depth in the pools and ensure they are mixed. As with Reach 1, although cease to flow events could be tolerated for short periods, they are not required.

4.4 Reach 2b (“dampland”)

The “dampland” (Reach 2b) is in good ecological condition. The waterlogged soils support a floristically diverse vegetation community that is in good health and is free of weeds. Groundwater level data, as measured at nearby groundwater bores, indicates that the waterlogged soils in the “damplands” are maintained by surface water flow (rather than the regional groundwater system).

Management objective: From a flow perspective, the management objective for Reach 2b is to **maintain** the currently good ecological condition of the dampland.

Targeted physical and ecological outcome: The key determinant of the condition of the “dampland” is the presence of waterlogged soils. Therefore, the critical flow requirement for Reach 2b is to maintain the sodden nature of the “dampland” so that it can continue to support the Swampy Riparian Woodland vegetation community and associated fauna (e.g. macroinvertebrates, crustaceans, small-bodied fish, frogs).

4.5 Reach 2c (Yeodene Swamp)

Yeodene Swamp is a peat swamp that has been subject to significant change since European settlement. Changes in the last 30 years have resulted in the peat becoming acidic, which has a direct impact on the swamp itself and the downstream water quality in Reach 3. Since 1999, the swamp has also undergone cease to flow event most years. The current ecological value of the vegetation in the swamp ranges from moderate to poor in some areas.

Management objective: The management objective for Yeodene Swamp is to ensure that the volume and quality of water (especially pH) that passes downstream is suitable to support the objectives of Reach 3.

Targeted physical and ecological outcome: Improve the water quality as indicated by pH. Water quality recommendations are documented in the *Yeodene Swamp Study* (Jacobs 2017c)

4.6 Reach 3 (downstream of Yeodene Swamp to the confluence with the Barwon River)

The current condition of Reach 3 is poor. The trapezoidal, excavated channel provides only limited habitat value for fish, Platypus and crustaceans and there is little native riparian vegetation. Changes to the hydrological functioning of the creek mean that Reach 3 dries out in most summers. Furthermore, when Reach 3 does flow, the acidification of soil in Yeodene Swamp means that the pH can be extremely low.

Management objective: The flow management objective for Reach 3 is to **improve** the condition of the reach. Improve in this instance means maintaining the current values supported by the creek and improving the condition to allow species known to formerly occur (e.g. River Blackfish and other small bodied fish species) to recolonise.

Targeted physical and ecological outcome: To enhance the condition of Reach 3, from a flow perspective both the water quality and the flow volume need to be improved.

The improvement of water quality in Reach 3 requires the remediation and recovery of Yeodene Swamp (Reach 2c). Water quality recommendations are documented in Jacobs (2017c).

From a flow volume perspective, the targeted management outcome required to improve the condition of Reach 3 is to maintain pool habitats and prevent, or at least limit the frequency and duration of, cease to flow events. Pools will provide habitat for fish, frogs and aquatic vegetation.

5. Minimum low flow volume required to achieve the management objectives for Boundary Creek

5.1 Chapter overview

The purpose of this chapter is to quantify the minimum low flow volume that would be necessary in each reach and sub-reach of Boundary Creek to support the key ecological values. It should be noted that the low flow requirements for most of the reaches (with the exception of Reaches 2b and 2c) have been identified independently from each of the other reaches, without consideration of the operational constraints of the system. This report does not outline how the low flows in each reach should be delivered. However, it should be noted, that if a higher flow is required through an upstream reach in order to deliver the recommended flow in a downstream reach, this would not be detrimental to the values or objectives of the upstream reach. The low flow recommendations represent the **minimum** flow required to achieve objectives.

Table 5-1 summarises the low flows required to meet the management objectives of Boundary Creek. More detail is provided in the following sections.

Table 5-1 Minimum low flow requirements for Boundary Creek and description of the targeted physical/ecological objective.

Reach	Flow volume	Rationale, targeted physical/ecological objective
Reach 1	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
	Minimum low flow of 0.5 ML/day (measured at the gauge upstream of “McDonalds Dam”)	• A flow of 0.5 ML/day corresponds with a water depth of between 30 and 70 cm in pools and 3 cm of water over riffles. This would provide habitat for small bodied fish, macroinvertebrates and frogs and allow movement of fish between pools. This flow volume would also be sufficient to mix pools.
Reach 2a	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
	Minimum low flow of 0.5 ML/day (measured at the gauge downstream of “McDonalds Dam”)	• A flow of 0.5 ML/day corresponds with a water depth of between 70 and 80 cm in pools and 12 cm of water over riffles. This would provide habitat for small bodied fish, macroinvertebrates and frogs, allow movement of fish between pools and would be sufficient volume to mix pools.
Reach 2b	Cease to flow	• Cease to flow conditions are not required to maintain the condition of the reach, however, the soil in the “damplands” would stay waterlogged for short periods (less than 2 weeks) without inflow with minimal impact on the ecology of the area.
	Minimum low flow of 1.5 ML/day (measured at the gauge downstream of “McDonalds Dam”)	• The water balance analysis and volume of water released historically from “McDonalds Dam” indicates that 1.5 ML/day measured at the gauge immediately downstream of “McDonalds Dam” is sufficient to maintain waterlogged soils in the “dampland”.
Reach 2c	Cease to flow	• Must be prevented. The main objective for this reach is to maintain inundation of the swamp to prevent oxidation of soils and improve water quality in Reach 3.

Reach	Flow volume	Rationale, targeted physical/ecological objective
	Minimum low flow of 1.5 ML/day entering the swamp (no gauge at this location, therefore, 3 ML/day measured at the gauge downstream of "McDonalds Dam" is required to achieve the objectives of the "damplands" and the Yeodene Swamp)	• Maintain waterlogged soils in the swamp, reducing the oxidation potential of the acid sulphate soils, with the objective of decreasing the incidence of very low pH water in Reach 3 (see Jacobs 2017c). Adaptive management may lead to the refining of the low flow recommendation to ensure flow at the Yeodene gauge is maintained throughout the year. • The water balance analysis and volume of water released historically from "McDonalds Dam" indicates 3 ML/day is required (measured at the flow gauge immediately downstream of "McDonalds Dam") from a volumetric perspective (e.g. independent of the pH of the water) to achieve the ecological objectives of the "damplands" and the Yeodene Swamp.
Reach 3	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
	Minimum low flow of 0.5 ML/day measured at the gauge at Colac-Forrest Road	• A low flow of 0.5 ML/day in Reach 3 corresponds to pools up to 40 cm deep and shallow runs of approximately 6 cm depth. This would provide habitat for small bodied fish, macroinvertebrates and frogs, allow movement of fish between pools and mix pools. Flow of that depth may also allow occasional use by Platypus, however, the structural habitat (clear banks) are unsuitable for resident individuals.

5.2 Overview of the flow recommendations

The low flows required to meet the management objectives and targeted physical and ecological outcomes for Boundary Creek were determined for each of the reaches in Boundary Creek by the EFTP. The flow recommendations have been designed to maintain or improve the ecological communities and species that are likely to be currently supported by the creek and in some cases, to allow species that have been lost as a result of flow changes to recolonise the system (particularly in Reach 3). These flow recommendations should be used to help ensure that any flow provided prevents further degradation in the condition of the creek.

This study focuses primarily on the low flow requirements of the creek as this is the flow component that has been impacted by the operation of the Barwon Downs Borefield as a result of lower groundwater levels in Reach 2 (Jacobs 2017b). Furthermore, this is also the flow component that can potentially be managed through controlled releases in the catchment.

The current study focusses primarily on the volume of low flow required to provide habitat suitable to support the ecological values of Boundary Creek (e.g. depth in pools and over riffles). A key additional ecological requirement is that the pools are sufficiently mixed, which will help to maintain water quality. Therefore, the EFTP considered pool mixing in the setting of objectives.

While the flow volumes recommended are sufficient to mix the pools in Boundary Creek, the current study assumes that the ambient water is of suitable quality (particularly pH) to support the targeted species and communities. The provision of suitable quality water in Reach 3 will require remediation of the Yeodene Swamp, which is discussed in detail in the *Yeodene Swamp Study* (Jacobs 2017c).

In addition to low flows, cease to flows have also been considered. Although there is limited flow data from the upper section of Boundary Creek, the accounts and observations of long term residents indicate that the creek did cease to flow in the upper reaches in summer (Gardiner 2017, S. Alford, pers. comm.). However, not far down the catchment (upstream of "McDonalds Dam") accounts indicate that the creek flowed all year (Gardiner 2017) and flow data from Yeodene suggest that the creek ceased to flow only very infrequently prior to 1999. As cease to flow periods do not appear to have been a feature of the creek historically they have not been recommended as part this study *per se*. It is important, however, to acknowledge that the aquatic values of the creek could tolerate short (i.e less than two weeks) cease to flow periods without a decline in condition, provided that the pools do not stagnate or drawdown to a significant degree. Therefore, managed flows are not required to avoid every cease to flow period, provided they are of short duration and are infrequent.

The minimum low flow requirements for most of the reaches (with the exception of Reaches 2b and 2c) have been identified independently from each of the other reaches, without consideration of the operational constraints of the system. This report does not outline how low flow requirements should be delivered. For example, it may only be possible to deliver managed flows at some locations in the catchment and so one reach may receive a flow higher than the minimum low flow recommendation to ensure a downstream reach receives its requirement. This should not be regarded at detrimental to the reach receiving the higher flow as the low flow recommendations are the minimum required to meet the objective. Determining the flow requirements independently, where possible, provides maximum flexibility to consider different operational scenarios.

The minimum required flows for each reach are outlined in the following sections.

5.3 Reach 1 (upstream of McDonalds Dam)

The management objective for Reach 1 is to maintain the current values, which require permanent pool habitats for fish, macroinvertebrates and aquatic plants with mixed pools. Any continuous flow through this reach will maintain pool habitats (i.e. pools would permanently hold water).

In addition to maintaining water in pools, the aquatic values of Reach 1 require flows sufficient to replenish and mix the water in the pools to prevent water quality deteriorating to a level that threatens aquatic biota. The main water quality concern from a volumetric perspective under very low flow conditions relates to dissolved oxygen concentrations, which can threaten the survival of aquatic biota if it drops below 2 mg/L.

The EFTP determined that a low flow of 0.5 ML/day would support the majority of species and communities that would be present in Reach 1 of Boundary Creek. The hydraulic model indicates that a flow of 0.5 ML/day corresponds to a depth of between 30 and 70 cm in pools and approximately 3 cm across riffles (Figure 5-1). Not only does this flow provide the physical habitat required for the aquatic species and communities likely to be supported by Reach 1 (i.e. small bodied native fish, aquatic plants, macroinvertebrates, crustaceans and frogs), it should also be sufficient to mix pools.

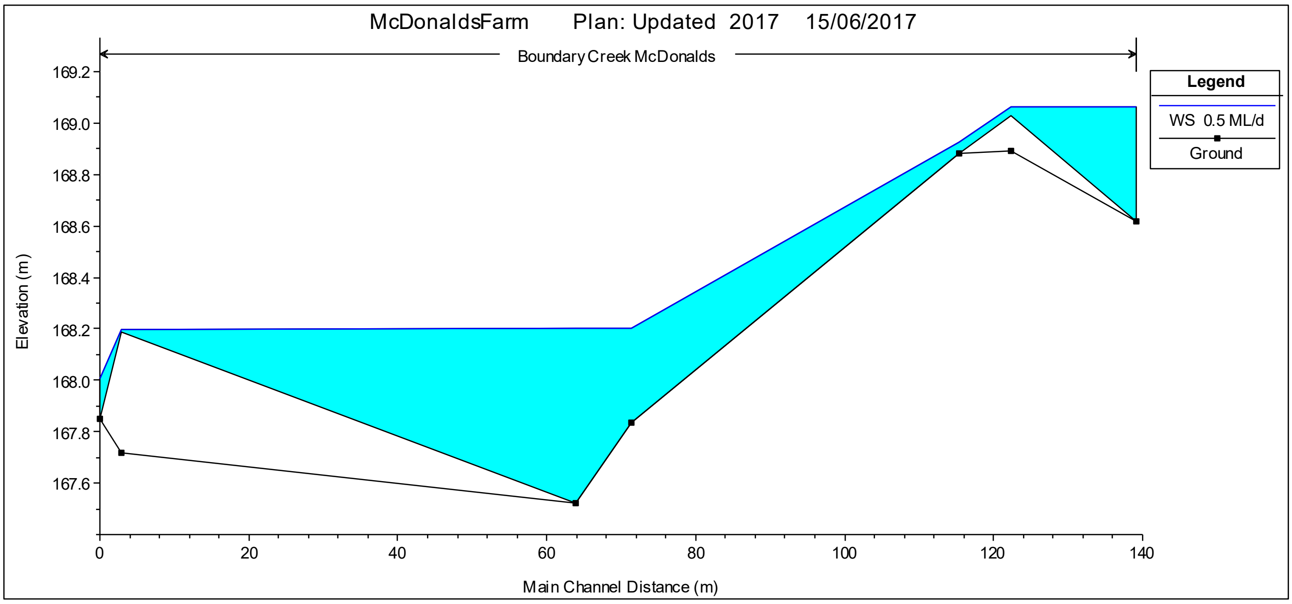

Figure 5-1 Hydraulic model long section for Reach 1 of Boundary Creek. Blue shaded area represents inundation under a flow of 0.5 ML/day.

The pool depth required for different fish species is dependent on their size and vertical body height and at a minimum, depth needs to be sufficient such that each fish species remains wholly submerged. There is a low probability that River Blackfish are supported by Reach 1, but they are the species with the most stringent habitat requirements and so by extension, flow suitable for this species will also be suitable for the other smaller bodied fish species supported by the reach. Studies of the habitat preferences of River Blackfish indicate that that the species preferentially uses relatively deep pools (40-60 cm deep; Khan *et al.* 2004). Pools between 30 cm and 70 cm would therefore support all the fish species that may be present in Reach 1 of Boundary Creek. The flow of 3 cm would not greatly impede the small bodied fish species supported in Reach 1 moving between pools and small increase in flow during rainfall driven events should provide further opportunities for fish to move throughout the reach.

The pools with a depth of 30-70 cm will also support the majority of aquatic vegetation species (primarily Water Ribbon) that currently occur in Reach 1. The riparian vegetation in Reach 1 is probably reliant on groundwater soaks, particularly on the northern bank of the creek, but continuous flows in the stream will help to wet the soil on the lower parts of the bank and therefore provide reliable access to water that will help to maintain some riparian plants.

Macroinvertebrates that use pool habitats would be supported under a flow of 0.5 ML/day. The upper reach of Boundary Creek has few significant riffle habitats and therefore most of the macroinvertebrates that naturally occur will be adapted to pool and edge habitats rather than fast flowing riffles. A minimum flow of 0.5 ML/day would provide a depth of 3 cm through riffle habitats and will not significantly increase width of riffles. This flow will not create conditions that will allow specialist riffle dwelling macroinvertebrates to colonise Boundary Creek, but will be sufficient to maintain the type of macroinvertebrate communities likely to be currently supported.

Frogs such as the Pobblebonk, Striped and Spotted Marsh Frog and the Common Froglet, would use the well vegetated margins of the slow flowing or still pools in Reach 1 under a low flow of 0.5 ML/day. This flow will not be of sufficient velocity to wash tadpoles out of their preferred habitat. Occasional rainfall driven high flows (which would be unimpacted by changes in baseflow conditions) may reduce tadpole survival, however, these flows would occur naturally and therefore the frog species in Boundary Creek would be adapted to occasional high flows.

It is likely that the species and communities of Reach 1 could tolerate short cease to flow periods (up to two weeks) without a significant decline in condition provided that they did not happen frequently (more than once a year).

The low flow requirements to maintain the ecological condition of Reach 1 are summarised in Table 5-2.

Table 5-2 Low flow requirements for Reach 1.

Flow volume	Rationale
Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
Minimum low flow of 0.5 ML/day (measured at the gauge upstream of “McDonalds Dam”)	• A flow of 0.5 ML/day corresponds with a water depth of between 30 and 70 cm in pools and 3 cm of water over riffles. This would provide habitat for small bodied fish, macroinvertebrates and frogs, allow movement of fish between pools and be sufficient to mix pools.

5.4 Reach 2a (channel immediately downstream of “McDonalds Dam”)

To maintain the moderate ecological condition of the channel immediately downstream of “McDonalds Dam”, flow should be sufficient to maintain water depth in pools and to maintain mixing through the water column. As with Reach 1, although cease to flow events could be tolerated for short periods of up to two weeks (provided that pools did not dry or stagnate), they are not required to maintain the condition of the species and communities in Reach 2a.

The EFTP determined that a flow of 0.5 ML/day is sufficient to provide suitable pool habitat in Reach 2a. The hydraulic model indicates that a flow of 0.5 ML/day corresponds to a depth of between 70 and 80 cm in pools and approximately 12 cm across riffles (Figure 5-2).

The low flows required to maintain the ecological condition of Reach 2a are summarised in Table 5-3.

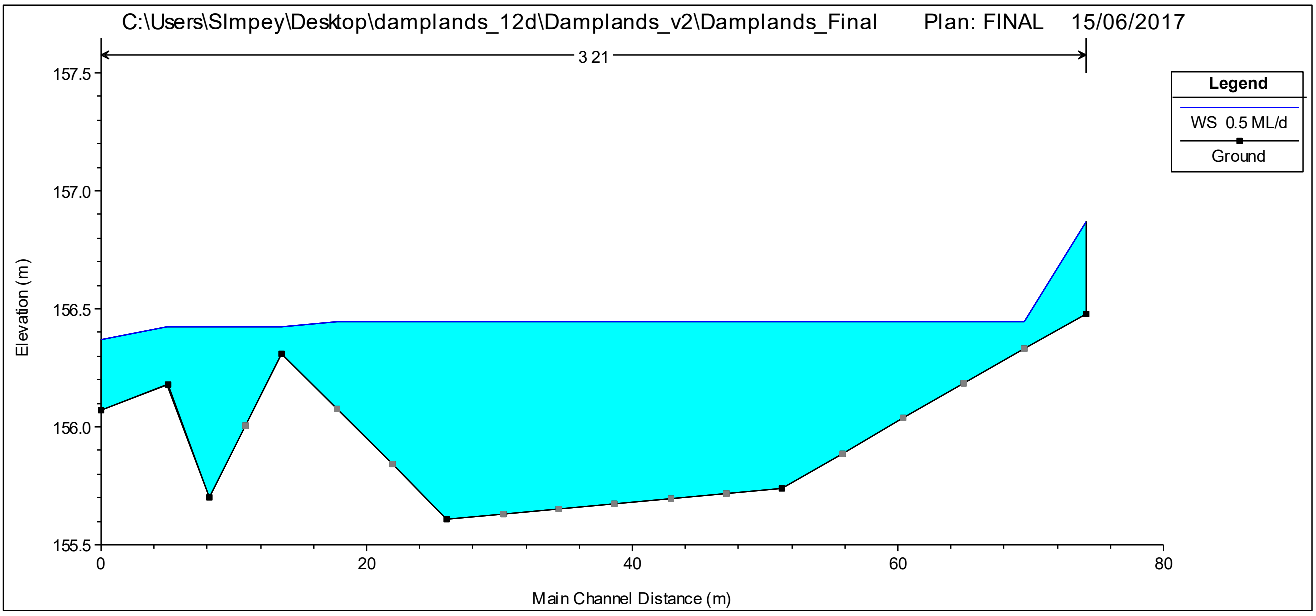

Figure 5-2 Hydraulic model long section for Reach 2a of Boundary Creek. Blue shaded area represents inundation under a flow of 0.5 ML/day.

Table 5-3 Low flow requirements for Reach 2a.

Flow volume	Rationale
Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
Minimum low flow of 0.5 ML/day (measured at the gauge downstream of "McDonalds Dam")	• A flow of 0.5 ML/day corresponds with a water depth of between 70 and 80 cm in pools and 12 cm of water over riffles. This would provide habitat for small bodied fish (e.g. River Blackfish preferentially use pools 40-60 cm deep, Khan *et al.* 2004), macroinvertebrates and frogs, allow movement of fish between pools and maintain mixed pools.

5.5 Reach 2b ("damplands")

The "dampland" is in good ecological condition, which is due to the waterlogged soils through the area. To maintain the condition of this reach, the soils need to be kept waterlogged so that it can continue to support the Swampy Riparian Woodland vegetation community and associated fauna (e.g. macroinvertebrates, Otway Bush Yabby).

As summarised in Section 2.2.2.3, the regional groundwater in this area is well below the surface, indicating that the maintenance of the waterlogged soils is due to surface flow, which in summer is usually exclusively the supplementary flow released at Bushby Road. As observed as part of this study, in summer the supplementary flow does not pass downstream of the "damplands", however, the "damplands" remain inundated and are in good ecological condition. This indicates that the current supplementary flow is sufficient to maintain the ecological condition of the "damplands" (Reach 2b).

As discussed in Section 2.3.3, the full 2 ML/day has not always been passed downstream of “McDonalds Dam”. From the short record reviewed as part of this study, the flow in the summer months downstream of McDonalds Dam is usually less than 1 ML/day (Figure 2-14). The water balance method estimated that in May 2017, 1.5 ML/day was being lost to the “damplands” (Jacobs 2017c).

Based on the loss estimate, and that the volume of water that has been released over the past has been sufficient to maintain the condition of the damplands, the EFTP determined that a flow of 1.5 ML/day (measured at the gauge downstream of “McDonalds Dam”) is sufficient to keep the soils of the “damplands” waterlogged and to maintain their ecological condition. It should be noted that 1.5 ML/day (measured at the gauge downstream of “McDonalds Dam” gauge), is similar to the volume that has been provided over the recent past (see Section 2.3.2), is unlikely to meet the minimum flow requirement of the Yeodene Swamp.

It is likely that cease to flows could occur for short periods (up to two weeks) without significantly impacting the ecological condition of the damplands, provided that the soils remain waterlogged. Cease to flow periods are not, however, required to maintain the ecological condition of the damplands.

The low flows required to maintain the ecological condition of Reach 2b are summarised in Table 5-4.

Table 5-4 Low flow requirements for Reach 2b.

Flow volume	Rationale
Cease to flow	• Cease to flow conditions are not required to maintain the condition of the reach, however, the soil in the “damplands” would stay waterlogged for short periods (less than 2 weeks) without inflow with minimal impact on the ecology of the area.
Minimum low flow of 1.5 ML/day (measured at the gauge downstream of “McDonalds Dam”)	• The water balance analysis and volume of water released historically from “McDonalds Dam” indicates that 1.5 ML/day measured at the gauge immediately downstream of “McDonalds Dam” is sufficient to maintain waterlogged soils in the “dampland”.

5.6 Reach 2c (Yeodene Swamp)

The main management objective for the Yeodene Swamp is to ensure that the volume and quality (pH) of the water that flows out of the swamp is suitable to achieve the objectives of Reach 3. Achieving suitable flow and water quality in Reach 3 will require remediation of the swamp, which is the focus of the *Yeodene Swamp Study* (2017c). The minimum low flow volume recommendations described in the current study represent a summary of the *Yeodene Swamp Study* (Jacobs 2017c). See that study for more detail of the methods used and description of the remediation of the swamp more broadly.

The low flow volume requirements of the swamp cannot be determined using a hydraulic model due to the unsuitability of hydraulic models in this reach (as outlined in Section 3). Instead, the low flow volume was considered using a water balance approach (Jacobs 2017c).

The review of historical data, together with the new information collected during the field program for the *Yeodene Swamp Study* (2017c), highlights the importance of maintaining flow all year round at the Yeodene gauge, which should prevent drying at Yeodene Swamp and subsequently improve the water quality downstream of the swamp (see Jacobs 2017c). The earliest recorded historic cease to flow event where there is both surface water flow and water quality data available was in 1990. The creek ceased to flow for approximately one month which caused parts of the swamp to dry and acid sulphate soils to oxidise. The water measured at the Yeodene gauge during and following that cease to flow event had a pH less than 5 for approximately 3 months. Low pH events were also recorded in the following two summers (1991 and 1992) as a result of low summer flows. The low pH events extended for a period of 4 to 5 months and the pH levels improved during the winter months.

It is difficult to determine the actual flow volume required to maintain flow through the swamp (and hence the water quality downstream of the swamp), because for significant periods of time during summer, less than 1 ML/day has been recorded downstream of “McDonalds Dam”. Observations made during the current study confirm that flow of less than 1 ML/day downstream of "McDonalds Dam" during summer, and possibly up to 1.5 ML/day, is not sufficient to result in flow into the Yeodene Swamp.

It is possible that 2 ML/day is sufficient to maintain inundation of the Yeodene Swamp, but there is limited scientific evidence to support this. Examination of the historical gauged records indicate that flow at the Yeodene gauge starts declining when the flow drops below 3 ML/day downstream of McDonalds Dam. The streamflow gauging undertaken for this study also estimated that approximately 1.5 ML/day was being lost through the Yeodene Swamp (Jacobs 2017c).

Therefore, based on the current understanding of the functioning of Boundary Creek, the low flow required to maintain inundation of the swamp through the summer is estimated to be 3 ML/day (measured at the flow gauge downstream of "McDonalds Dam") which should be sufficient to maintain inundation of Yeodene Swamp and to maintain the waterlogged soils required to preserve the ecological condition of the "damplands".

The objective of the minimum low flow recommendation in Yeodene Swamp is to prevent the oxidation of acid sulphate soils and in the process, to maintain the flow and water quality into Reach 3. The review of historic data indicates that a cease to flow period of only a month in 1990 was sufficient to result in persistent low pH conditions. While it is possible that cease to flow periods shorter than a month could occur without negative impact there is no strong justification with the current information to recommend cease to flows for Yeodene Swamp.

As outlined, the volumetric low flow recommendation for the swamp determined as part of this study must be considered in conjunction with the *Yeodene Swamp Study* (2017c) which assesses options for remediating the Yeodene Swamp. Of particular concern is the pH in the swamp and downstream in Reach 3. The options for remediating the swamp, including a discussion of the ecological risk of low pH in Boundary Creek, is considered in detail as part of the *Yeodene Swamp Study* (2017c).

The flow recommendation for Yeodene Swamp outlined in this study is an estimate and therefore ongoing groundwater and surface water monitoring in the context of adaptive management is recommended to confirm the flow recommendation is meeting the desired outcome (i.e. improved flow and water quality in Reach 3) within 6 months. If water quality has not improved sufficiently, additional flow into the "damplands" may be required or further remediation activities. Alternatively, if the water quality improves to a level deemed acceptable, the volume may be able to be reduced over time.

The low flows required to maintain the ecological condition of Reach 2c are summarised in

Table 5-5 Low flow requirements for Reach 2c.

Flow component	Rationale
Cease to flow	• Must be prevented. The main objective for this reach is to maintain inundation of the swamp to prevent oxidation of soils and improve water quality in Reach 3.
Minimum low flow of 1.5 ML/day entering the swamp (no gauge at this location, therefore, 3 ML/day measured at the gauge downstream of "McDonalds Dam" is required to achieve the objectives of the "damplands" and the Yeodene Swamp)	• Maintain waterlogged soils in the swamp, reducing the oxidation potential of the acid sulphate soils, with the objective of improving the water quality with respect to pH water in Reach 3. Adaptive management may lead to the refining of the low flow recommendation to ensure flow at the Yeodene gauge is maintained throughout the year (see the *Yeodene Swamp Study*, Jacobs 2017c). • The water balance analysis and volume of water released historically from "McDonalds Dam" indicates 3 ML/day is required (measured at the flow gauge immediately downstream of "McDonalds Dam") from a volumetric perspective to achieve the ecological objectives of the "damplands" and the Yeodene Swamp.

5.7 Reach 3 (downstream of Yeodene Swamp to the confluence with the Barwon River)

The management objective for Reach 3 is to improve the ecological condition, which from a flow perspective, requires improvements in both the quality of water flowing out of Yeodene Swamp and the flow volume. Improvement of the water quality in Reach 3 requires remediation of Yeodene Swamp. The options for remediating the swamp, including a discussion of the ecological risk of low pH in Boundary Creek, is considered as part of the *Yeodene Swamp Study* (2017c).

From a volume perspective, improvement of the ecological condition requires suitable pool habitats for fish, frogs and aquatic vegetation. An examination of the outputs of the hydraulic model led the EFTP to determine that a minimum flow of at least 0.5 ML/day would provide the habitat required to support the fish, crustacean and vegetation species predicted in Reach 3. According to the hydraulic model, 0.5 ML/day in Reach 3 corresponds to pools up to 40 cm deep and shallow runs of approximately 6 cm depth (Figure 5-3). The EFTP determined that a minimum flow of 0.5 ML/day would also mix pools sufficiently to prevent adverse water quality condition during summer (provided that the water flowing out of Yeodene Swamp was of suitable quality). A flow of 0.5 ML/day may also be sufficient to allow small-bodied fish to move between some pools, although larger fish may only be able to move during rain driven higher flow events.

The genetic analysis undertaken as part of this study did not detect any evidence of Platypus in Boundary Creek. The analysis also found no evidence of Platypus from two sites in the Barwon River, upstream of the confluence with Boundary Creek at Dewings Bridge Road (in the Barwon River East Branch) and downstream of the confluence at Colac-Lorne Road. While there is no evidence from this eDNA analysis that Platypus were present in the Barwon River near the Boundary Creek confluence at the time of sampling, the species has been recorded from the West Barwon River, East Barwon River, the Barwon River near the confluence with Boundary Creek and Pennyroyal Creek (APC 2002; Environous 2008; McKinnon and Milner 2009). It is therefore possible that if flow in Reach 3 was sufficient to provide pools of suitable water quality that Platypus could occasionally use habitat in Boundary Creek to forage. It should be noted that the trapezoidal channel would not support resident populations of Platypus and so at the best this use would be intermittent.

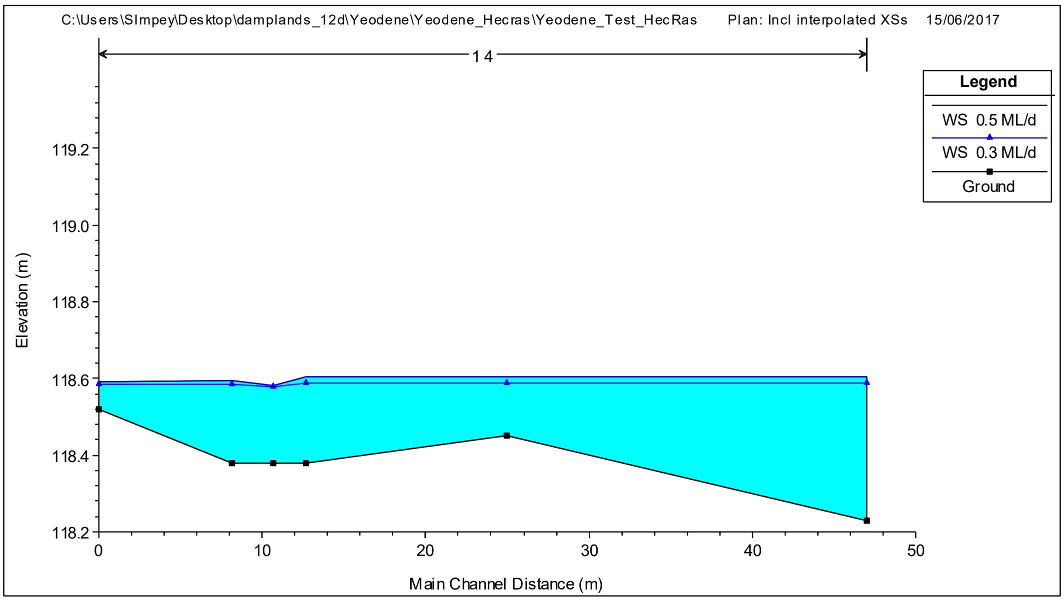

Figure 5-3 Hydraulic model long section for Reach 3 of Boundary Creek showing flows of 0.5 ML/day and 0.3 ML/day.

An analysis of flow data from the gauge at Yeodene shows that between 1985 and 1998 there were very few cease to flow events and summer flows exceeded 0.4 ML/day 80% of the time (Figure 5-4). Although rare, it is highly likely that the aquatic values and communities that could be supported by Reach 3 could tolerate cease to flow events without a decline in condition if they were of short duration (i.e. less than two weeks) that did not result in pools drying or stagnation. The values of Reach 3 do not require cease to flow events to maintain condition.

It is important to note that flow is only one issue in Reach 3 of Boundary Creek. Providing the correct flow regime may not allow the creek to support all the values it once did. Woody snags are required by River Blackfish as they provide cover habitat and as egg attachment sites. Likewise, Southern Pygmy Perch would be unlikely to re-establish unless dense vegetation beds, which provide important habitat, do so first. The flow requirements presented here should therefore be considered in the context of these other catchment factors.

The flow recommendations to support the species and communities likely to be present in Reach 3 of Boundary Creek are summarised in Table 5-6.

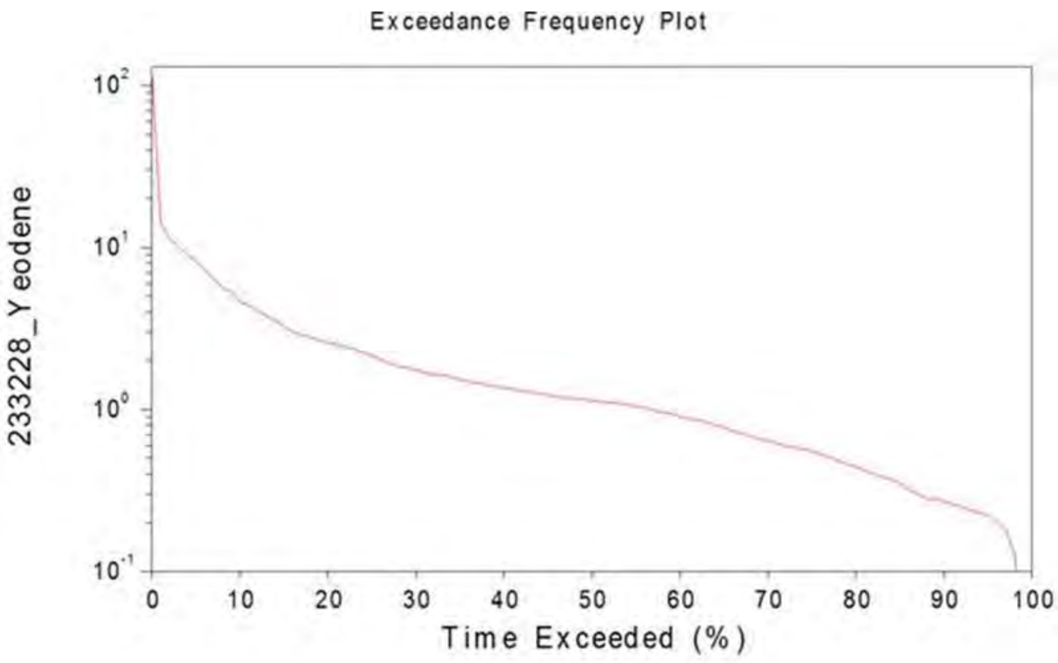

Figure 5-4 Flow exceedance curve for Boundary Creek at Yeodene from 1985-1998.

Table 5-6 Low flow requirements for Reach 3.

Flow component	Rationale
Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
Minimum low flow of 0.5 ML/day measured at the gauge at Colac-Forrest Road	• A low flow of 0.5 ML/day in Reach 3 corresponds to pools up to 40 cm deep and shallow runs of approximately 6 cm depth. This would provide habitat for small bodied fish, macroinvertebrates and frogs, allow movement of fish between pools and maintain mixed pools. Flow of that depth may also allow occasional use by Platypus, however, the structural habitat (e.g. straight banks and lack of vegetation cover) is unsuitable for resident individuals.

6. Summary of ecological condition, management objectives and low flow volume requirements for Boundary Creek

Table 6-1 provides a consolidated summary of the ecological condition assessment of each reach and sub-reach, the management objective and associated targeted outcomes and the minimum low flows required to meet the management objectives. The minimum flow volume recommendations assume that the water quality (particularly pH) is suitable to support the values of Boundary Creek, which will require remediation of Yeodene Swamp. See the *Yeodene Swamp Study* (2017c) for a detailed discussion of pH in Boundary Creek.

Table 6-1 Ecological condition (i.e. good, moderate, poor), management objectives (i.e. to maintain or improve), targeted physical and ecological outcomes and associated low flow requirements for Boundary Creek.

Reach	Ecological condition	Management objective	Targeted physical and ecological outcome	Minimum Low Flow volume	Description
1	Good	Maintain	• Provide pool habitats for fish, frogs, vegetation. • Allow fish to move between pools. • Mix pools.	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
				Minimum low flow of 0.5 ML/day (measured at the gauge upstream of “McDonalds Dam”)	• A flow of 0.5 ML/day corresponds with a water depth of between 30 and 70 cm in pools and 3 cm of water over riffles. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch, Mountain Galaxias), macroinvertebrates and frogs, allow movement of fish between pools and maintain water quality.
2a	Moderate	Maintain	• Provide pool habitats for fish, frogs, vegetation. • Allow fish to move between pools. • Mix pools.	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
				Minimum low flow of 0.5 ML/day (measured at the gauge downstream of “McDonalds Dam”)	• A flow of 0.5 ML/day corresponds with a water depth of between 70 and 80 cm in pools and 12 cm of water over riffles. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch, Mountain Galaxias) macroinvertebrates and frogs, allow movement of fish between pools and maintain water quality.
2b	Good	Maintain	• Maintain waterlogged soils to continue to support Swampy Riparian Vegetation,	Cease to flow	• The soil in the “damplands” would stay waterlogged for short periods (less than 2 weeks) without inflow with minimal impact on the ecology of the area. Cease to flow conditions are not required to maintain the condition of the reach.

Reach	Ecological condition	Management objective	Targeted physical and ecological outcome	Minimum Low Flow volume	Description
			macro-invertebrates and Otway Bush Yabby.	Minimum low flow of 1.5 ML/day (measured at the gauge downstream of “McDonalds Dam”)	• The water balance analysis and volume of water released historically from “McDonalds Dam” indicates that 1.5 ML/day measured at the gauge immediately downstream of “McDonalds Dam” is sufficient to maintain waterlogged soils in the “dampland”.
2c	Poor	Improve	• Flow (of any magnitude) recorded at the Yeodene flow gauge throughout the year • Improve the water quality as indicated by pH. Water quality in Boundary Creek is discussed in detail in Jacobs (2017c).	Cease to flow	• Must be prevented. The main objective for this reach is to maintain inundation of the swamp to prevent oxidation of soils and improve water quality in Reach 3.
				Minimum low flow of 1.5 ML/day (to provide 1.5 ML/day in Reach 2c, 3 ML/day needs to be measured at the gauge downstream of “McDonalds Dam”)	• Maintain waterlogged soils in the swamp, reducing the oxidation potential of the acid sulphate soils, with the objective of decreasing the incidence of very low pH water in Reach 3. Adaptive management may lead to the refining of the low flow recommendation to ensure flow at the Yeodene gauge is maintained throughout the year. • The water balance analysis and volume of water released historically from “McDonalds Dam” indicates 3 ML/day is required (measured at the flow gauge immediately downstream of “McDonalds Dam”) from a volumetric perspective (e.g. independent of the pH of the water) to achieve a flow of 1.5 ML/d at the “damplands” and hence achieve the ecological objectives of the “damplands” and the Yeodene Swamp.
3	Poor	Improve	• Provide pool habitats for fish, frogs, vegetation and possibly occasional use by Platypus. • Provide opportunity for fish movement between pools • Minimise frequency and duration of cease to flow events. • Improve the water quality as indicated by pH. Water quality in Boundary Creek is discussed in detail in Jacobs (2017c).	Cease to flow	• Cease to flow periods are not required to maintain the ecological condition of the reach, however, they could occur occasionally (e.g. once a year) with minimal impact on the ecological condition of the stream provided the cease to flow periods are of short duration (e.g. less than two weeks).
				Minimum low flow of 0.5 ML/day (measured at the Yeodene flow gauge)	• A flow of 0.5 ML/day in Reach 3 corresponds to pools up to 40 cm deep and shallow runs of approximately 6 cm depth. This would provide habitat for small bodied fish (e.g. Southern Pygmy Perch), macroinvertebrates and frogs, allow movement of fish between pools and maintain water quality. Flow of that depth may also allow occasional use by Platypus that enter the creek from the Barwon River to forage, however, the structural habitat (clear banks) are unsuitable for resident individuals.

7. References

APC (2002) Ecology and conservation of Platypus in the Barwon River Catchment: II. Results of population surveys, Summer 2002. Australian Platypus Conservancy.

ARI (2001) Boundary Creek Fish Fauna Survey, November-December 2001. Freshwater Ecology Section, Arthur Rylah Institute for Environmental Research, Department of Natural Resources and Environment.

Barwon Water (2004) Groundwater Licence No. 893889 Gerangamete Area 2003/2004 Report. Barwon Water.

Colac Otway Fire Management Plan (2015): Version 11: September 2012-2015, updated to March 2017. Colac Otway Shire Council, CFA, Department of Environment, Land, Water and Planning.

Coughran, J. & Furse, J. 2010. *Euastacus yarreansis*. The IUCN Red List of Threatened Species 2010: e.T153639A4524409. http://dx.doi.org/10.2305/IUCN.UK.2010- 3.RLTS.T153639A4524409.en; accessed 16-06-2018.

DELWP (2018) Victorian Biodiversity Atlas. Department of Environment, Land, Water and Planning. Accessed 16-06-2018.

DEPI (2013) FLOWS: A method for determining environmental water requirements for Victoria, Edition 2. Department of Environment and Primary Industries

DSE (2009) Advisory List of Threatened Invertebrate Fauna in Victoria - 2009. Victorian Department of Sustainability and Environment, East Melbourne, Victoria.

Environous (2009) Selected fish surveys in the Barwon and Moorabool River catchments following the prolonged low period of 2006-2007. Report by Environous for the Corangamite CMA.

Gardiner, M. (2017) Otway Water Book 39: Review of Barwon Water's Boundary Creek Aquatic Ecology Investigation of 2017.

Himmelreich, E. (2010) Peat fire repeats – after 13 years. The Standard, 19 March 2010, http://www.standard.net.au/story/744270/peat-fire-repeats-after-13-years/, accessed 7 November, 2016.

Jacobs (2016) Barwon Downs Vegetation Survey 2016. Report by Jacobs for Barwon Water.

Jacobs (2017a) Boundary Creek aquatic ecology investigation. March 2017.

Jacobs (2017b) Barwon Downs Technical Works Program – Integration Report. March 2017.

Jacobs (2017c) Barwon Downs Technical Works Program – Yeodene Swamp Study Final June 2018.

Johnston, K. and Schultzm M. (2010) *Geocharax gracilis*. The IUCN Red List of Threatened Species. Vesrion 2014.3, www.iucnredlist.org. Downloaded, 5-2-2015.

Khan, M. T., T. A. Khan and M. E. Wilson (2004) Habitat use and movement of river blackfish (*Gadopsis marmoratus* R.) in a highly modified stream, Australia. Ecology of Freshwater Fish, 13: 285-293.

Lloyd *et al.* (2005) Environmental flow determination for the Barwon River (Site, Issues and Recommendations Papers). Report by Lloyd Environmental, Fluvial Systems and Ecological Associates for the Corangamite Catchment Management Authority.

McKinnon, L.J. and G.L. Milner (2009) Empowering industry R and D: trials of gear modification to reduce bycatch in freshwater fyke nets. Report, FRDC project 2008/017.

SKM (2006) Central Region Sustainable Water Strategy. Configuration of a basin wide REALM model for the Barwon/ Moorabool Basin. Final 1. 19 July 2006. Sinclair Knight Merz for Department of Sustainability and Environment. (SKM Ref: WC03467).

Southern Rural Water (2006) Barwon Region Water Authority – Groundwater Licence No 893889.

Tunbridge, B. R. (1988) Environmental flows and fish populations of waters in the South-Western Region of Victoria. Arthur Rylah Institute for Environmental Research, Technical Report Series No. 65.

Weeks, A., A. van Rooyen, A. Griffiths and R. Tingley (2015) Determining the effectiveness of eDNA for monitoring platypuses (Report to Melbourne Water) cesar, Parkville.

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.