Final Report of the Lower Moorabool River Groundwater and FLOWS Project

(CCMA Project No. 1731)

Report prepared by:

In Conjunction with

Project Ref: LE2003

3rd July 2020

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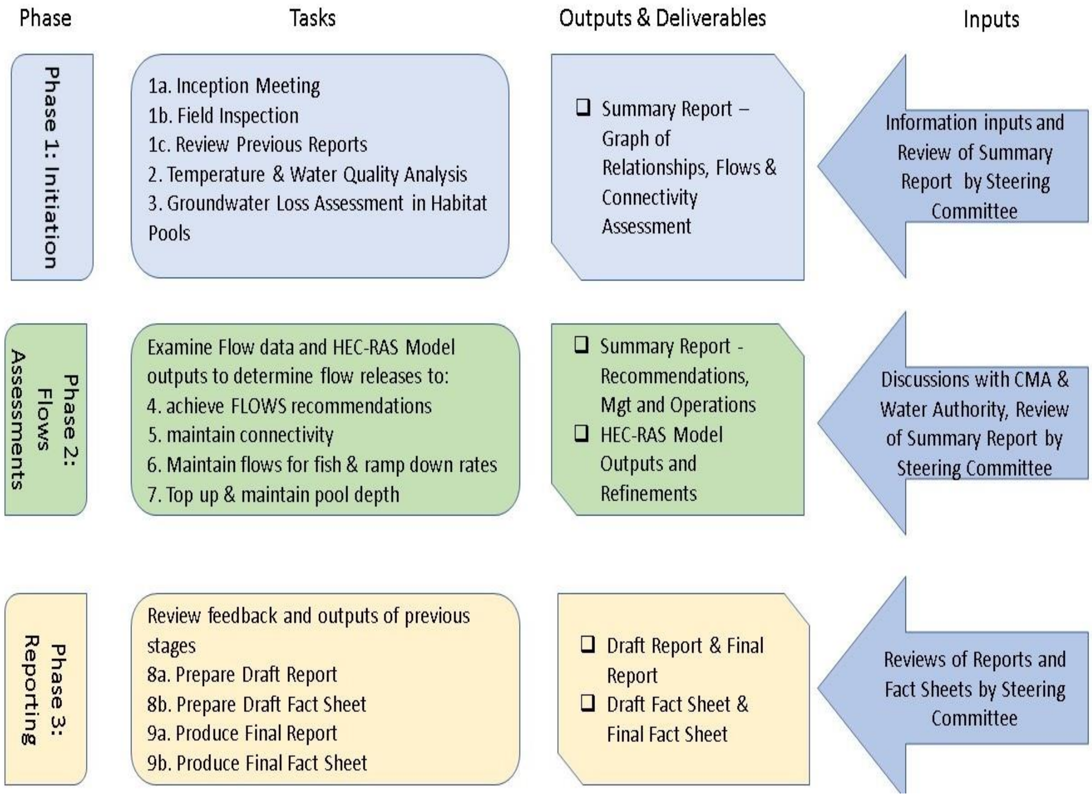
EXECUTIVE SUMMARY

The Moorabool River is one of the most flow stressed rivers in Victoria and the current environmental entitlement, which is held in Lal Lal Reservoir, does not provide for the majority of the River's ecological needs. Despite this, the Moorabool River still supports a number of species of native fish. In addition, the operation of the Batesford Quarry required the diversion of the Moorabool River from its original course to a new concrete-lined channel to the north and east, which is now, in part, a deteriorated and broken-up concrete channel. The quarry has also created a significant cone of depression causing significant groundwater losses in the lower Moorabool, which is impacting further on the ecosystem. This project is aimed at gaining a better understanding of the relationship between flow and losses to groundwater, which is a priority for the CCMA in order to protect and enhance native fish populations. There are further threats, due to habitat degradation, as well as ground water loss, and a loss of connectivity with other sections of the River, often resulting in fish deaths as the habitat refuge pools dry out.

This project analysed the existing (and recently collected) data to define the scale and nature of groundwater loss in the Lower Moorabool River near the Batesford Quarry. The project used the existing FLOWS study (Jacobs 2015) as a reference, and an updated FLOWS (HEC_RAS) analysis to develop recommendations around the scale of environmental water releases required to achieve existing FLOWS recommendations for Reach 4 of the Moorabool River, and to maintain connectivity through to the confluence with the Barwon River. The project provides specific recommendations around flows components required, and rise and fall rates, to facilitate fish passage, escape, and survival once flows cease, considering planned complementary works at two key habitat refuge pools in Reach 4 (see method below).



The lower Moorabool River is notable because of the amount of water the reach loses to groundwater. This is exacerbated by the quarry in the lower reaches of the river which creates a significant cone of depression further drawing the water from the river. While direct data for assessing the actual loss of water from the river to the groundwater is lacking, the losses can be estimated from the pool scale or on a reach scale.

Calculations at various scales provide some good lines of evidence that the leakage directly from the river to groundwater is significant in Reach 4. These scales are, increasing in significance of water loss from the river, as shown below.

- At the individual pool scale - the assessment in section 6.4, indicates that the loss could reach up to 0.3 ML/d (300 m^3/day; 0.3 ML/d).
- At the cone of depression scale (about 7.5 km of river), Nolan ITU (2002) estimated the leakage could be as high as = 0.28 ML/d but this is considered to be an under-estimate as they did not consider direct leakage through disturbed river sediments and mining spoil.
- At the habitat pools reach scale (about 1km of stream incorporating the pools) a significant proportion (possibly 75%) of lost water could be due to leakage, which represents up to 6 to 7 ML/d which otherwise would be available as baseflow to the Moorabool River.
- On a reach scale (about 1 km of stream), a loss in daily flow from Batesford to the habitat pools typically varying in volume from 3 ML/day to 20 ML/day (median of 5.14 ML/d; section 6.5) is corroborated by the observed flow data.

These observations and monitoring over the last 2 years (outlined in section 3) are consistent with data which shows the pools typically drying within 3 to 10 days of a cease to flow event. The rapid drying was observed when river flows were below 10ML/d in the antecedent period. At antecedent flows of 20 ML/d the pools did not dry even if there are short cease to flows. Section 6 shows that with pool volumes being relatively small at 1500-2000 m^3 (1.5 to 2ML), the pools could empty within 7 days of a cease-to-flow event occurring. This strongly supports the low flow recommendations throughout the year (sections 7.1.1, 7.1.3 & 8).

The observed flow data, demonstrated a loss in daily flow from Batesford to the habitat pools typically varying in volume from 3 ML/day to 20 ML/day (median of 5.14 ML/d) or 29% to 41% of daily flows depending on the season. This suggests that there is a significant impact on the river from drawdown due to the cone of depression associated with the quarry.

The losses to groundwater in the Reach 4 flows means that the flow recommendations would need to be topped up by the amount of these losses at the habitat pools site in Reach 4. The same analysis was undertaken for the Upper Moorabool to look at losses along the system to help make recommendations for flows at the sites at Lal Lal, and Morrisons (Section 6.6; and summarised in the table below).

The flows required to **achieve FLOWS recommendations in Reach 4 of the Moorabool River (as measured at the Batesford gauge)** are:

- **to maintain connectivity within all of Reach 4** requires flows of 128 – 145ML/d which allow fish to move from downstream to upstream reaches;
- **to maintain flows for fish to move between habitat pools (includes rates of rise and fall),** a flow fresh of 67 ML/day for one day will allows the habitat pools to be drowned-out (as the flow will drop down to 23ML/d over 3 days) and allow fish to escape the pools as they dry out; and
- **to top-up & maintain pool depth at the habitat pools,** low flows of 23 ML/day – 40 ML/day will be required in all seasons, especially during the summer/autumn period to ensure the necessary longevity of water in the pools at all times to support the fish and aquatic fauna upon which they depend to persist.

Flow Recommendations for the flows at Lal Lal, Morrisons, and Batesford sites to meet requirements at the habitat pools accounting for losses to groundwater in Reach 4.

Season	Flow Component	Magnitude Lal Lal	Magnitude Morrisons	Magnitude Batesford	Magnitude Habitat Pools	Duration	Frequency	Rise and Fall
Summer/Autumn (Dec to May)	a) Low Flow to maintain Pools	27 – 44 ML/day	27 – 44 ML/day	23 – 40 ML/day	20 ML/day	Continuous	Continuous	1.86/0.68
	b) Fresh 1 - Provide water over riffles	132 – 169 ML/day	132 – 169 ML/day	128 – 145 ML/day	125 ML/day	3 days	5 per season	1.86/0.68
	c) Fresh 2 - Trigger fish spawning &/or migration	287 – 304 ML/day	287 – 304 ML/day	283 – 300 ML/day	280 ML/day	3-5 days	3 Per season	1.86/0.68
	d) Fresh 3 – Scour pools/support blackfish breeding	907 – 924 ML/day	907 – 924 ML/day	903 – 920 ML/day	900 ML/day	1 day	2 per season	1.86/0.68
Winter Spring (June to Nov)	e) Low Flow to maintain pools	27 – 44 ML/day	27 – 44 ML/day	23 – 40 ML/day	20 ML/day	Continuous	Continuous	1.86/0.68
	f) Fresh 1 - Provide water over riffles and longitudinal connectivity	132 – 169 ML/day	132 – 169 ML/day	128 – 145 ML/day	125 ML/day	3 days	5 per season	1.86/0.68
	g) Fresh 2 - Trigger fish spawning &/or migration	287 – 304 ML/day	287 – 304 ML/day	283 – 300 ML/day	280 ML/day	3-5 days	3 Per season	1.86/0.68
	h) Fresh 3 - Provide prolonged inundation to stimulate breeding and growth	907 – 924 ML/day	907 – 924 ML/day	903 – 920 ML/day	900 ML/day	3-5 days	2 per season	1.86/0.68

1 INTRODUCTION

The Moorabool River is one of the most flow stressed rivers in Victoria and the current environmental entitlement, which is held in Lal Lal Reservoir, does not provide for the majority of the River's ecological needs. Despite this, the Moorabool River still supports a number of species of native fish. This project is aimed at gaining a better understanding of the relationship between flow and losses to groundwater, which is a priority for the CCMA in order to protect and enhance native fish populations. There are further threats, due to habitat degradation, loss to ground water, and a loss of connectivity with other sections of the river, often resulting in fish deaths as the habitat refuge pools near Batesford Quarry dry out.

The operation of the Batesford Quarry required the diversion of the Moorabool River from its original course to a new concrete-lined channel to the north and east. The channel to the north is now a deteriorated and broken-up concrete channel. This section has two large habitat refuge pools, and a newer concrete channel, which is in good condition, immediately downstream of the deteriorated area. Groundwater seepage that collects in the quarry is pumped back, under EPA licence, into the river near the start of the newer concrete section, downstream of the habitat refuge pools under EPA licence. This discharge (~9 ML/d) back into the river from the quarry is an important source of flow for the river, but enters the river below the key habitat pools. There is good data collection in this region, both in the river and discharge out of the quarry.

This project analysed the existing (and recently collected) data to define the scale and nature of groundwater loss in the Lower Moorabool River near the Batesford Quarry. The project used the existing FLOWS study (Jacobs 2015) as a reference, and an updated FLOWS (HEC_RAS) analysis to develop recommendations around the scale of environmental water releases required to achieve existing FLOWS recommendations for Reach 4 (Figure 1), and to maintain connectivity through to the confluence with the Barwon River.

The project provides specific recommendations around minimum flows and water recession timing to facilitate fish passage, escape, and survival once flows cease, considering planned complementary works at two key habitat refuge pools in Reach 4. These actions may be supplemented by newly identified actions arising from other recommendations relating to hydro-ecological relationships in Reach 4 and the habitat pools developed as part of this project.

1.1 Project Objectives

The Moorabool Groundwater and FLOWS project aimed to better understand the scale and nature of flows and groundwater dynamics on the Lower Moorabool River at Batesford Quarry, and identify the actions required to maintain connectivity through this reach, in the short and medium term.

Figure 1: Moorabool Catchment and Environmental Flow Reaches (From Jacobs 2015)

2 PROJECT APPROACH

The Moorabool Groundwater Flows Project:

- built upon the previous FLOWS studies,
- undertook a field habitat assessment,
- investigated groundwater losses and interactions,
- reviewed and updated ecology-flow relationships,
- refined and re-ran hydraulic and hydrology models, and
- makes updated flow and complementary recommendations.

The project comprised of 9 major tasks undertaken in 3 phases (Figure 2):

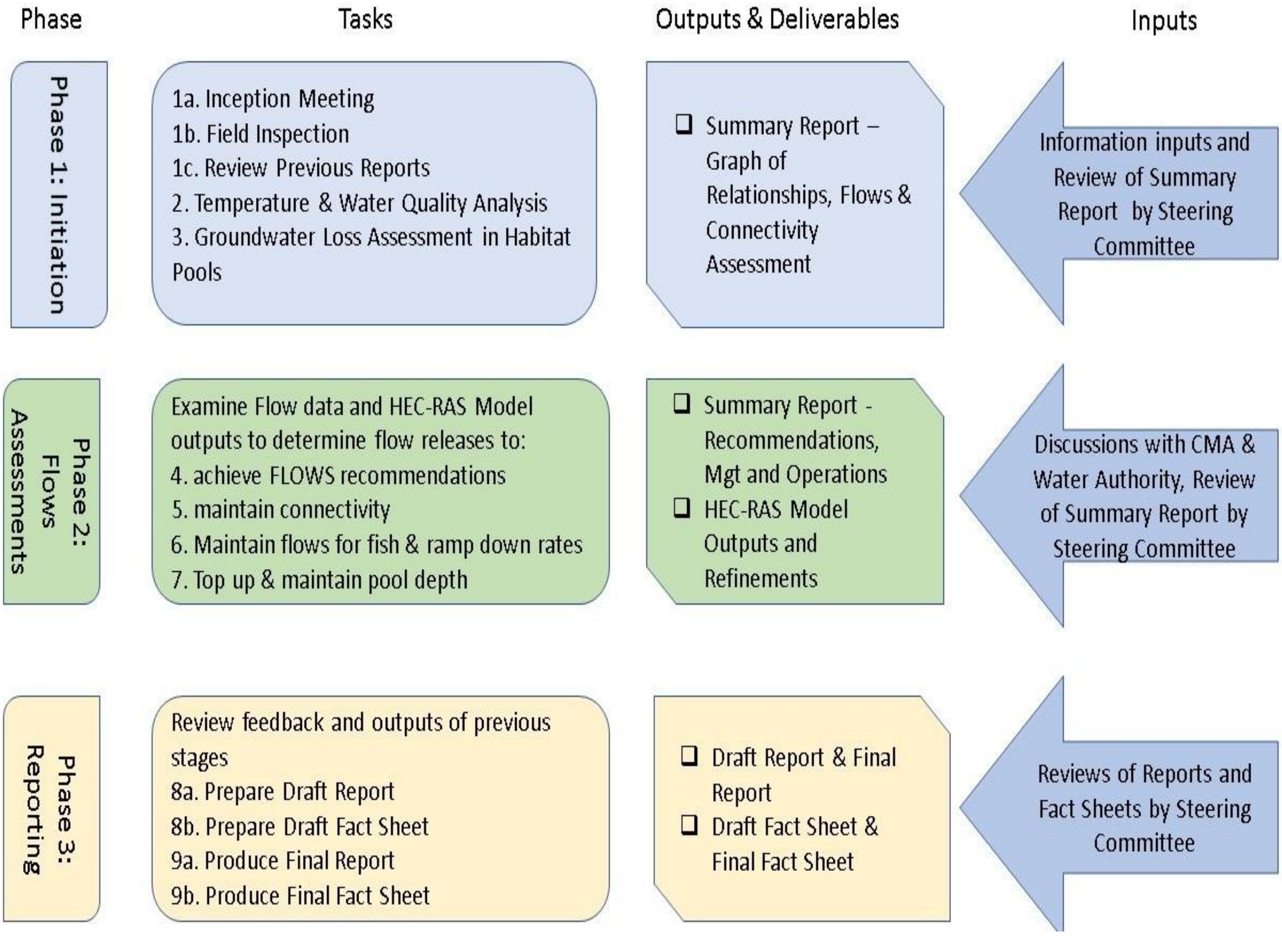


Figure 2: Project Approach

2.1 Task 1: Inception

The first task of this project was an inception meeting with CCMA, DELWP, and quarry staff to discuss the scope of work and how it is addressed by the project methodology. We also undertook a field inspection of the habitat pools and discussed the past and current operations of the quarry and the river. Notes and photos from the site inspection were shared with the project team and will be used throughout the project. Finally, this task also included a review of previous reports and information, now listed in the references section.

2.2 Task 2: Temperature and WQ analyses

The second task included an analysis of the recently collected temperature and historical water quality data from various sources. We collated the data and prepared graphs of the data and changes in water quality and temperature over time. Existing and recently collected temperature and flow data at two habitat refuge pools was analysed with reference to Batesford Gauge data, Lal Lal Reservoir flow release data, and other available gauge data (including quarry discharge data), to determine relationships between flow, groundwater loss and river surface water connectivity.

The sources of data included, but were not be limited to:

- Ventia (2018-20) flow and temperature data- Lower Moorabool Habitat, Refuge pools.
- Historical environmental water release data from Lal Lal Reservoir,
- DELWP, Water Measurement Information System (WMIS), www.http://data.water.vic.gov.au, and
- Batesford Quarry Gauge data.

2.3 Task 3: Groundwater Loss Assessment

The groundwater loss assessment examined the groundwater interactions at the habitat pools and surrounds, as well as on the reach scale. We used the VVG (Visualising Victoria's Groundwater) database (www.vvg.org.au), previous reports and publications, and our previous work on the site to further understand and define the scale and nature of groundwater loss at the two habitat refuge pools in Reach 4.

2.4 Tasks 4 to 7: Environmental Flows Determination

Tasks 4 to 7 were aimed at determining the type and scale of environmental water flows at Lal Lal, Morrisons and Batesford to:

- achieve existing FLOWS recommendations in Reach 4 of the Moorabool River;
- maintain connectivity within Reach 4;
- maintain flows for fish movement and ramp down rates that avoid fish being stranded; and
- top up and maintain pool depth at the habitat pools.

Our Environmental Flow Technical Panel (Lloyd, Dahlhaus, and Clarke) considered the information on the site, the key species (largely fish but also aquatic fauna and flora required to support the fish fauna) and, in particular, groundwater systems and surface flows to determine the environmental flow recommendations. The EFTP Panel workshop included CCMA staff and the steering committee members which ensured the outcomes are understood and are grounded.

We used the standard FLOWS methodology to provide outputs for these tasks. This included:

- Identifying the fish and other values and their environmental flow requirements.
- Reviewing existing modelling for analysis and undertaking both the hydraulic and hydrological modelling necessary to take species environmental flow requirements into flow recommendations.
- Reviewing, updating and documenting the existing hydro-ecological relationships for interpretation and use in the workshops.
- Reworking the modelling for the purposes of the groundwater impact assessment and environmental flow re-analysis.
- Facilitating and participating in a workshop to discuss the site attributes, the ecosystem requirements and running the hydraulic modelling with the project team to derive results and relationships leading to the development of environmental flow requirements.
- Reviewing and updating results following workshop.

2.5 Task 8 & 9: Prepare and Finalise a Report and Fact Sheet

The outputs of all previous stages and feedback received were used to prepare a draft Report and a draft Fact Sheet. The documents were largely written by Lloyd and Clarke, with specialist inputs from Dahlhaus, with internal review by Dahlhaus and Vietz. The drafts were reviewed by the CCMA and Steering Committee staff with a final draft produced after review and revision.

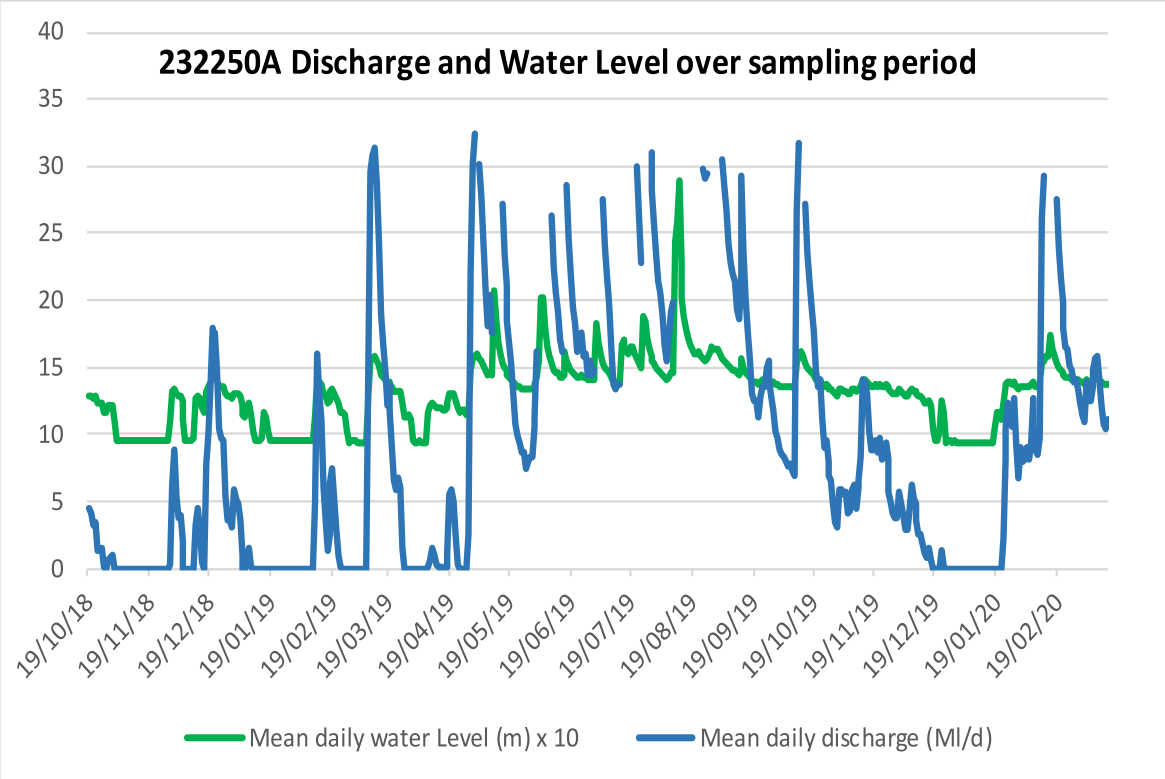
3 DISCHARGE, WATER LEVEL & TEMPERATURE AT THE HABITAT POOLS

Two habitat pools have been monitored for water levels, discharge and temperature (by Ventia) from October 2018 to March 2020 within Reach 4 of the Moorabool River (Figure 3).

These data provide accurate information on the flow and water conditions within these pools in recent times (October 2018 to March 2020) and assisted the determination of recommendations for Reach 4 to be developed in tasks 4-7.

Figure 3: Map of habitat pool gauges – 232250A (d/s) and 232251A (u/s) (CCMA)

The water levels in the habitat pools (see Figures 4 and 5) show there is a close correlation between water depth and flow levels. It further shows that flow is required continuously if these pools are to retain water.



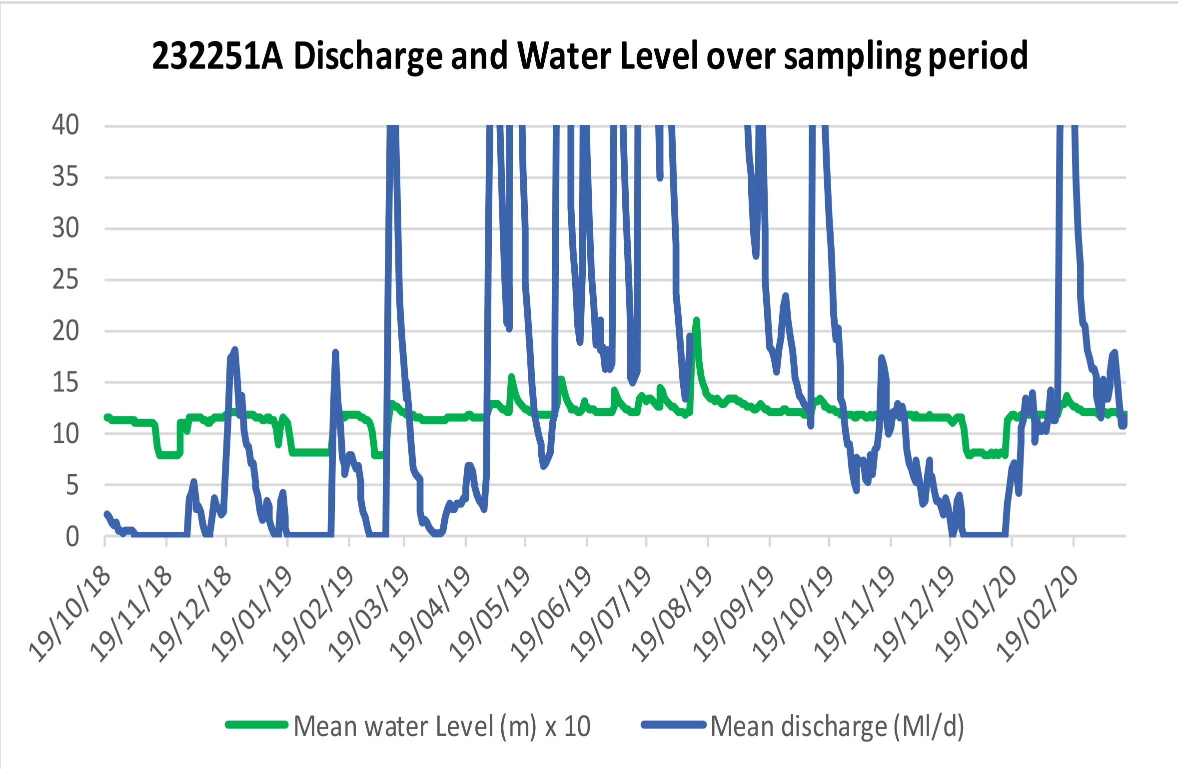
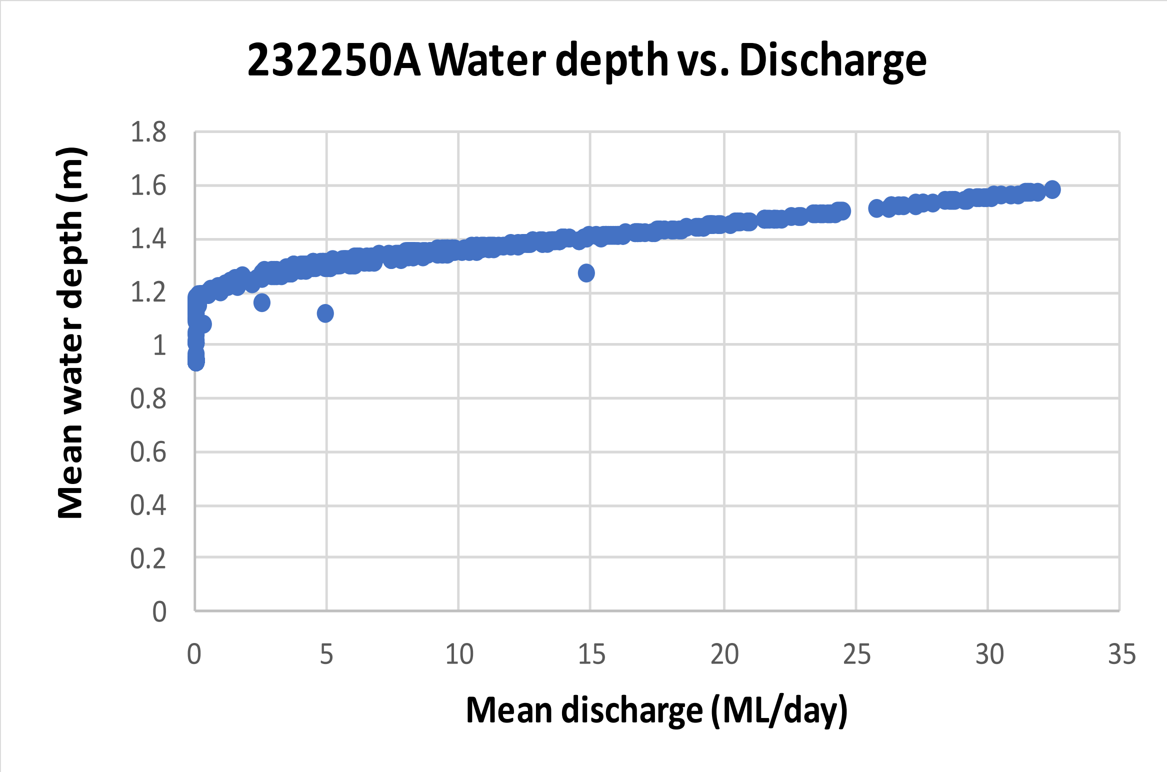


Figure 4: Discharge & water level at the habitat pools – 232250A (d/s) and 232251A (u/s)



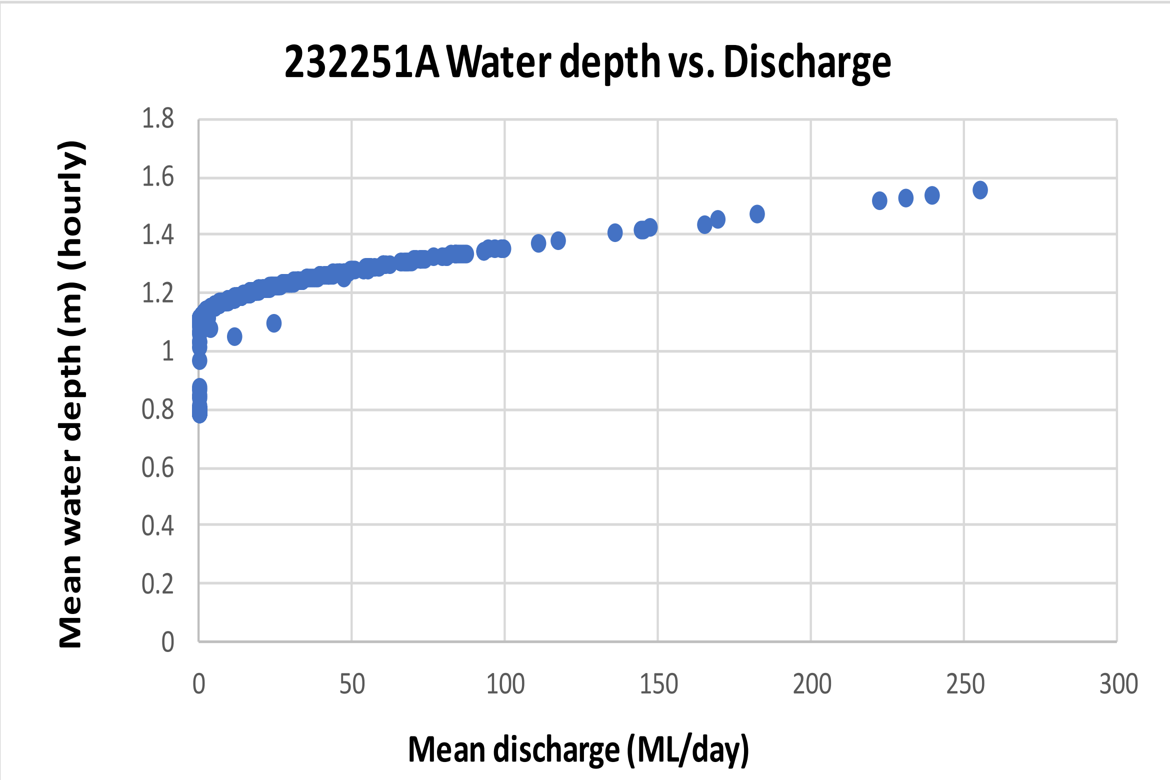


Figure 5: Water Depth vs Discharge at the habitat pools – 232250A (d/s) and 232251A (u/s)

A closer examination of the dataset (see Figure 4) indicates that the pools dry out after only 3 to 10 days, depending upon the flows in the preceding period.

- The pools dry rapidly (within 3 days) if the flows are below 10 ML/day in the period preceding a zero flow period.
- If the flows are above 10 ML/day then the pools dry more slowly (retaining water for up to 10 days).
- If flows are generally above 20 ML/day, even if zero or very low flows occur for a short period, then the pools do not dry at all.

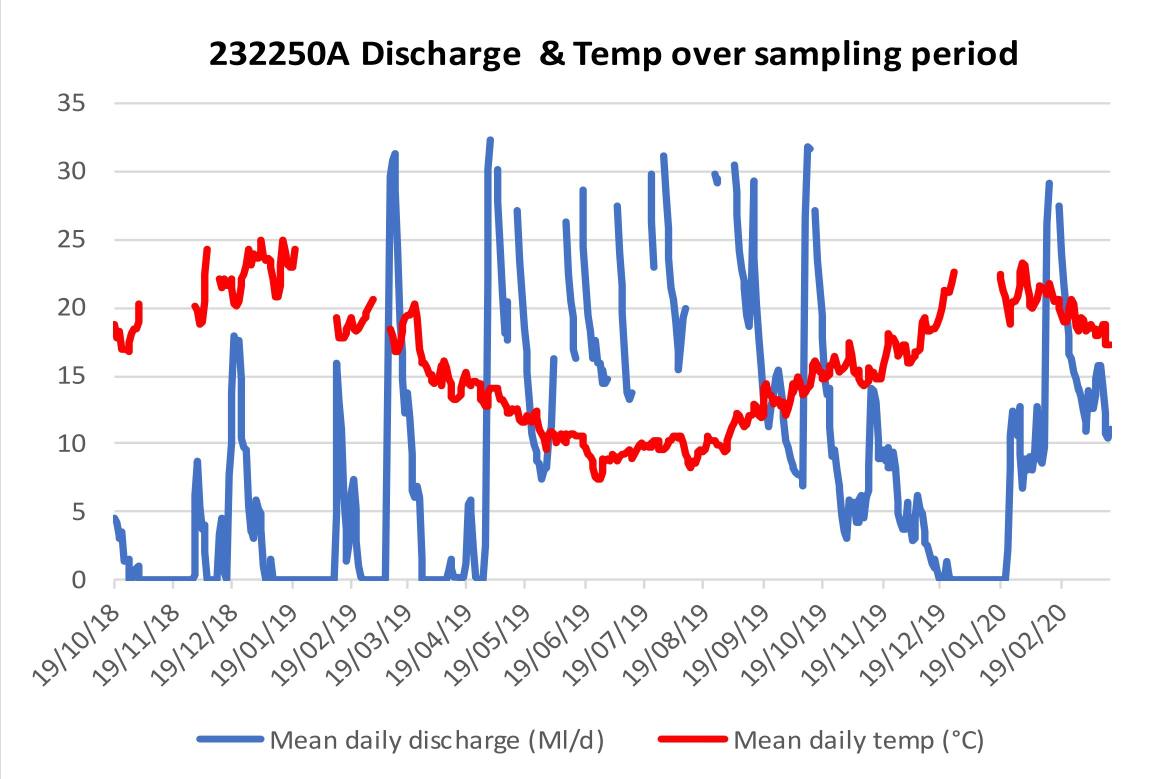
In addition, the season is important as drying is more rapid in summer (due to lower antecedent flows and warmer temperatures) than in other seasons.

Figure 6 shows that stream temperature is highly seasonal but also indicates that flow events can drop the stream temperature by 2-4 degrees in summer and autumn (also spring to a lesser amount), but not in winter. However, water temperatures were largely below 25 degrees with the exception of one period in Jan 2019 when the water temperature in the drying pools reached 27 degrees.

Importantly, the flow events observed at the Batesford Gauge (Figure 7) are very similar to the types (if not magnitude) of events which are observed at the habitat pool gauges.

The relative impact of flows from the Lal Lal Reservoir on the flows at the Batesford gauge are shown below in Figures 8 and 9.

Figure 10 below shows the current environmental releases from the Lal Lal reservoir for 2018/19 and highlights that significant additional volume of entitlement will be required to meet the environmental flow recommendations in Reach 4 and to offset the losses to groundwater identified for the Lower Moorabool. By “piggybacking” larger flow recommendations, such as freshes, on anticipated waterway flows for the Moorabool, the ultimate volumetric commitment for these flow recommendations can be offset or minimised.



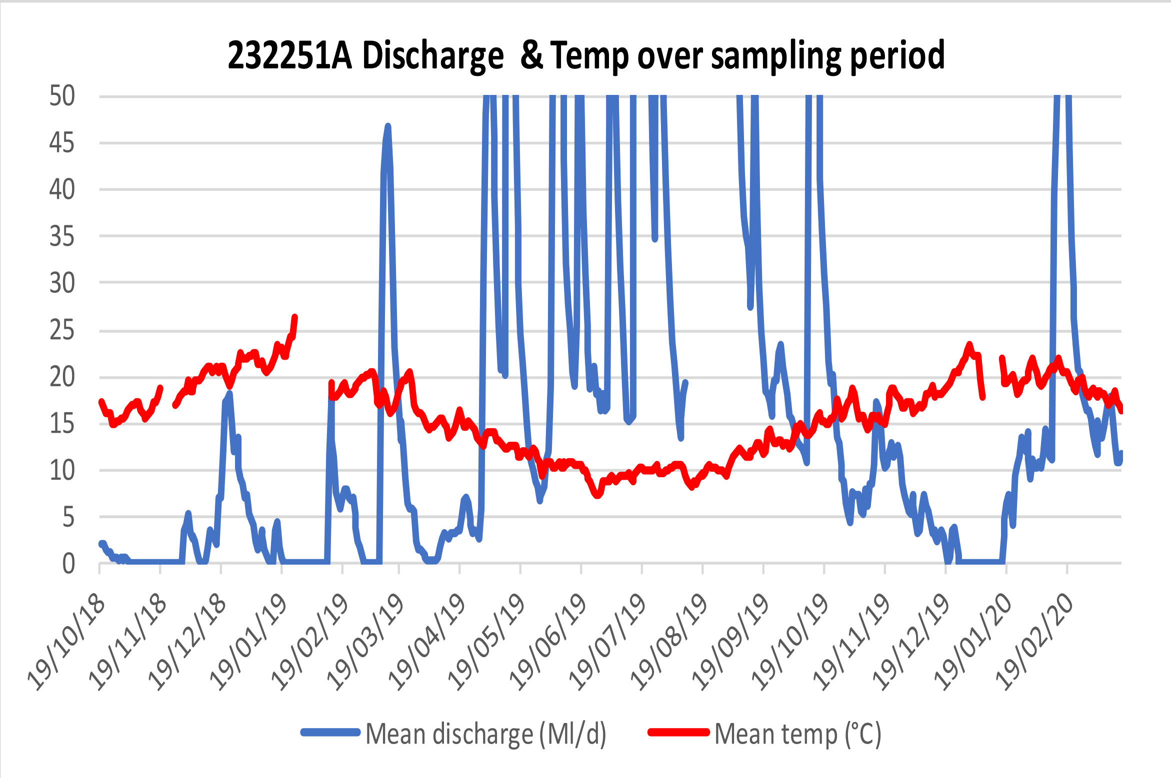
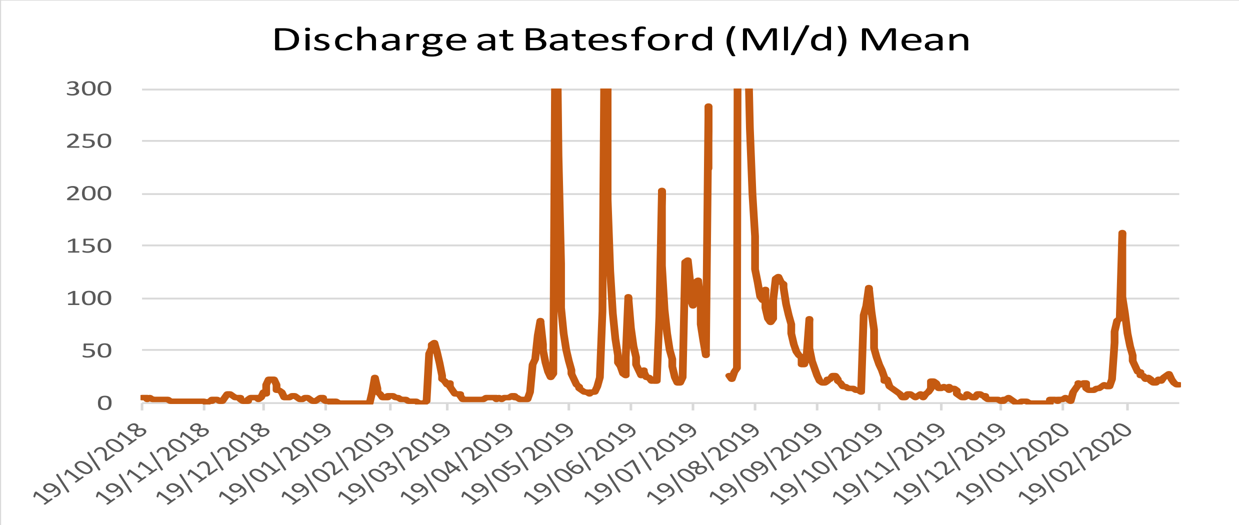
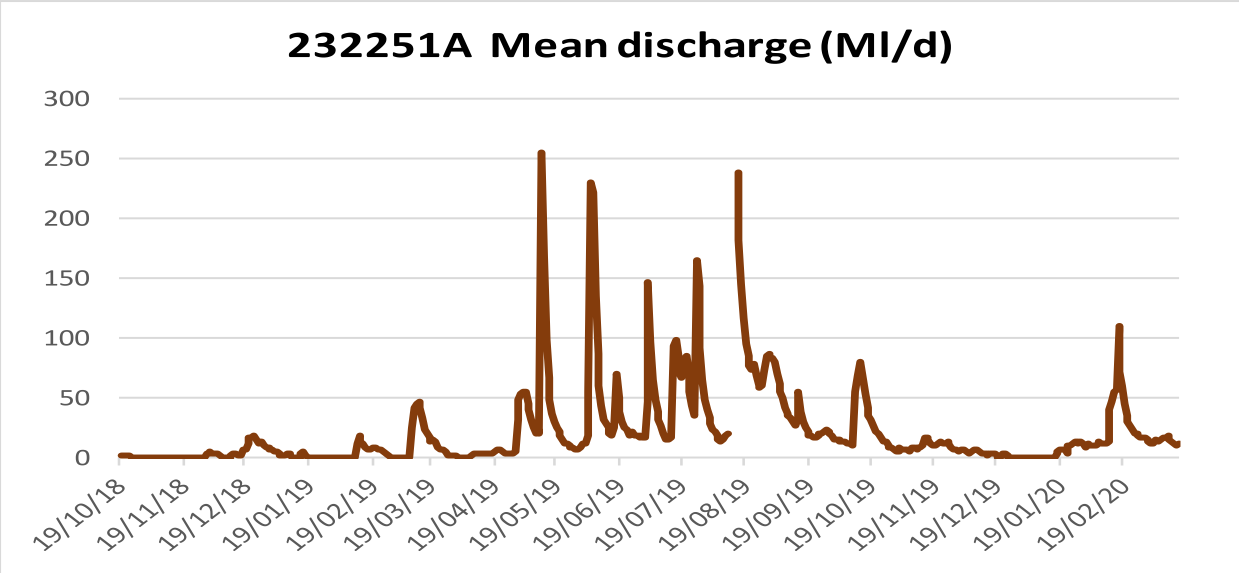


Figure 6: Discharge & temperature at the habitat pools – 232250A (d/s) and 232251A (u/s)





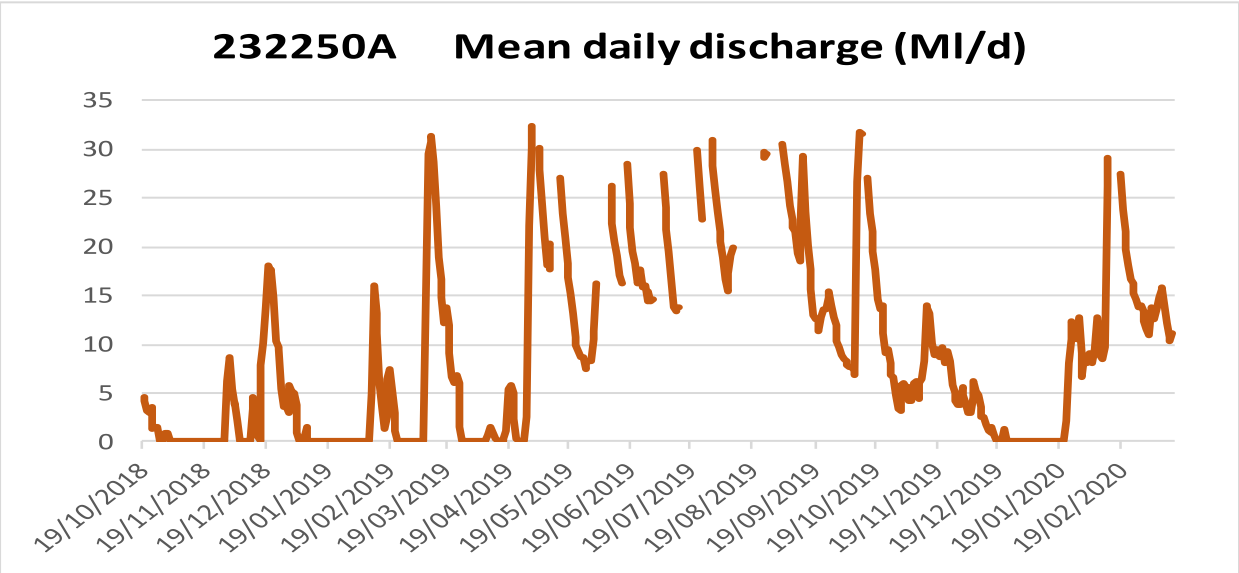


Figure 7: Comparing flows at Batesford Gauge and the gauges at habitat pools

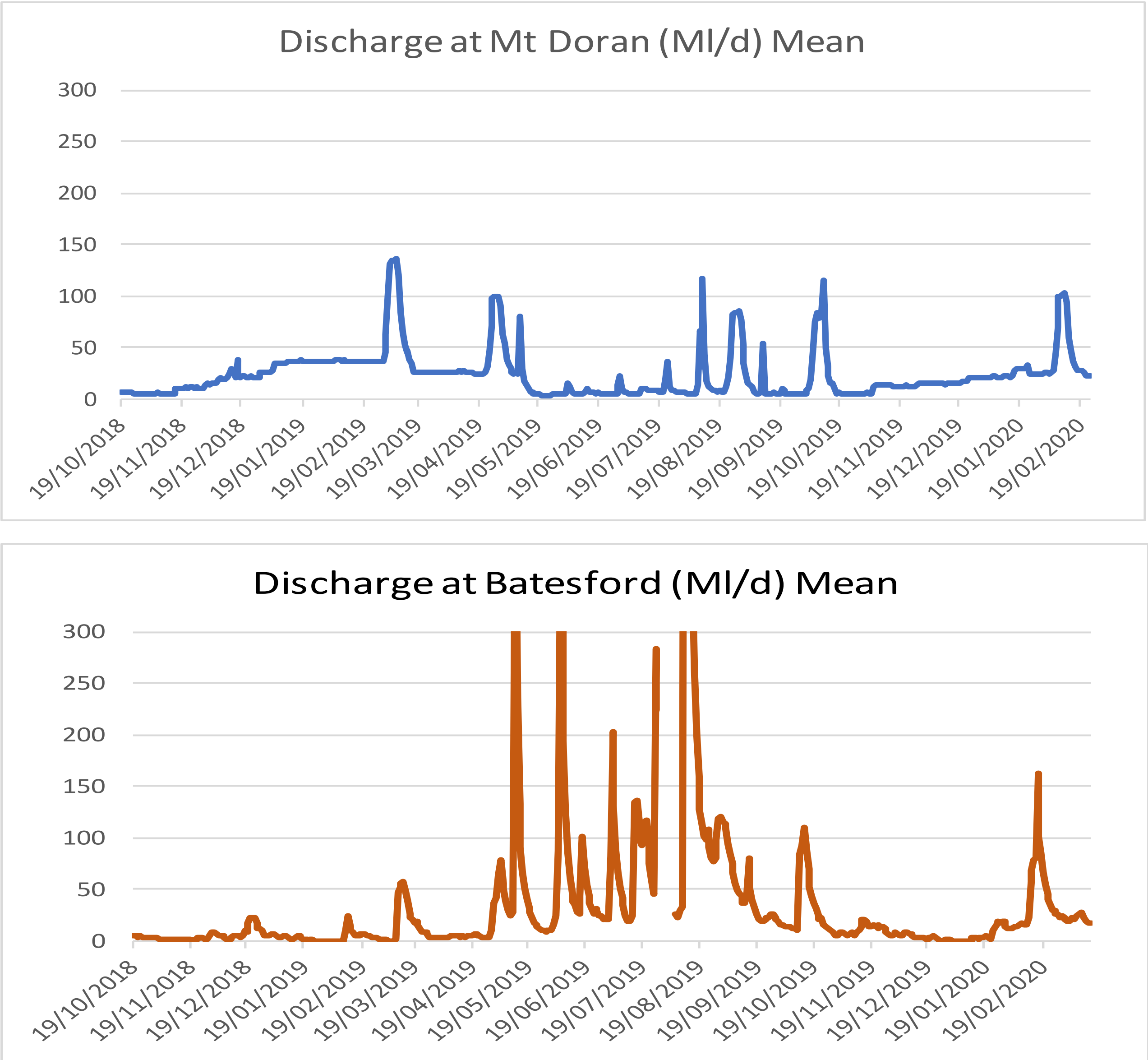
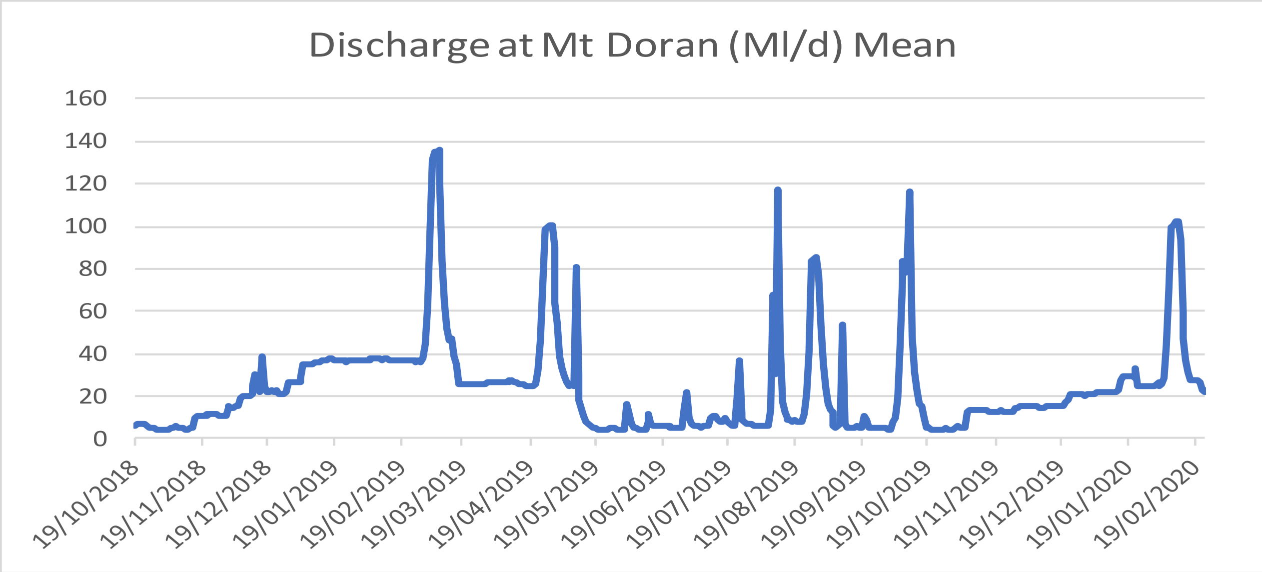


Figure 8: Comparing flows at Batesford gauge and the Mt Doran gauge (downstream of Lal Lal)



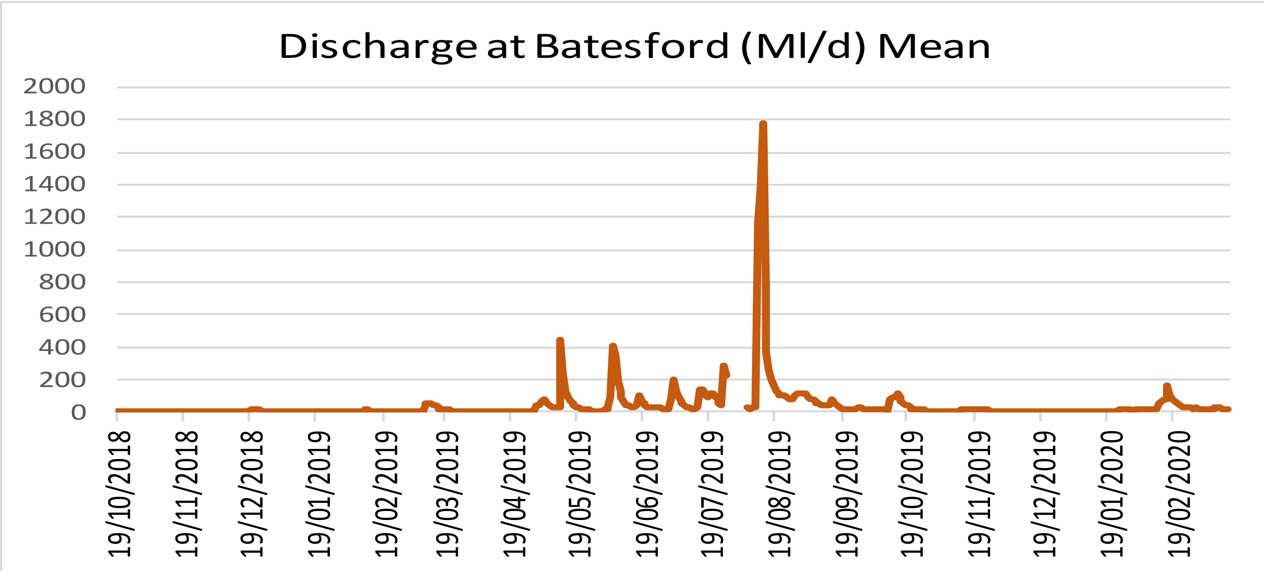


Figure 9: Comparing flows at Batesford Gauge and the Mt Doran gauge (downstream of Lal Lal)

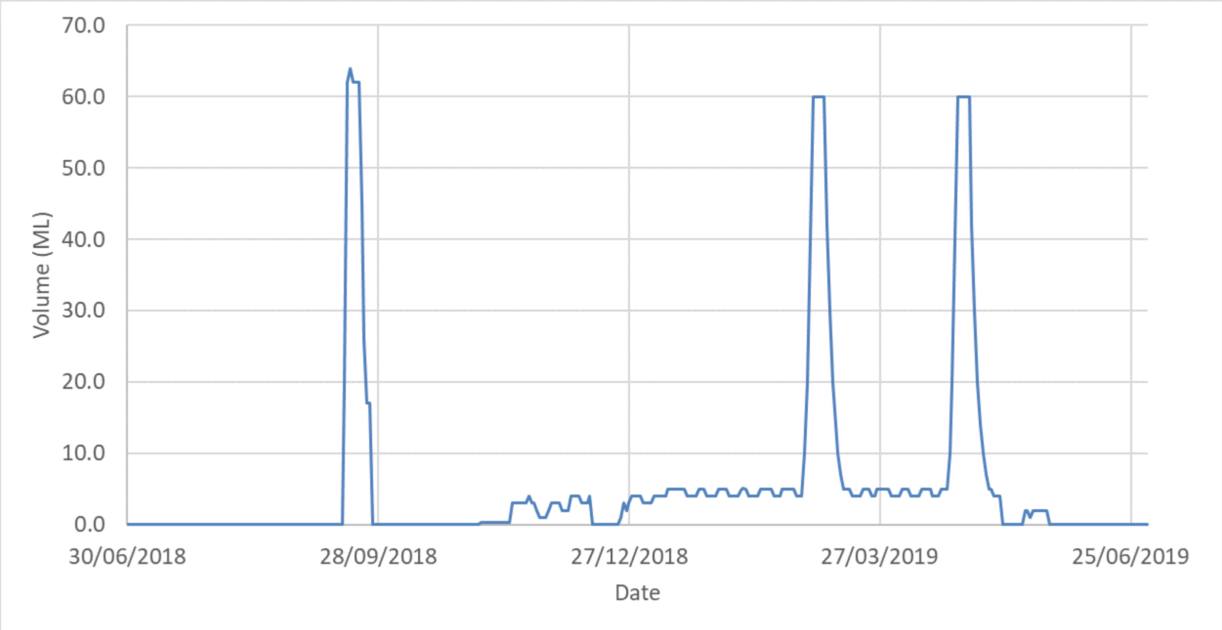


Figure 10: Environmental Flow releases from Lal Lal Reservoir for the 2018/2019 Water Year.

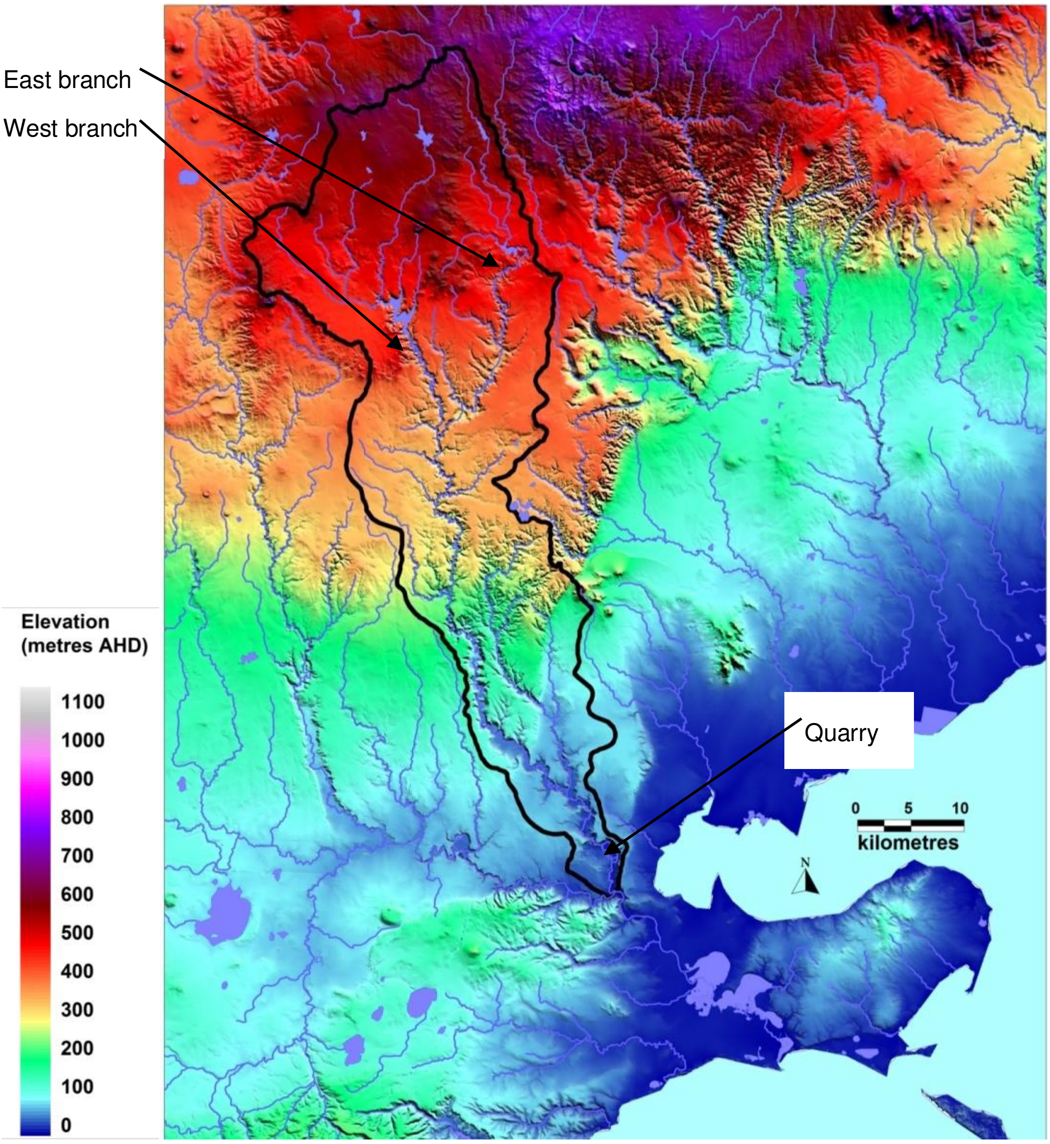
4 GROUNDWATER LOSS ASSESSMENT

To assess the extent of loss to groundwater, previous reports and publications on groundwater were used to further understand and define the scale and nature of groundwater loss at the two habitat pools in Reach 4. The following review provides the background on information for this assessment. We have undertaken other examinations (see sections 6.4, 6.5, 8.1). The groundwater loss assessment examines the groundwater interactions at two scales - the habitat pools scale, and the reach scale.

Groundwater contributes baseflow to the Moorabool River and the groundwater systems of the Moorabool River catchment have been investigated through various academic research projects and catchment investigations over the past 20 years (SKM 2003, Evans 2006, Horgan 2006, Dahlhaus, Evans et al. 2010, Harbour 2012).

The physiography and drainage of the Moorabool River catchment is shown in Figure 11. In the upper reaches of the Moorabool River West Branch (West Moorabool River), springs discharging groundwater from the aquifer of the Bungaree Water Supply Protection Area are an important contribution to flows and ecosystems (SKM 2012). This contribution has been estimated as 50% to 60% of the total flow in the West Moorabool River upstream of Moorabool Reservoir, and 30% to 40% of the river flow between the Moorabool and Lal Lal Reservoirs (SKM 2003).

In the Moorabool River East Branch (East Moorabool River), the contributions are less obvious and the limited research indicates that the aquifers of the Newer Volcanics and Neogene age sediments contribute baseflow to the river in average climatic conditions (Harbour 2012). The baseflow contributions have been estimated at around 30% but, without a gauging weir, they cannot be accurately quantified.



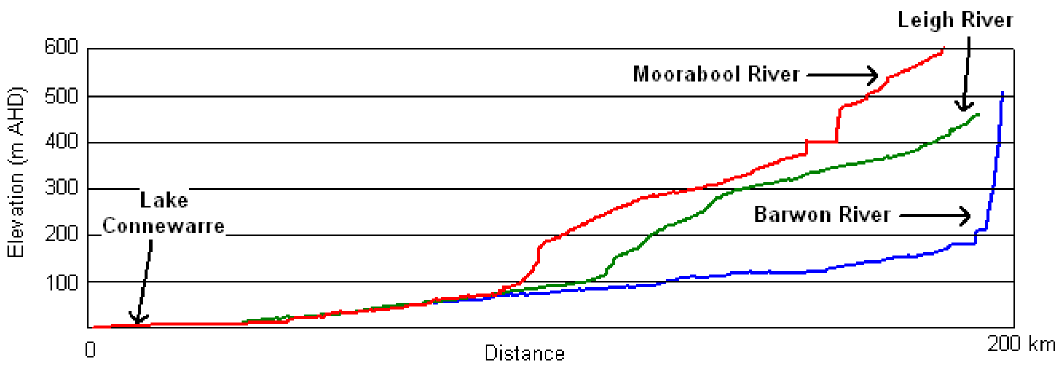


Figure 11. Physiography and drainage of the Moorabool River Catchment.

Below the confluence of the west and east branches, the underlying geology of the river is largely the basement sedimentary rocks (sandstones, shales and slates) of the Palaeozoic age. Geophysical data, specifically the magnetic intensity, have been used to interpret the pre-volcanic drainage of the river, indicating pathways for the groundwater along the ancient buried river valleys (Figure 12).

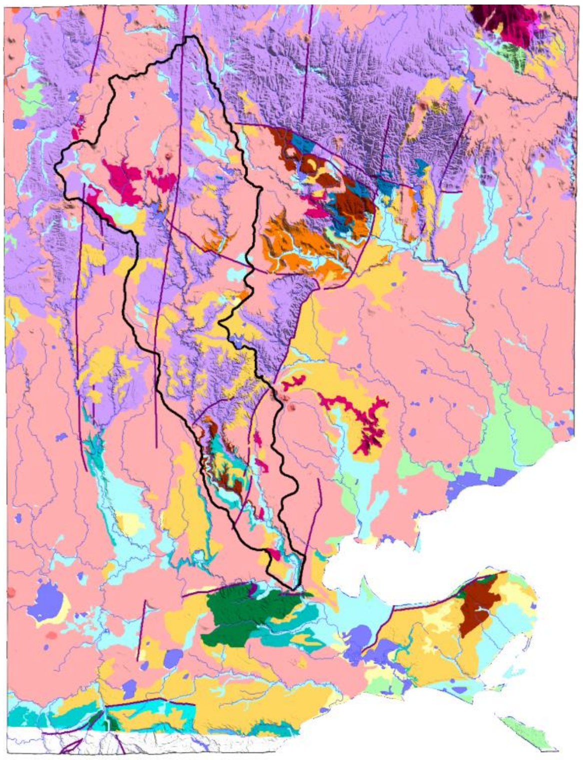
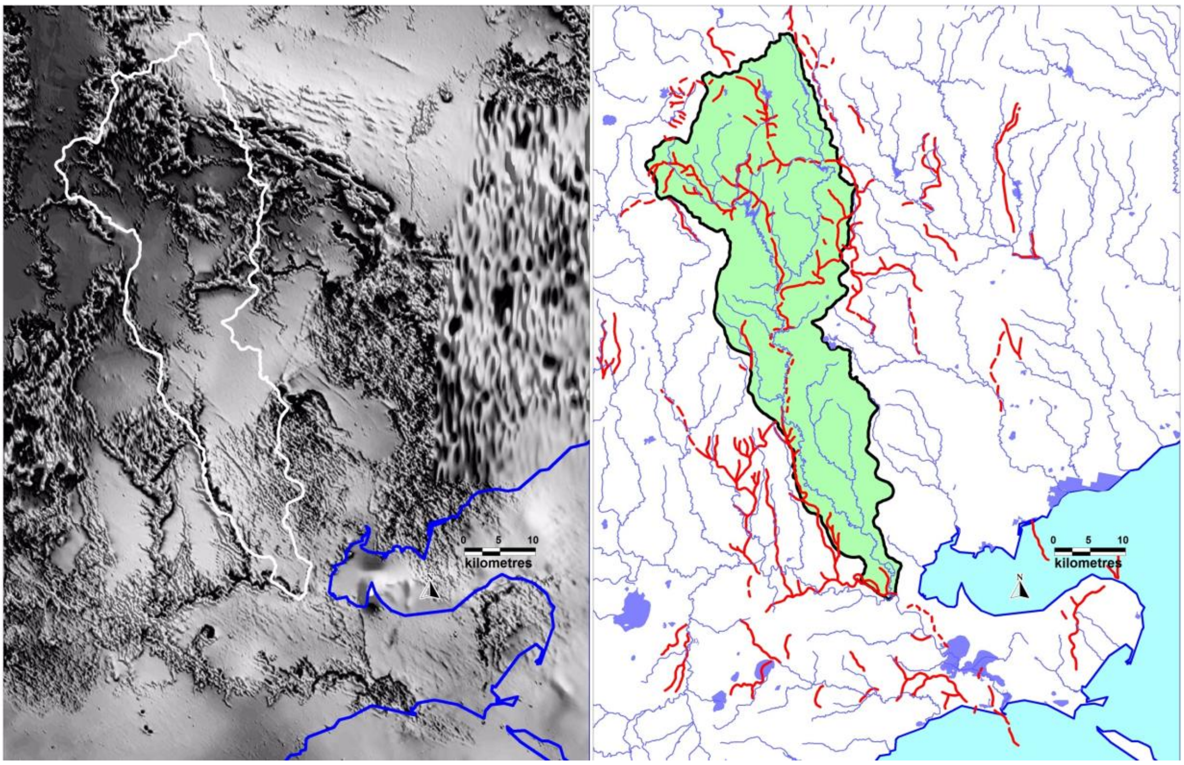


Figure 12. Moorabool River catchment showing A) the geological units and structures, B) the total magnetic intensity, and C) an interpretation of the palaeo-drainage (red lines) and current drainage (blue lines).



Investigations of the groundwater contribution to the Moorabool River in the Morrisons-Sheoaks area (upstream of Batesford) indicate that the baseflow is largely from the basement rocks, being lower volume discharge of saline groundwater (Barton 2000, SKM 2003, Horgan 2006). These investigations and the geophysical interpretation (Figure 12) suggest that the groundwater contributions to the middle reaches (Reach 3 and most of Reach 4) of the Moorabool River (between Morrisons and Bannockburn) are relatively low volume flows of moderately saline water from the basement aquifer. Even where the river has incised through the volcanic rocks, the direction of groundwater flow in the fractured basalts is away from the river towards the palaeo-channels on the west, and adjacent to Little River catchment to the east.

The groundwater contribution to baseflow in Reach 4[1] is derived from shallow water tables in very localised unconfined aquifers comprising the alluvial infill of the Moorabool River valley, in addition to the low volume discharge from the basement aquifer. This is confirmed by the depth to watertable modelling undertaken for the Secure Allocation Future Entitlements (SAFE) project (SKM 2011), as illustrated in Figure 13. While it can be assumed that the Moorabool River is a gaining stream along the majority of Reach 4 upstream of Batesford, the groundwater baseflow volumes will be considerably lower than in Reaches 1 and 2, and is estimated to contribute less than 10% of the river flows. This conclusion is based on the observation by SKM (2004) that during the Millennium Drought (i.e. a period of negligible surface water component) the low flows (80% exceedance) downstream of Sheoaks dropped from 22 ML/day to 5 ML/day.

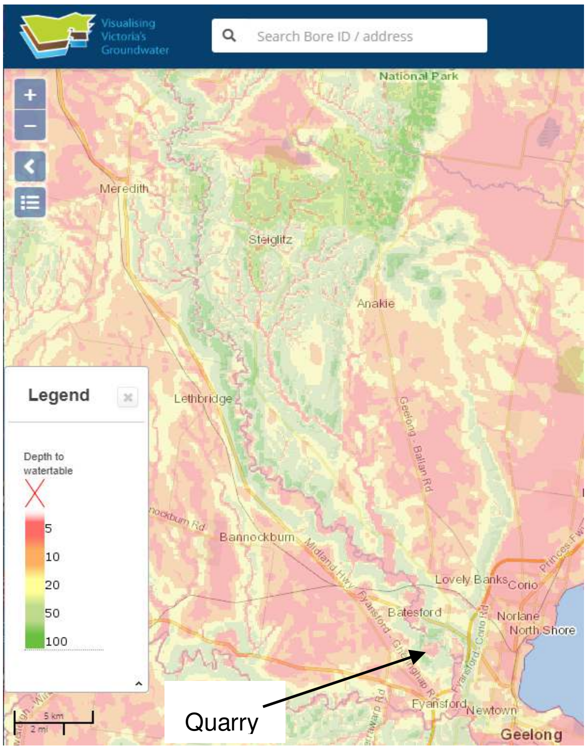


Figure 13. Depth to watertable along Reach 4 of the Moorabool River (VVG 2020).

Between the Barkers Bridge Road and the Sutherland Creek confluence, the course of the Moorabool River is controlled by the You Yangs Granite to the west, marking a change in geology to the complex sedimentary rocks of the Palaeogene and Neogene age that surround the granitic outcrops of Dog Rocks. The hydrogeology of this area has been described by Nolan-ITU (2002) and GHD (2001) for the Batesford Quarry operation and the Fyansford cement works. The geology comprises deposits of basalt rocks of the Newer

[1] Reach 4 is below Sharp Road, Sheoaks to the confluence with the Barwon River.

Volcanic Formation overlying littoral sands of the Moorabool Viaduct Formation, which in turn overlie the marl rocks of the Fyansford Formation, overlying Batesford Limestone, above the basement rocks of Palaeozoic granite and sandstones, slates and shales.

Extensive hydrogeological investigations have confirmed that although each of the formations can be considered part of the groundwater system, the Batesford Limestone is the principal aquifer (Nolan-ITU 2002). Prior to the development of the limestone quarry, the groundwater would have contributed only minor baseflow to the Moorabool River. The extraction of the limestone for industrial and agricultural supplies has required dewatering of the open pit, which results in the absence of shallow groundwater around the river adjacent to the quarry operations, as illustrated in Figure 13. In the area around the quarry, the regional groundwater flows radially towards the open pit (Figure 14) and draws water from the Moorabool River to the groundwater sink.

4.1 Groundwater loss at Reach 4

The current groundwater loss in the lower portion of Reach 4 of the Moorabool River is of concern due to the impact on the river fauna (fish, in particular) and the habitat pools that act as refugia. This area of the river where the pools are located has been historically modified by the quarry operations, with the channel having been rerouted on occasions. In general, there are two diversions, an older diversion north west of the current quarry pit, where the river has been rerouted through quarry spoil and roughly concreted to seal the channel (the concrete has now broken into slabs), and a more recent diversion north east of the quarry pit, which comprises an engineered concrete channel (intact and in reasonably good condition).

The quarry operations, which date from the 1890s, have been primarily for cement production, and in more recent years, for agricultural lime. At various times during its history the quarry operation has included a railway tunnel, dewatering of the open pit, removal and stockpiling of significant volumes of overburden, and diversion of the Moorabool River up to one kilometre form its original position (Nolan-ITU 2002). All of these have progressively impacted on the current groundwater hydrology.

4.1.1 Groundwater modelling (2002)

The most comprehensive investigation undertaken on the groundwater around the quarry is that by Nolan-ITU (2002) using an extensive three-dimensional finite difference numerical model (visual MODFLOW). The purpose of the model is stated (p. 19, Nolan-ITU 2002) as:

- Predict the timing and level of the recovery in groundwater and quarry surface water following cessation of dewatering at the quarry;
- Predict the groundwater piezometric levels (and hence porewater pressures) close to the quarry faces to enable geotechnical assessment of the quarry face slope stability; and
- Estimate the impact of the recovery in water levels on the regional environment, groundwater users and surface water bodies.

The model is constructed using five layers: 1) the Quaternary alluvium and Moorabool Viaduct Formation (uppermost layer), 2) the Fyansford Formation, 3) Batesford Limestone units A & B, 4) Batesford Limestone unit C, and 5) Batesford Limestone unit D (lowermost layer). The model area is 100km^2 (10 km x 10 km) with square grid mesh sizes of 250 metres at the boundary to 62.5 metres at the quarry. The coverage of the model is illustrated in Figure 15.

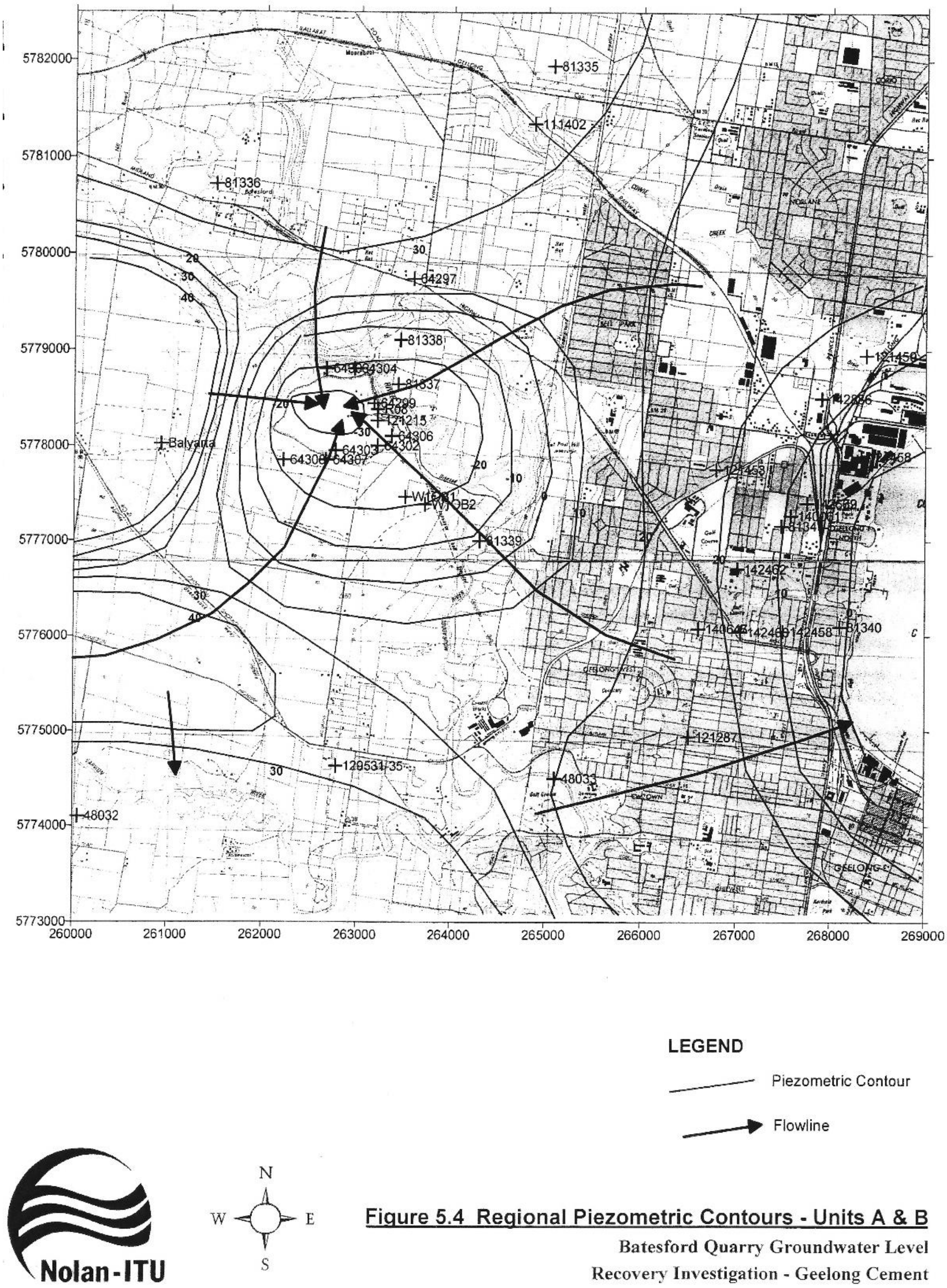


Figure 14. Regional groundwater flows towards the Batesford Quarry (Nolan-ITU 2002).

Note that the equipotential lines (the 'water level contours') are 10 metre intervals, and these represent the main aquifer.

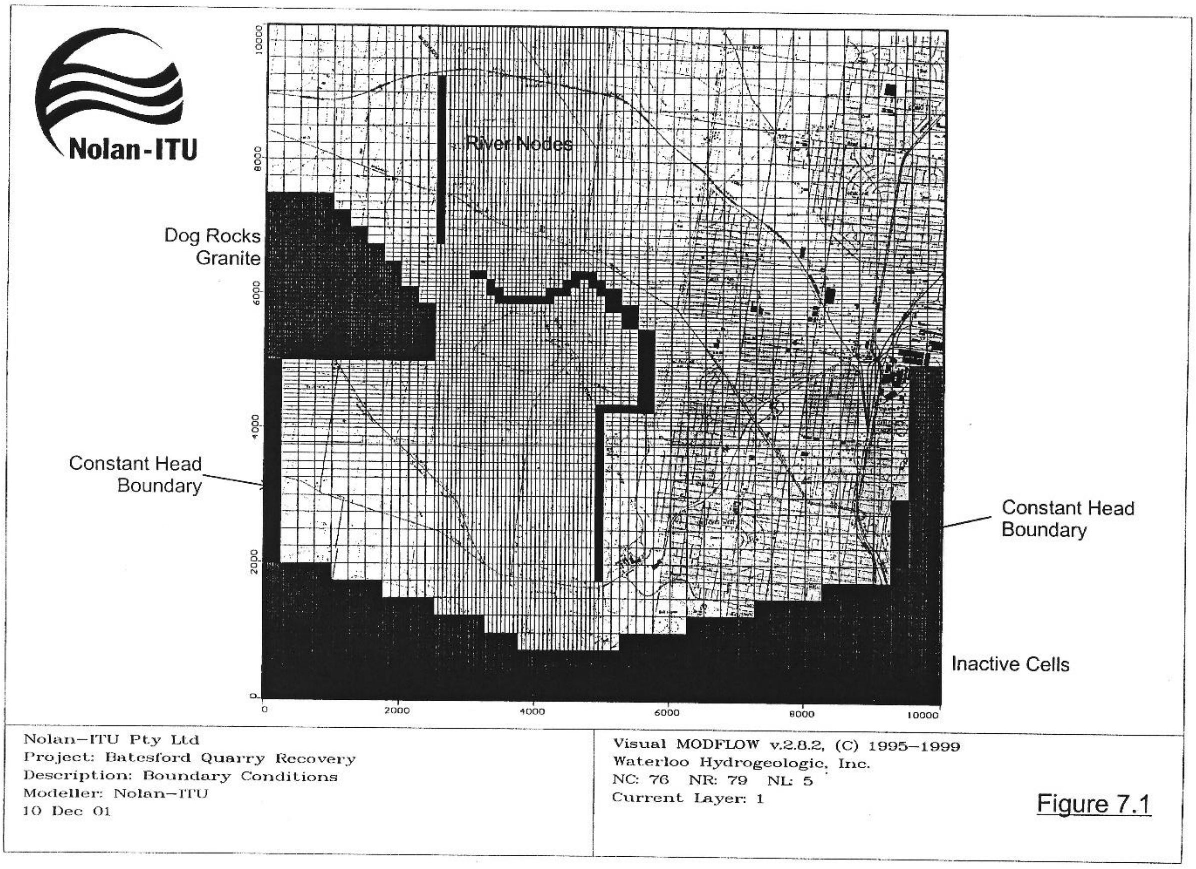
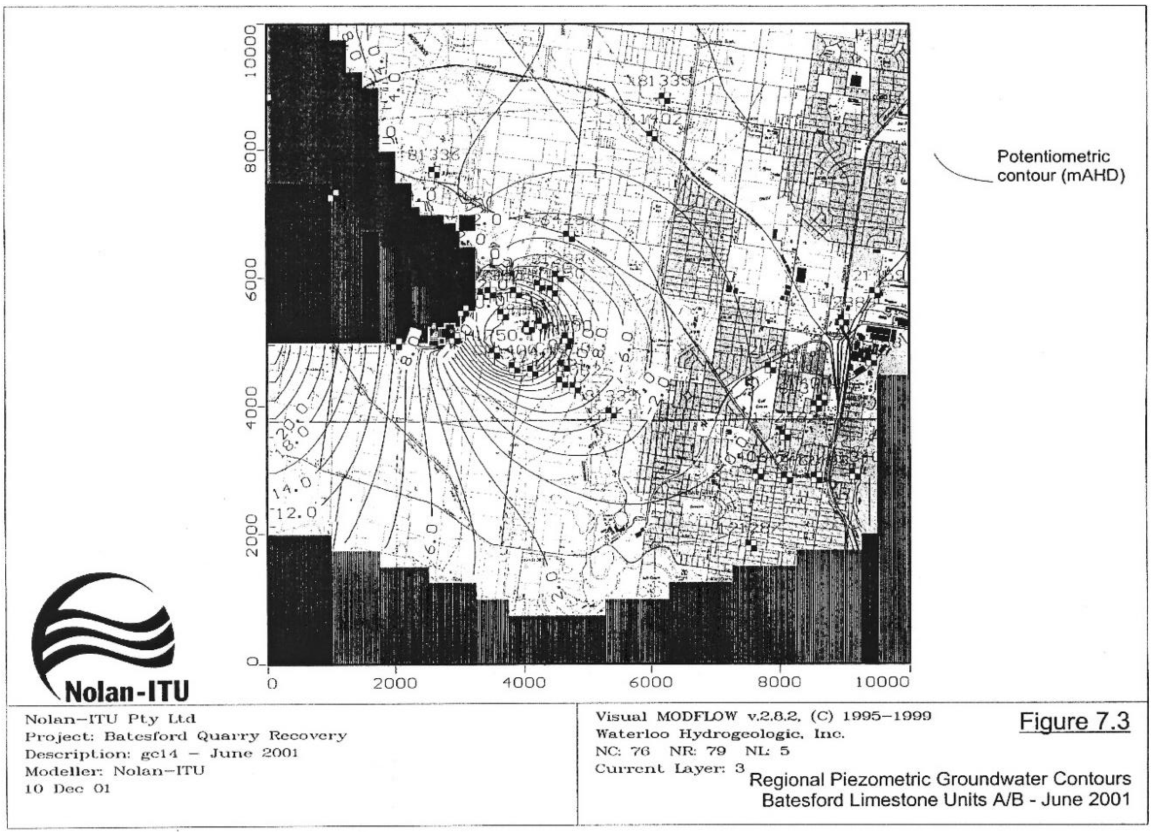


Figure 15. The numerical model layout (Nolan-ITU 2002).

The aquifer parameters in the model were calibrated over the period from June 1981 to June 2001 and included a sensitivity analysis. Predictive scenarios were run simulating the recovery of groundwater and surface water levels after cessation of dewatering (Figure 16).

Data input to the model is taken from 17 existing bores identified within the quarry lease, 31 bores of active groundwater users within 6 km of the quarry lease boundary, and an additional 16 bores were drilled, logged and constructed at nine sites within the quarry lease area. Three Lugeon tests and one pumping test were conducted to calculate aquifer parameters. Groundwater chemistry was determined from nine samples taken from the bores. Additional measurement and monitoring points were established within the bores, quarry sump and ponds. A pilot flooding of the quarry was monitored when the dewatering was ceased from 13:20 3/9/2001 to 14:07 12/9/2001.

The model included the Moorabool River as a variable head boundary with nodes along the river interpolated and extrapolated from stream gauge records. The hydraulic conductance through the riverbed was set at one metre per day (1m/d) for the unlined sections and 0.001 m/d for the lined section, based on figures from 1999 reports by GHD (cited by Nolan-ITU, but unseen by this author). Quarry dewatering volumes were estimated from the recorded pumping hours, flow rate estimates and EPA reported discharge data. Rainfall and evapotranspiration were sourced from the local weather stations and a surface runoff model was developed by N.M. Craigie P/L.



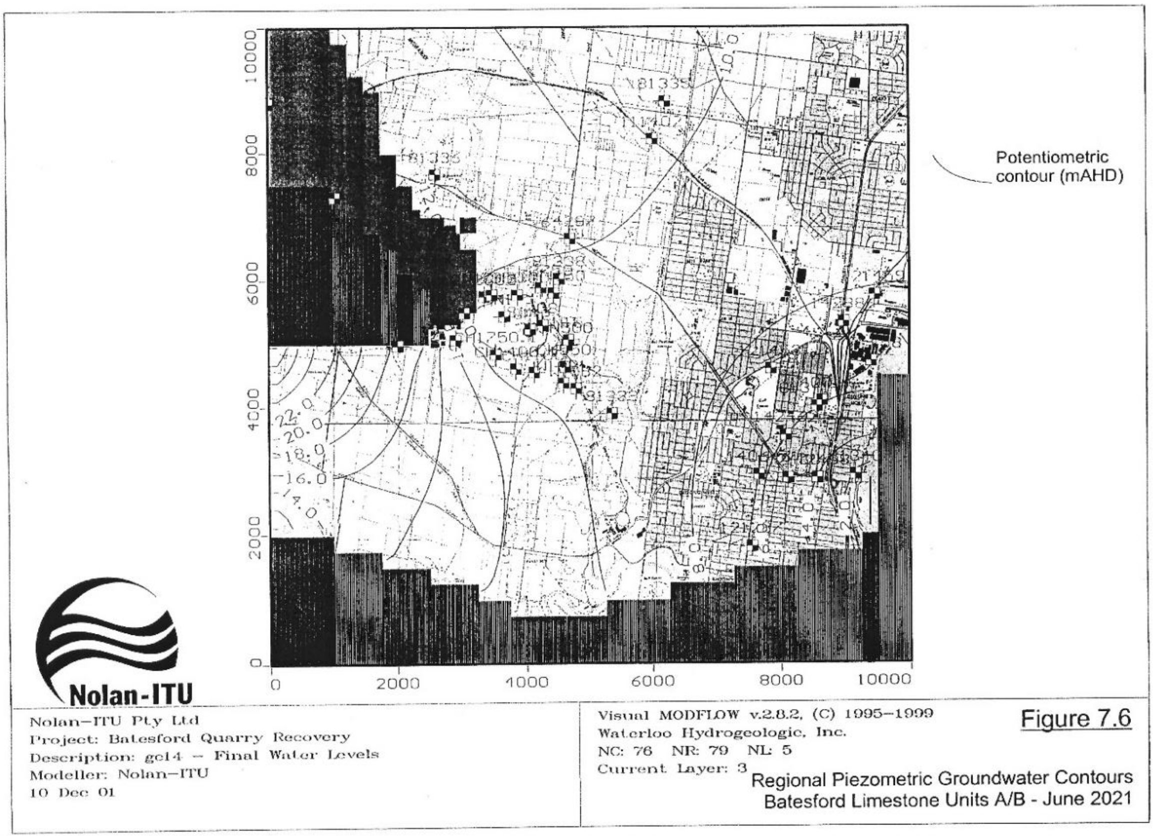


Figure 16. Modelled piezometric water levels in the main aquifer for the quarry operations before (top) and after (bottom) proposed closure.

Model calibration runs and sensitivity analyses were undertaken and settled on +0.6% difference between the modelled to actual dewatering rate and water level differences of 0.0m (quarry sump) to +2.9m (distant bore). Importantly for this study, the model compared reasonably well to the measured shallow watertable (bore N2, actual water level = -2.5m, modelled water level = -3.3m).

Annual water budgets for the flow components of the calibrated model were estimated in the final year of the run as follows (Table 7.3, p. 29, Nolan-ITU 2002):

Table 1. Modelled annual water budget 2000 – 2001 (Nolan-ITU 2002).

Flow component	**Volume (ML)**
Horizontal groundwater inflow to quarry from Batesford Limestone units A & B	3189
Direct net recharge into the quarry (actually, annual excess evaporation)	-512
Upward groundwater flow from Batesford Limestone unit C to the quarry	968
Quarry dewatering	-3461
Change in storage	-178
Leakage from the Moorabool River	102

4.1.2 Groundwater Discussion

The modelled annual water budget for the quarry for 2000-2001 indicates that the majority (~75%) of groundwater flowing into the quarry is sourced from the uppermost units of the Batesford Limestone. The middle Batesford Limestone unit also contributes (~23%). The remainder (~2%) is leakage from the Moorabool River.

The calculated leakage from the Moorabool River was assumed to be that which leaked into the Fyansford Formation within the cone of depression. It compares to the mean annual river flow (1981 – 2000) of 47,600 ML for the modelled period (Nolan-ITU 2002). In the conceptual model the Fyansford Formation – a calcareous sand grading to a marl and silty clay at the base – is regarded as an extensive lower permeability unit of around 20m thick in the vicinity of the quarry. Based on previous literature and the Lugeon tests, the adopted hydraulic conductivity for the Fyansford Formation is 0.01 m/d and the specific yield is 0.15[2]. By comparison, the hydraulic conductivity of the underlying Batesford Limestone is 3.75 m/d to 8.7 m/d and the specific yield is also 0.15.

Given that the numerical groundwater model has been 1) built on reasonable quality data, some of which was specifically collected for the model inputs, and 2) calibrated to an acceptable accuracy, the modelled leakage from the Moorabool River is considered credible, i.e. in the context of the numerical model only. This considers both the statistical variability (known as aleatory uncertainty) and lack of information (known as epistemic uncertainty) of the model.

However, it is likely that the conceptual model (on which the numerical model is built) does not accurately reflect reality. The cross-sections in the Nolan-ITU report assume the continuity of the geological strata as interpolated from the available bore logs and outcrop

[2] Additional FEFLOW modelling of cross-sections through the quarry pit for geotechnical stability adopt a horizontal hydraulic conductivity of 0.01m/d and a vertical hydraulic conductivity of 0.0005m/d. This is for both the intact Fyansford Formation units and the fill comprising Fyansford Formation material.

data (Figure 17). The model assumes that leakage from the Moorabool River is through the undisturbed Fyansford Formation. But in the area surrounding the habit pools, the leakage is more likely to be through the disturbed quarry spoil of the historic quarried landscape.

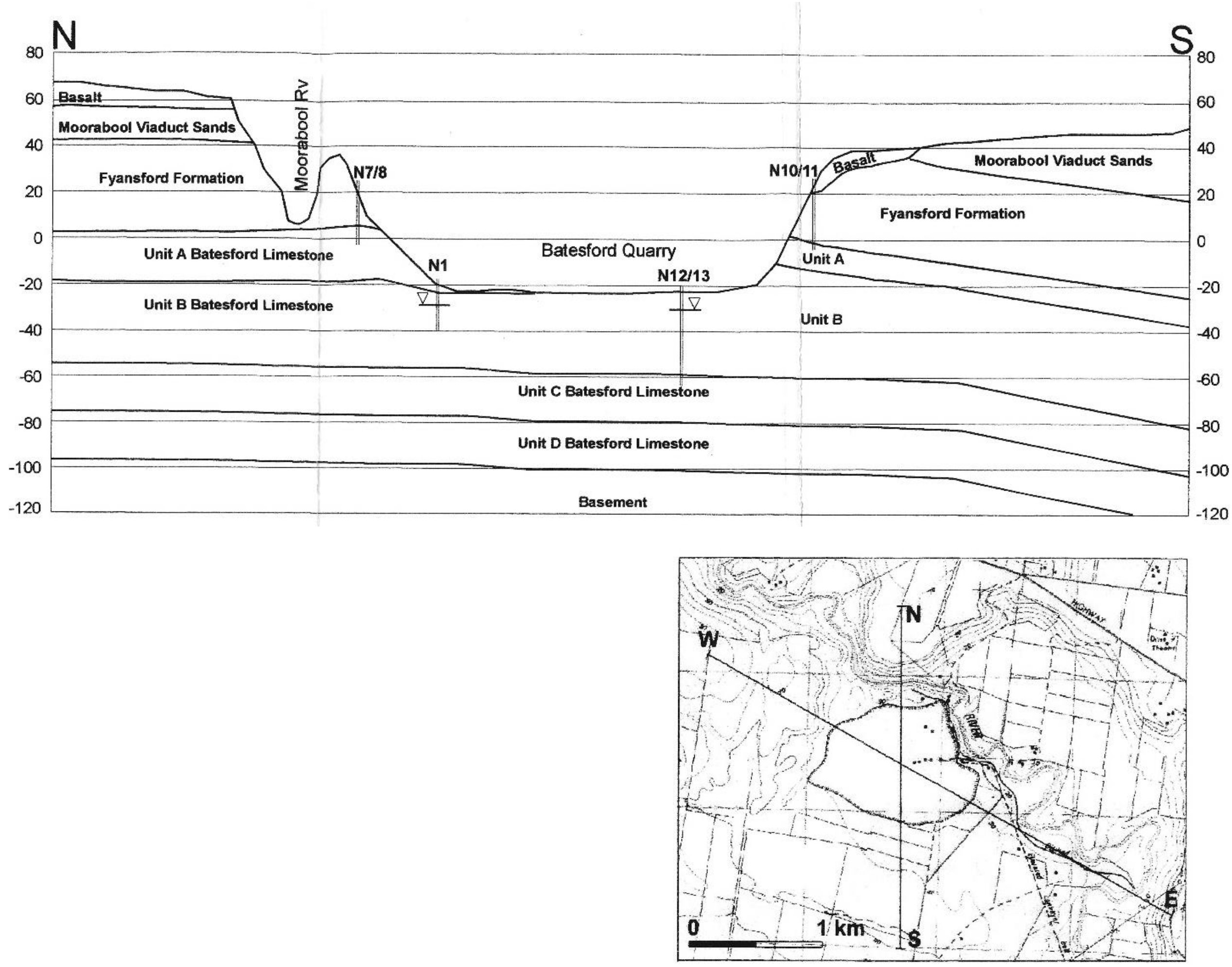


Figure 17. The north – south cross section of the conceptual groundwater model used to construct the numerical model (Nolan-ITU 2002).

It is an open question as to whether there are preferential hydraulic pathways between the Moorabool River, where it has been historically diverted through the previously quarried area, and the underlying higher permeability Batesford Limestone. The evidence for a greater hydraulic connection is based on:

- the information provided on the field visit (17/10/2019) suggesting that the concreted channel of the older river diversion is constructed in the historic quarry spoil,
- the observations of the broken concrete channel and quarry spoil (i.e. geological materials) at the area of the habitat pools,
- the rates and volumes of stream water leakage at the habitat pools, and
- the similarity in the water chemistry of the Moorabool River and groundwater inflows to the quarry.

With a greater hydraulic connection between the Moorabool River and the more permeable Batesford Limestone, a proportion of the modelled groundwater inflows from the upper units of the Batesford Limestone to the quarry (i.e. the 3189 ML/yr in Table 1) would also be drawn from the Moorabool River leakage. Without detailed investigations, such as drilling, bore construction and geophysical surveys, the actual amount remains speculation.

Based on their predictive model results, Nolan-ITU (2002) recommend that a final water level ranging from 8.0 m to 9.6 m AHD be used for the final quarry closure and rehabilitation planning. The model runs indicate that it would take 19 years to reach this final level (90% after 15 years). In the final scenario, the water table gradients after 20 years remain gently sloped towards the quarry (Figure 16), implying that the groundwater baseflow to the river will not be significantly restored. The evaporation of water from the quarry lake creates the gentle cone of depression in the water table. In other words, even after quarry closure and the quarry lake is completely filled, water will still be drawn away from the Moorabool River towards the quarry lake.

4.2 Conclusions of Groundwater Loss Assessment

In summarising the above data and information, the following conclusions can be drawn:

1. While groundwater is a significant contributor to baseflows in the Moorabool River, the majority of the contribution is in the upper reaches.
2. Groundwater contributions to the middle reaches (Reach 3 and most of Reach 4) of the Moorabool River (between Morrisons and Bannockburn) are low volume flows of moderately saline water from the basement aquifer.
3. There is currently no groundwater (baseflow) contribution to the Moorabool River flows in the vicinity of the habitat refuge pools in Reach 4. The cone of depression in the watertable caused by the dewatering of the limestone quarry extends to at least one kilometre upstream of the pools.
4. At the habitat pools in Reach 4, the Moorabool River is a losing stream. The leakage to the quarry has been previously calculated as 102 megalitres per year for the 2000 -2001 period, based on a calibrated numerical groundwater model run from June 1981 to June 2021. The model assumes that the river leakage occurs through a stratigraphically continuous low permeability Fyansford Formation layer, that acts as a semi-confining layer over the Batesford Limestone aquifer.
5. This assumption is questioned, as it is apparent that in the area of the habitat pools preferential hydraulic pathways are highly likely to cause the Moorabool River to leak into the highly permeable aquifer of the Batesford Limestone. Therefore, is it asserted that the Moorabool River leakage is considerably higher than the previously modelled volume. Further investigations would be required to verify and quantify the rates and volumes (See section 6.4).
6. The modelled scenario for quarry closure is that even after two decades when hydraulic equilibrium is reached, the evaporative losses from quarry lake will still slowly draw water away from the Moorabool River back towards the quarry lake.

5 ECOLOGICAL VALUES AND FLOW REQUIREMENTS

The determination of environmental flow requirements of a river is based on the key ecological values of the system and the extent to which flows support key parts of their life history. In the habitat pools in Reach 4 of the Moorabool River, fish are key species and the revision and specification of flow requirements for this reach will be based largely on the needs of fish as well as macroinvertebrates and aquatic vegetation required by fish.

5.1 Fish

Twelve species of native fish (Table 2) are found in Reach 4 of the Moorabool River (SKM 2004b; Environous 2008; McGuckin and Ryan 2009; Raymond 2015; Ryan and McGuckin 2007; Jacobs 2015).

Table 2: Fish present or previously recorded in Reach 4 of the Moorabool River

Common Name	Scientific Name	Freshwater Species	Migratory Species
Native fish			
Southern pygmy perch	*Nannoperca australis*	√	
River blackfish	*Gadopsis marmoratus*	√	
Flat headed gudgeon	*Philypnodon grandiceps*	√	
Blue spot goby	*Pseudogobius olorum*	√	
Mountain galaxias	*Galaxias olidus*	√	
Common galaxias (jollytail)	*Galaxias maculatus*		√
Spotted galaxias	*Galaxias truttaceus*		√
Australian grayling^	*Prototroctes maraena*		√
Tupong	*Pseudaphrits urvilli*		√
Short finned eel	*Anguilla australis*		√
Short-headed lamprey	*Mordacia mordax*		√
Australian smelt	*Retropinna semoni*		√
Exotic fish			
Eastern gambusia	*Gambusia holbrooki*	√	
Redfin perch	*Perca fluviatilis*	√	
Brown trout	*Salmo trutta*	√	
Goldfish	*Carassius auratus*	√	
Carp	*Cyprinus carpio*	√	
Roach	*Rutilus*	√	
Tench	*Tinca tinca*	√	

^ Listed Species (under EPBC Act or FFG Act);
* Exotic fish are not used in the analysis or determination of flow requirements

Understanding the fish present and their ecological requirements greatly assists developing flow requirements for Reach 4 of the Moorabool River. This reach is particularly important as it provides a connection for fish in the upper catchment of the Moorabool and the lower Barwon River and the sea. There are three broad types of fish present: freshwater species, migratory species and exotic fish.

Freshwater species, including mountain galaxias, southern pygmy perch and Flat-headed gudgeons, are non-migratory species but do undertake local movements to find mates, new habitat and better food resources. pygmy perch require heavily vegetated waters for breeding and protection, whereas the blue spot goby only requires good vegetation to provide cover to protect them from predation. The mountain galaxias is able to survive in pools over the dry period, provided some water remains in the pools and its water quality is acceptable.

Migratory species present within the Moorabool River live most of their lives in freshwater but migrate between the estuary or sea and freshwater environments to complete their life-cycle. Migration is critical for the reproductive success of native fish. Many of the fish must migrate to breed in the estuary or the sea and are classified as estuarine dependent (Lloyd et al. 2012b). In the Moorabool, Reach 4, this group includes the Australian grayling, tupong, short-finned eel, short-headed lamprey, Australian smelt, common jollytail and spotted galaxias. The Australian grayling migrates down to the upper estuary to breed in freshwater with the larvae returning to the estuary by drifting with the flow downstream. Once they grow to juveniles, they return upstream to grow and mature. Most migratory fish are restricted to the lower reaches of the Moorabool by instream barriers, except the short-finned eel, which is capable of climbing over barriers. However, spotted galaxias, common galaxias and tupong are able to take advantage of migration opportunities, when low level barriers are inundated during elevated flow freshes. The Australian grayling and the common galaxias (jollytail) require access to move up and down the river to find food resources or to get to the estuary to breed. Instream barriers such as road crossings, piped sections, weirs, and zones of very poor habitat can all prevent fish being able to move within the system. If species are restricted to one section of the stream, they may not be able to breed or find suitable food or habitat to persists and this increases the likelihood of local extinctions of species.

The **exotic species** within the Moorabool are largely freshwater species, although some have high salinity tolerances. Reach 4 has seven species of exotic fish including goldfish, carp, roach, tench, eastern gambusia, redfin perch, and rainbow trout. While the exotic fish are not used in the analysis or determination of flow requirements, all species pose threats to native fish from competition, predation and other impacts on native fish. Gambusia, redfin and trout are the most significant predators on native fish (Lintermans 2007).

5.2 Flow requirements of fish communities

Each fish species has a unique suite of flow requirements but often different groups of fish are found to have largely overlapping requirements as well as being quite flexible, robust and opportunistic in their response to flow events. Further, native fish have a broad range of water quality, salinity and habitat requirements to enable them to thrive in our river systems (DELWP 2013; Lloyd et al. 2006 & 2012a, Koehn & O'Connor 1990, McDowall 1980). Physical habitats required by native fish such as pools, riffles, runs, woody debris, undercut banks, rocks & boulders, wetlands, and floodplains are created and maintained by adequate flow regimes. The species listed in Table 3 are those recorded in Reach 4 of the Moorabool River. Also outlined in Table 3 are the biological requirements of each species which are used when developing flow requirements, in order to allow them to recolonise or to restore these populations. The conceptual models show in Figures 17 and 18 summarise the tabulated information into a graphical and narrative form. These are useful for explaining the species requirements.

Table 4 distils all the information, in this section, to produce specific objectives for flow components which, when combined with the hydraulic modelling, will allow the recommendation of flow events to meet the suite of requirements of the habitat pools reach of the lower Moorabool River system.

Table 3. Ecological requirements of key fish species of the Lower Moorabool River[3].

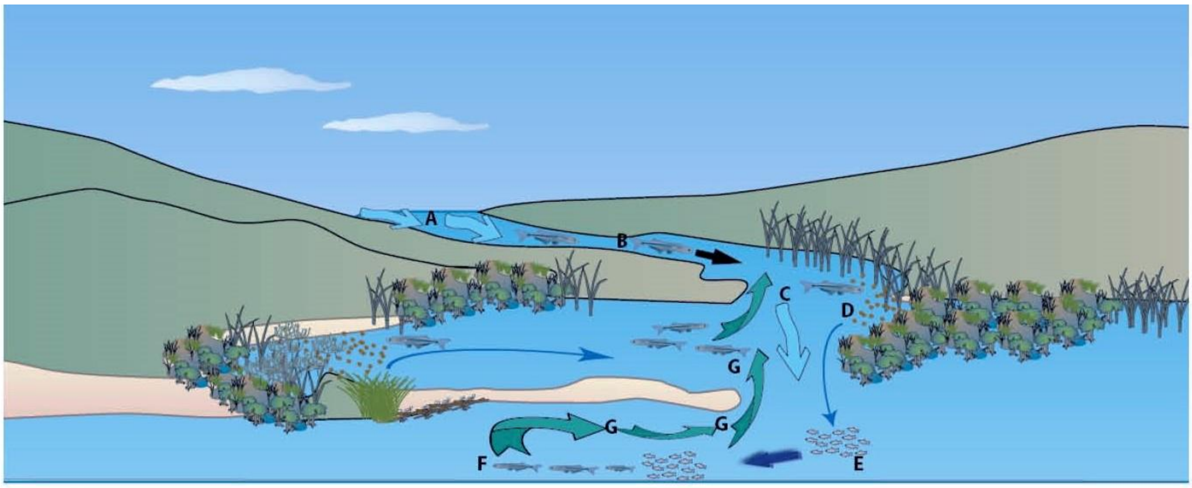
Fish Species		**Life Span**	**Spawning Season**	**Incubation Duration***	**Migration**	**Other Requirements (esp spawning)**
Common Name	**Scientific Name**					
Western Blue-spot Goby	*Psuedogobius olorum*	2-3 years	Oct-Jan	4 days	Local only	Need hollow in log or burrow under rock or wood as a substrate for laying eggs
Australian Smelt	*Retropinna semoni*	1-2 years	Sept - Nov	9-10 days	Active movers between habitats & along rivers	Aquatic vegetation required as a substrate for laying eggs
Australian Grayling	*Prototroctes maraena*^V, @V	Males 1-2 years Females 2-3 years	Feb - May	14-21 days in freshwater <2ppt	Adults migrate downstream Feb to May but April/May is peak period. Larvae washed to sea/estuary in May to July. Juveniles migrate from sea upstream Oct - Dec	Demersal non-adhesive eggs with slender and buoyant fry. Spawning occurs after high flow – full moon to last quarter; Eggs develop in slow water to 5m deep; Juveniles spend May to Oct in estuary
Tupong (Congolli)	*Pseudaphritis urvillii*	>5years	Sept – Dec	Unknown (likely to be short - 3 or so days)	Adults migrate downstream to estuary for breeding May to August. Juveniles migrate upstream Oct – Feb.	Tupong are susceptible to impacts from the presence of water flow barriers
Common Galaxias (Jollytail)	*Galaxias maculatus*	2-3 years	April -June	10-16 days between flow events or tides	Downstream to estuary in autumn	Aquatic/riparian/intertidal macrophytes required as a substrate for laying eggs
Spotted galaxias	*Galaxias truttaceus*	2-4 years (Uncertain)	May-June	28 days at 12 degrees	Downstream to estuary in the wet period (May-June). Larvae swept to sea. Juveniles return	Woody debris, undercut banks, boulders and good riparian vegetation however have are also found in habitats with silt substrates and turbid water. Pools are

[3] Derived from Froese and Pauly (2018), Allen *et al.* (2002); Koehn & O'Connor (1990); Lloyd (1987); Merrick & Schmida (1984); McDowall (1980); Treadwell & Hardwick (2003); DELWP (2013); Lloyd *et al.* (2006 & 2012a); Growns (2004); McKinnon (2007); Raadik (2014); Koster et. al. (2013); Crook (2004); Crook et al. (2010).
* Time that eggs take to develop into larvae (eggs require inundation at least for this period)
^V Listed as vulnerable species under FFG Act
@V Listed as vulnerable under EPBC Act

Fish Species		Life Span	Spawning Season	Incubation Duration*	Migration	Other Requirements (esp spawning)
Common Name	**Scientific Name**					
					from sea upstream in spring and early summer (Oct – Jan)	also used extensively. Highly salt tolerant
Mountain galaxias	*Galaxias olidus*	2-4 years	July - Oct	5-7 days	Upstream, if at all	Leaf litter required
River Blackfish	*Gadopsis marmoratus*	4–7 years	Nov - Jan	7 - 10 days (21 days for 'tethered' larvae)	Local	Hard substrate required – hollow logs as a substrate for laying eggs
Southern Pygmy Perch	*Nannoperca australis*	2-5 years	Sept – Nov	2-4 days	Local	Aquatic plants for spawning and habitat Vegetation or rocks for instream habitat required
Big-headed Gudgeon	*Philypnodon grandiceps*	4-7 years	Oct - Feb	4-6 days	Local	Hard surfaces required as a substrate for laying eggs
Short-finned Eel	*Anguilla australis*	32 years	June - Mar	Unknown as it occurs in the marine environment	Adults migrate to sea during late spring, summer and autumn (Oct to May). Elvers return to the estuary after being spawned at sea in winter to spring (Jul-Nov) and undertake upstream migrations Nov - May	Flow requirements really need to consider preservation of adult habitat – rivers and lakes. Breeding is cued by non-flow factors and occurs at sea.

The ecology-flow requirements have been summarised in conceptual models. Conceptual models are both diagrams and text which describe our understanding of the biological and flow requirements of the species of concern (Figures 17 and 18).

The conceptual model with explains the common galaxias (jollytail) lifecycle and flow needs is shown in Figure 17 below and in the text, which follows (Taken from Lloyd 2015):



A Freshwater flows provides longitudinal connection for Common Galaxias **B** to move down to the estuary from freshwater habitats in January to March. **C** Larger flows allow the river mouth to open. **D** Common Galaxias lay their eggs in samphire and wetlands in estuary. **E** Common Galaxias larvae hatch and are washed out to sea by mouth opening flows in autumn to mature **F,** before returning to the estuary **G** in July to December.

Figure 17. Conceptual model of common galaxias (jollytails) life cycle and flow requirements.

Representative Objective – Common Galaxias (Jollytail; Galaxias maculatus) – Estuarine Dependent (Freshwater Derived)

Common galaxias (jollytails) are a widespread and often abundant species in Australia found in coastal lakes and streams at low altitudes from Adelaide in the west to Southern Queensland in the east (McDowall and Fulton, 1996). They are also present in New Zealand and South America having a Gondwanian distribution. They are a significant species in the ecosystem as a food source for other fish and birds and are a significant invertebrate predator (Koehn and O'Conner, 1990; McDowall, 1996; Merrick and Schmida 1984). Ecological and hydrological requirements are shown below.

Habitat

Common galaxias (jollytails) are able to utilise a wide range of habitats and have a preference for still or slow moving waters. They are capable of withstanding from freshwater to very high salinities (well above that of sea water). They are known to also occur in landlocked populations (Koehn and O'Connor, 1990; McDowall, 1996; Merrick and Schmida, 1984).

Movement

In autumn, adults move downstream to the estuary to spawn on a full or new moon and a high spring tide. The eggs hatch and the small, slender larvae are washed out to sea. The juveniles spend winter at seas and return to freshwater about 5 to 6 months later (Treadwell and Hardwick, 2003; McDowall and Fulton, 1996; Crook *et al.* 2006)

Reproduction

Common galaxias (jollytails) spawn amongst vegetation (grasses, samphire and other low vegetation) around estuary entrances when under water at high tide. Most adults die after spawning. The eggs remain out of water for two weeks or more until the next spring tides, the eggs hatch on being re-inundated and the larvae migrate (or are washed out) to sea (McDowall and Fulton, 1996). Eggs can tolerate and hatch in salinities ranging from fresh to seawater (Cadwallader and Backhouse, 1983).

Information for conceptual model for common galaxias (jollytail)

- Provide flows (dry season freshes) to allow longitudinal connection in the channel for adult jollytail movement down to the estuary in January to March.
- Provide flows to open mouth to allow downstream migration of larvae in autumn.
- Provide flows (wet season freshes) to open mouth to allow juveniles to migrate upstream from sea between July and December.
- Provide flow freshes to inundate vegetation beds and instream benches to stimulate invertebrate production for fish condition.

Jacobs (2015) developed and illustrated the conceptual model for the Australian grayling using the scientific understanding from Koster et al. (2013). This research demonstrated that Australian grayling undertook long-distance downstream spawning migration to lower river reaches immediately upstream of the estuary, associated with increased river discharge in autumn (Figure 18). Flow events of sufficient magnitude and duration are required enable the adults to reach spawning areas (e.g. lower freshwater reaches of the Barwon River). The key downstream migration and peak egg abundance occur predominantly in April-May (Koster et al. 2013), so flows are required during autumn.

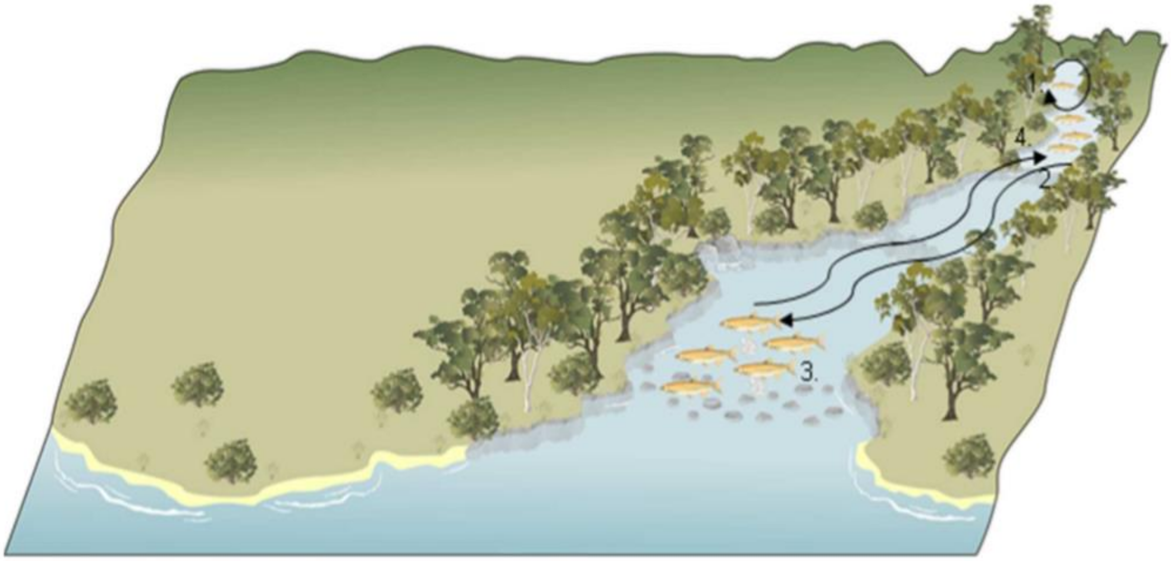


Figure 18: Summary of movement behaviours of adult Australian Grayling and links to flow. 1. Fish display only small-scale movement prior to migrating downstream. 2. Fish undertake rapid long-distance downstream migrations to the lower reaches of rivers in April–May, coinciding with increased flows. Fish that have not arrived at the lower reaches during the high flows cease their migrations temporarily, and then recommence migration on the next flow event. 3. Spawning activity is concentrated in the lower freshwater reaches. 4. Following downstream migration, most individuals return upstream to the area they previously occupied (From Jacobs 2015).

Table 4. Ecological objectives for migratory and freshwater resident fish.

Value group	Objective	Function	Season	Component	Hydraulic Criteria
Migratory fish	Maintain abundance of migratory fish (short-finned eels, Australian grayling and tupong)	Provide water in pools for habitat & food sources	All	Low flow	Flow between Pools
		Provide water over riffles to allow fish to migrate upstream from estuary	Oct to Feb (Oct to May for eels)	Fresh	500mm over riffles
		Provide water over riffles to allow longitudinal connectivity and for fish to move between pools	Aug to Nov	Fresh	300mm over riffles
		Trigger downstream spawning migration of adult migratory fish	April-May - Australian grayling May-Aug – tupong Jan-March - shortfinned eel	Fresh	500mm over riffles
	Improve breeding and recruitment of migratory fish (spotted and common galaxias)	Provide connectivity to allow fish to migrate downstream to breed	May to June	Fresh	300mm over riffles
Resident freshwater fish	Maintain abundance of resident freshwater fish (galaxias, smelt, big headed gudgeon and southern pygmy perch)	Provide water in pools for habitat & food sources	All	Low flow	Pools full
		Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	Aug to Nov	Fresh	300mm over riffles
	Improve breeding & recruitment of resident freshwater fish (blackfish)	Submerge/clean woody debris & hard surfaces to provide breeding substrate	Nov to Jan	Fresh	500mm over instream benches
	Improve breeding and recruitment of resident freshwater fish, (mountain galaxias, smelt, big headed gudgeon and southern pygmy perch)	Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding	Aug to Nov	Fresh	500mm over instream benches

6 MODELLING

To complement and inform the eco-hydraulic metrics outlined in Table 4 of Section 5, a hydrodynamic relationship for the pools was investigated to provide relevant flow and pool relationships.

6.1 Existing Modelling

It was identified that existing modelling has been undertaken for the Bakers Road Bridge upstream of Batesford. Unfortunately, the distance upstream from the nominated fish habitat pools of this model preclude its inclusion or use in the determination of the hydrological flows required to satisfy the ecohydaulic components required of the flow recommendations (Figure 19).

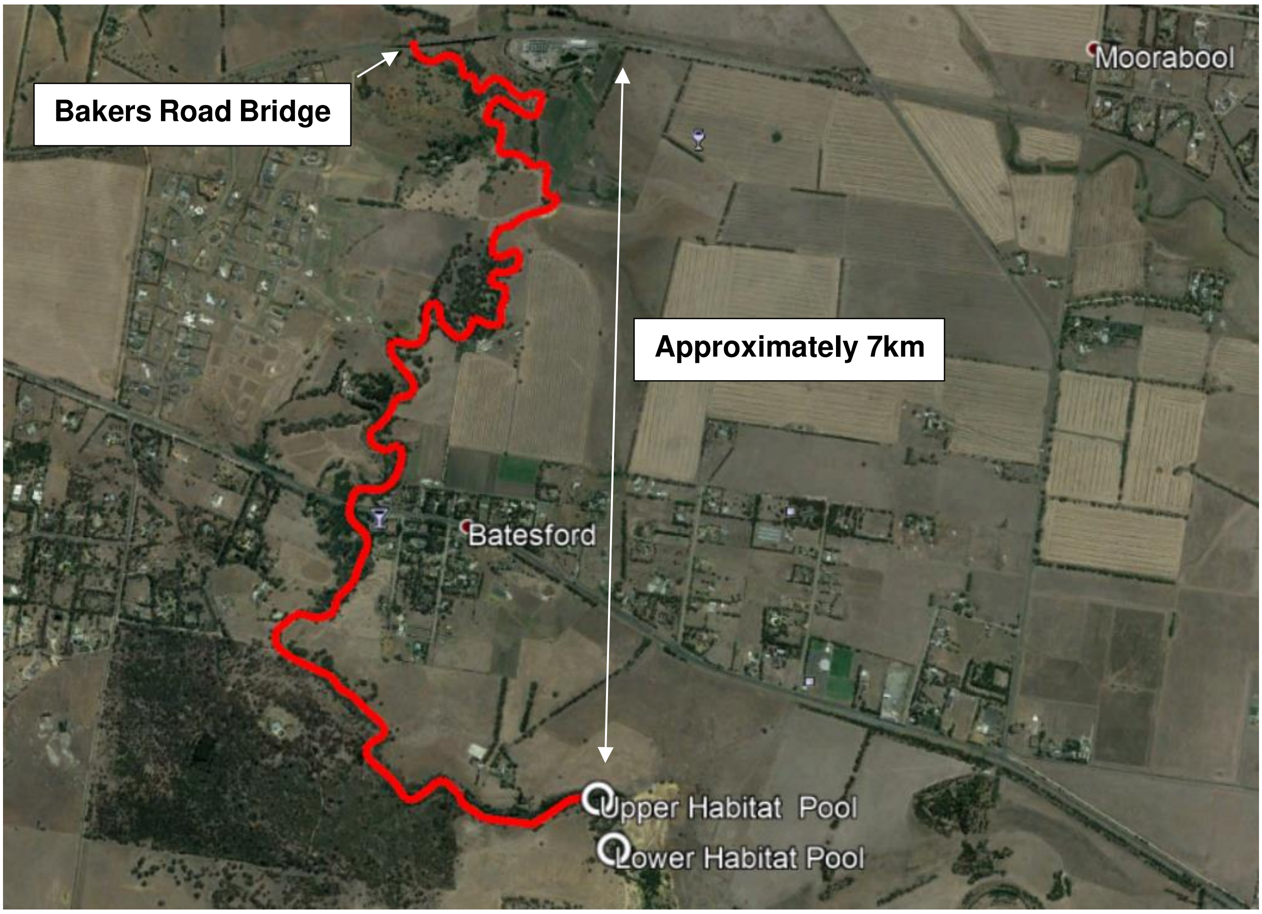


Figure 19. Location of Bakers Road Bridge in reference to the Lower Moorabool habitat pools

This existing modelling work was used to develop a reference point of hydraulic conditions upstream of the habitat pools and to inform the boundary conditions to be used for hydraulic modelling of the habitat pools themselves.

6.2 Monitoring Data and Hydrography

The monitoring data produced for the Moorabool at Batesford gauge and the two gauges installed at the habitat pools (232250A and 232251A) were evaluated for their suitability in providing calibration to the hydraulic modelling of the pools.

The relationship between flow and elevation that was reported for both habitat pools was assessed to identify the critical hydraulic components of the system.

This is demonstrated below in Figures 20 and 21.

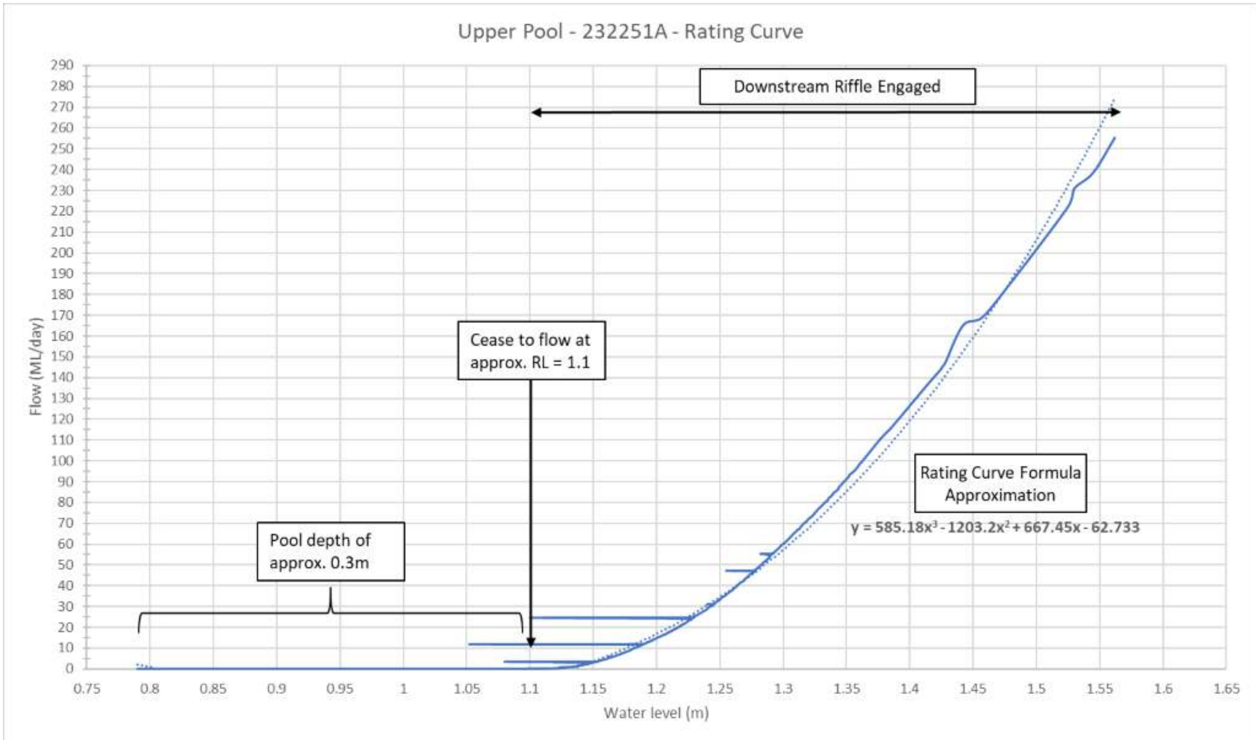


Figure 20. Upper habitat pool rating curve with mark up.

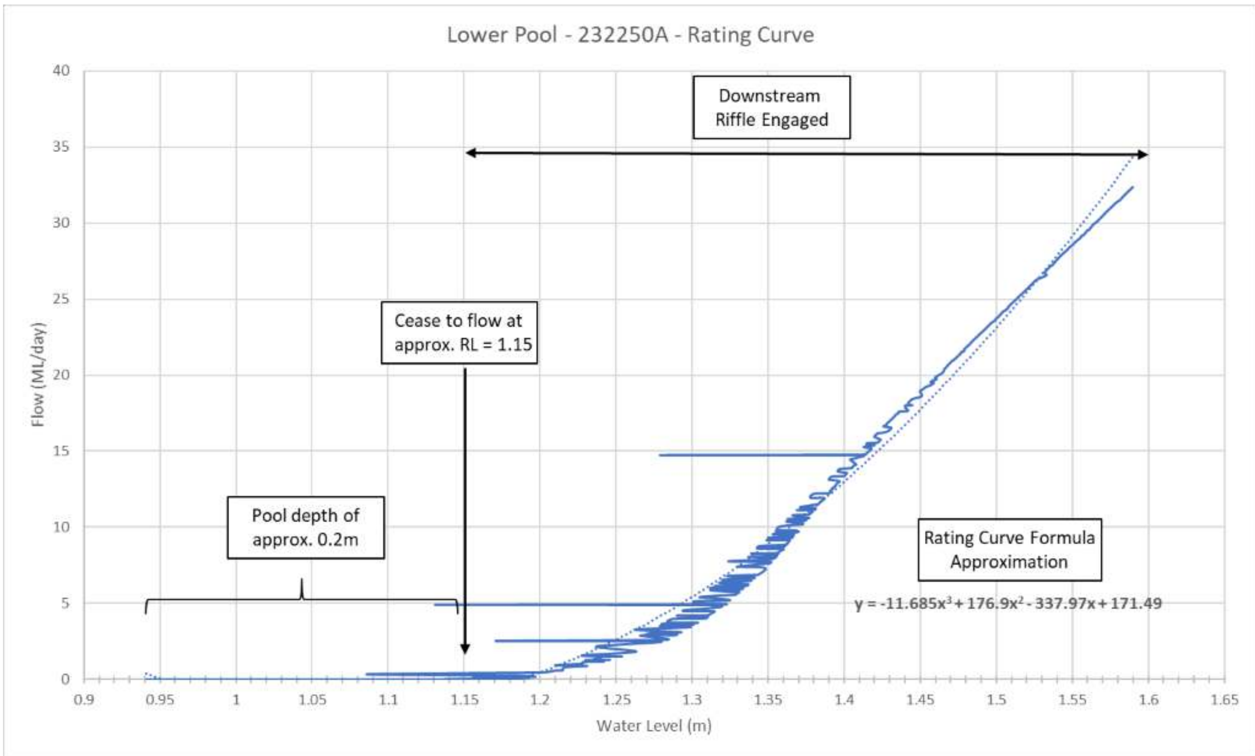


Figure 21. Lower habitat pool rating curve with mark up.

The rating curves reported for the habitat pools contained very different results from one another, with only the Upper Pool's flow data being comparable and compatible with that reported for the Moorabool at Batesford Gauge. This is due to the gaps (potentially due to the pooling having gone dry, the probe having been moved or other data quality issues) in the records demonstrated in Figures 20 & 21, removing the higher flows for the habitat pools. This is particularly evident for the lower habitat pool, 232250A.

A breakdown of the flows for the Batesford flow gauge demonstrated that the river at and below this point can expect to experience zero flow in the system up to 15% of the time, with more than 20% of the time in autumn months experiencing zero flow. This is demonstrated with flow duration curves below in Figure 22 and 23.

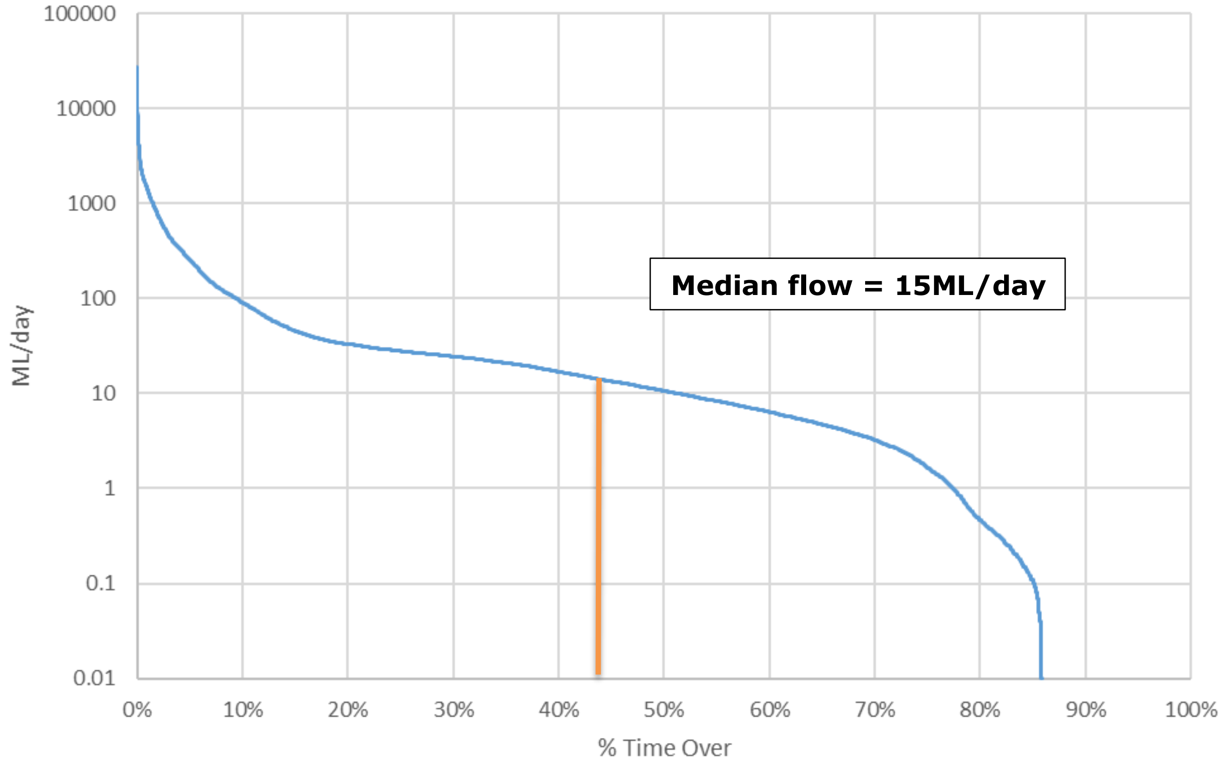


Figure 22: Flow duration curve for Moorabool at Batesford flow gauge.

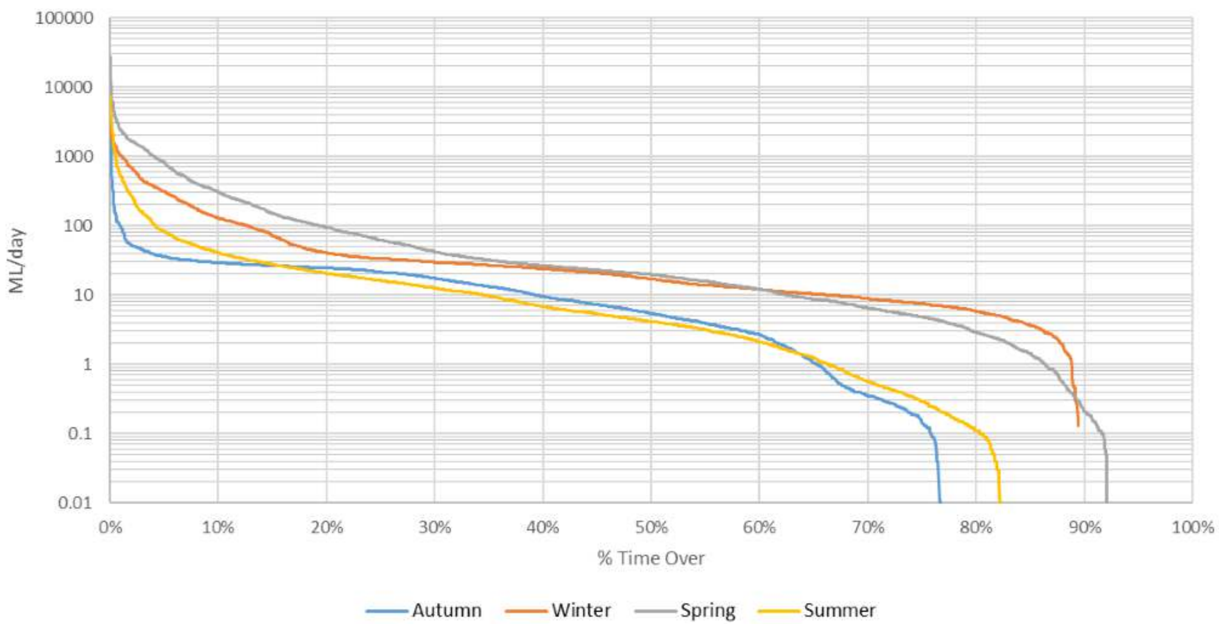


Figure 23: Seasonal flow duration curves for Moorabool at Batesford flow gauge.

6.3 Hydraulic Modelling

A 1-dimensional hydraulic model was developed using HEC-RAS (v.5.0.7) and the survey provided for the two habitat pools. The survey used for both pools is demonstrated in Figures 24 and 25.

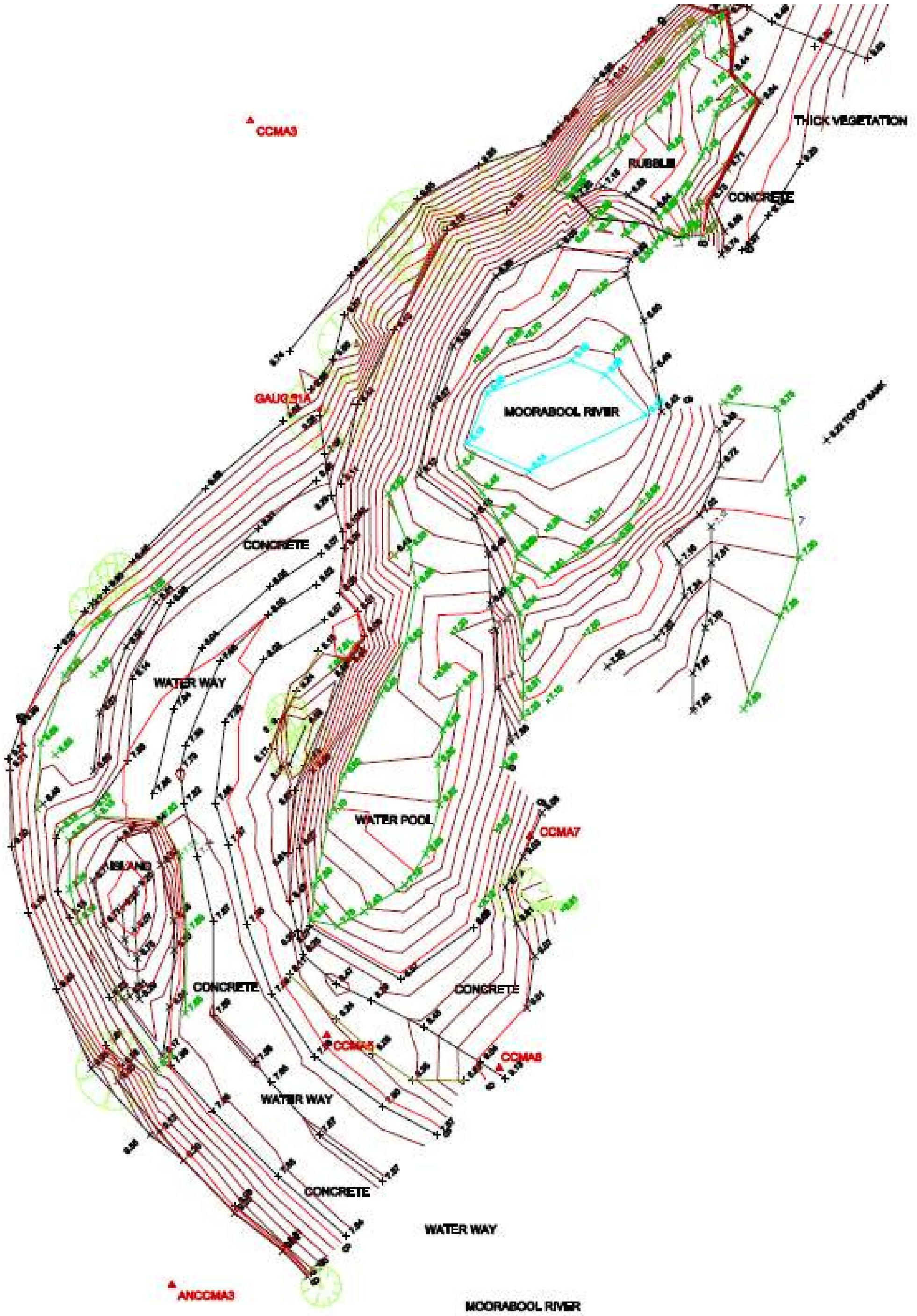


Figure 24: Upper Habitat Pool for Ventia gauge 232251A (South West Survey Group, 2019).

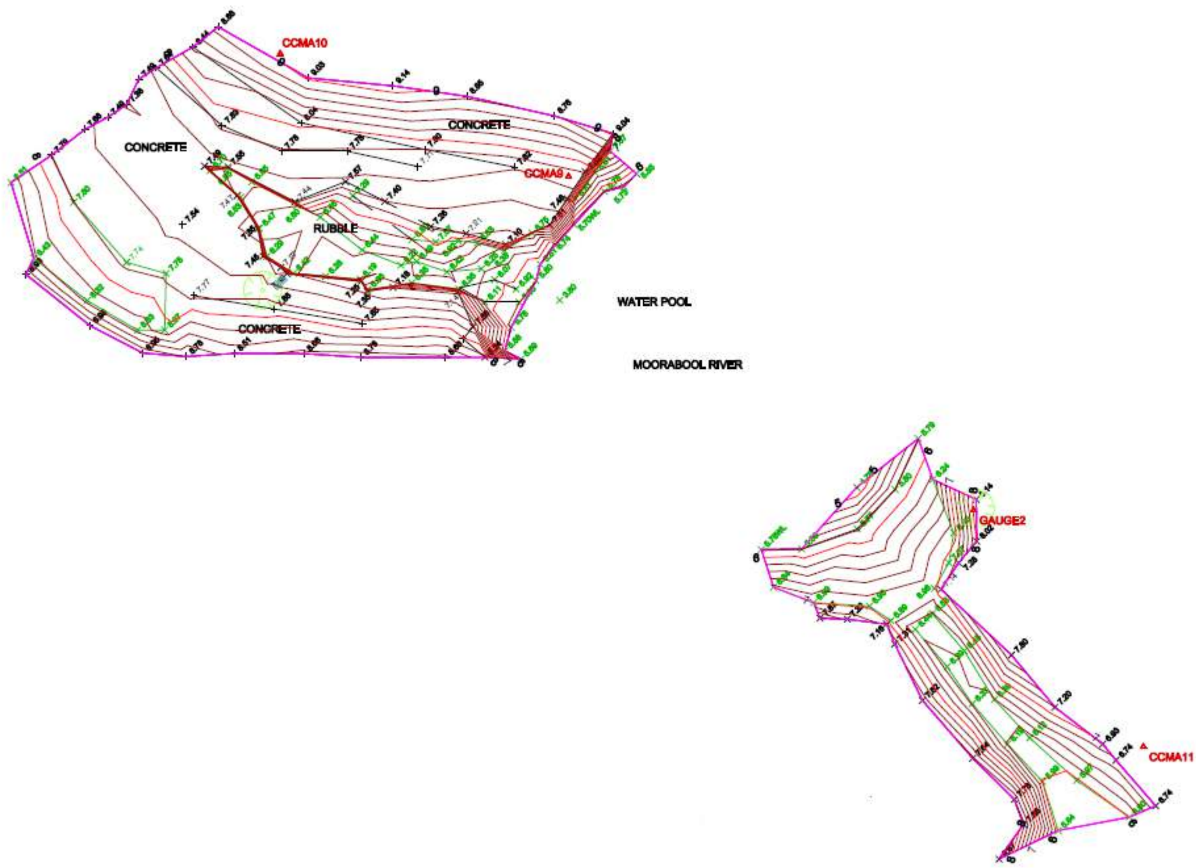


Figure 25: Lower Habitat Pool for Ventia Gauge 232250A (South West Survey Group, 2019).

Upon review of the survey data provided, it was evident that the lower pool's substantial data gaps would preclude it from being a beneficial inclusion in the modelling exercise.

6.3.1 Flows modelled

In order to produce a full suite of flows for the habitat pool system, a range of 15 flows from 5 ML/day to 3,000 ML/day was evaluated. To provide direct assessment of the system for the specific eco-hydraulic flow objectives underpinning the flow recommendations, these flows were adjusted in order to produce the desired depths within the system.

6.3.2 Results

A rating curve for the upper habitat pool was output for use in identifying the depth of flow over the downstream riffle and in evaluating the performance of the system for its discharge and relative fit for calibration purposes. Due to the superior data quality and coverage of the upper habitat pool's survey, this rating curve and the associated results from the upper habitat pool's modelling were evaluated as a proxy for the lower habitat pool.

Figure 26 below provides the rating curve for the upper habitat pool's downstream cross section. It should be noted that, at the time of writing, the depth of flow has not been corroborated against the water level reported for the cross sections and gauging produced for either 232250A or 232251A by Ventia, due to an inability to directly link the cross section to the survey undertaken. This was decided to maintain the confidence in the results reported.

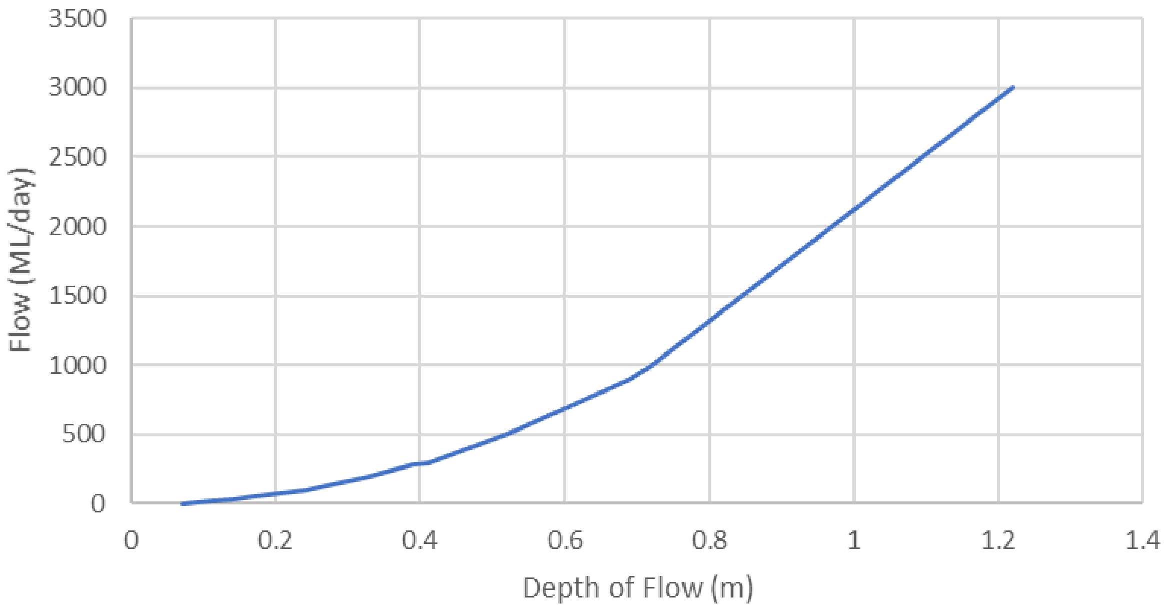


Figure 26: Upper habitat pool downstream rating curve.

This rating curve is complemented by an assessment of water depth over the upper pool's length for select flows that satisfy the ecohydraulic requirements of the flow recommendations. This depth assessment is provided in Figure 27.

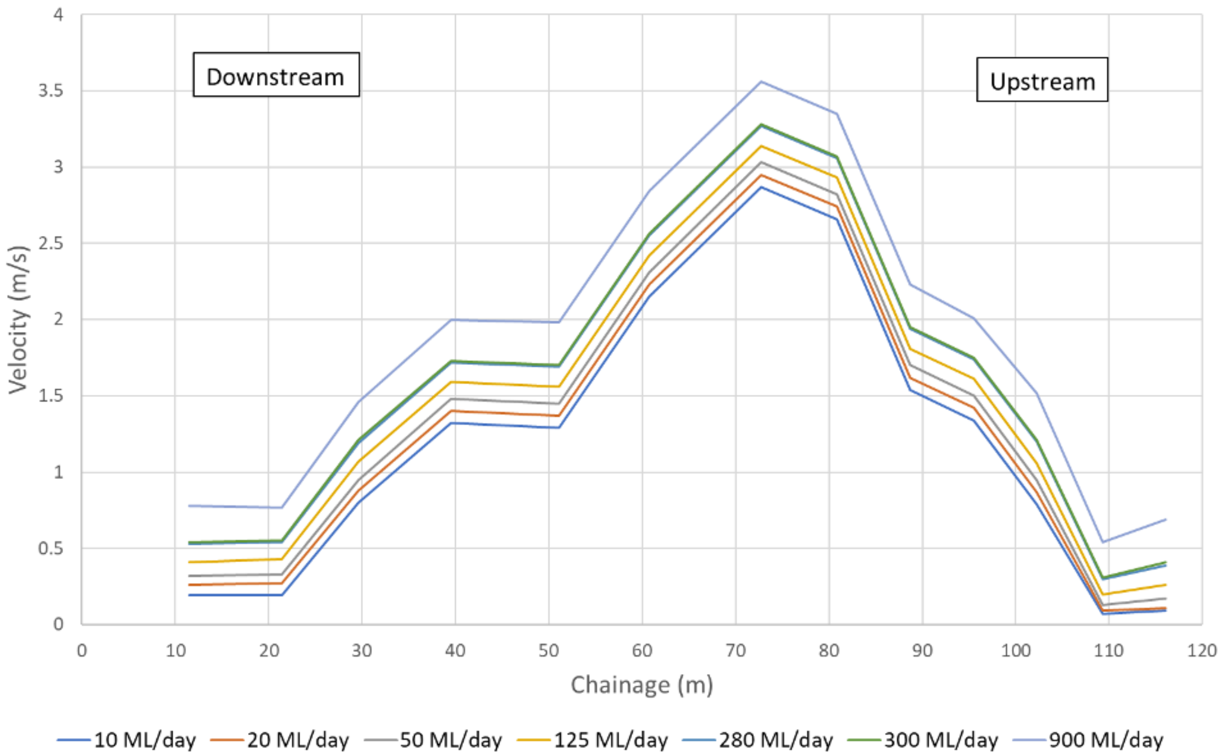


Figure 27: Assessment of velocity at upper habitat pool profile for select flows.

A cross-sectional assessment of the water profile at the downstream end of the upper pool has also been output from HEC-RAS to demonstrate the depth of flow across the waterway to satisfy the flow recommendations (Figure 28).

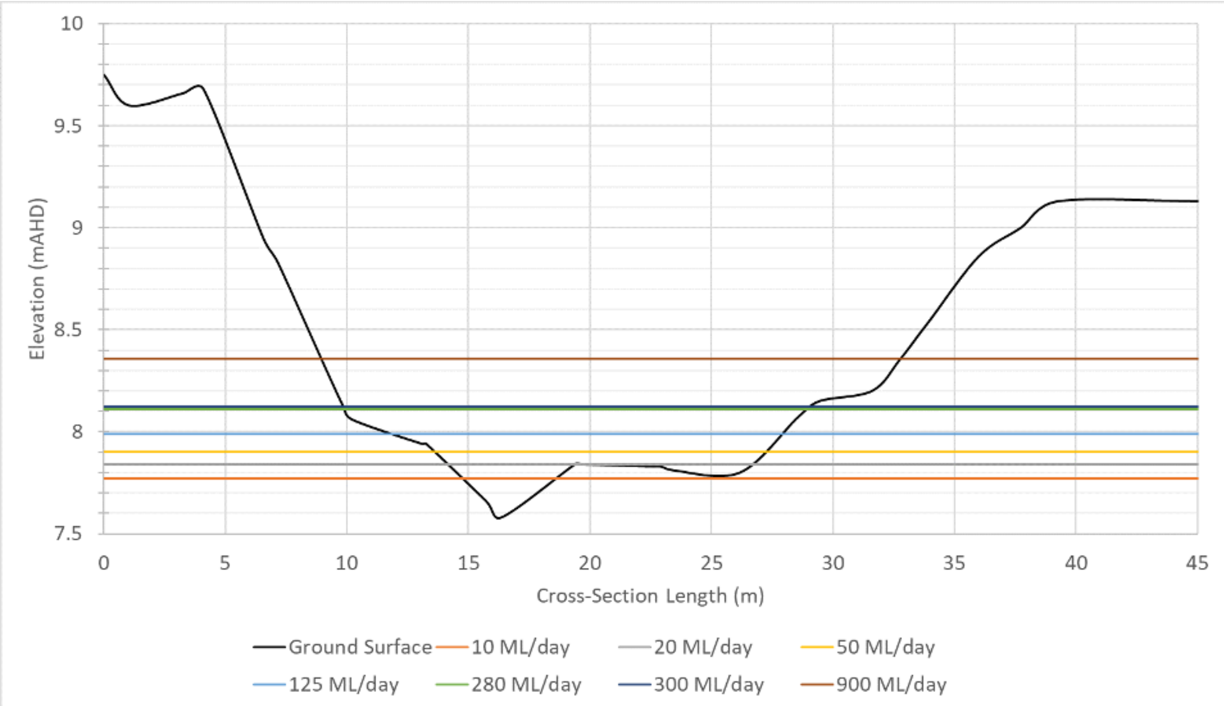


Figure 28: Upper habitat pool cross section water surface elevation results for select flows from HEC-RAS.

6.4 Habitat Pool Groundwater Loss Assessment

Quantifying the rate at which the upper pool infiltrates into the groundwater requires an understanding of the relationships between water surface elevation, pool volume, and discharge within the system.

An assessment of pool geometry was first undertaken to identify the water surface elevation marking the cease to flow point, where water below this height is confined within the pool. This point was identified at 8m in height (AHD) (Figure 29).

Figure 29: Triangulated surface for the upper habitat pool for volumetric analysis (colours show the depth change but not contours)

Further assessment of the geometry within the pool was undertaken to corroborate height against pool volume. This involved an analysis of area (m^2) per contour within the pool, with results input into a frustum calculation, to quantify the relationship between volume and elevation within the pool (Figure 30).

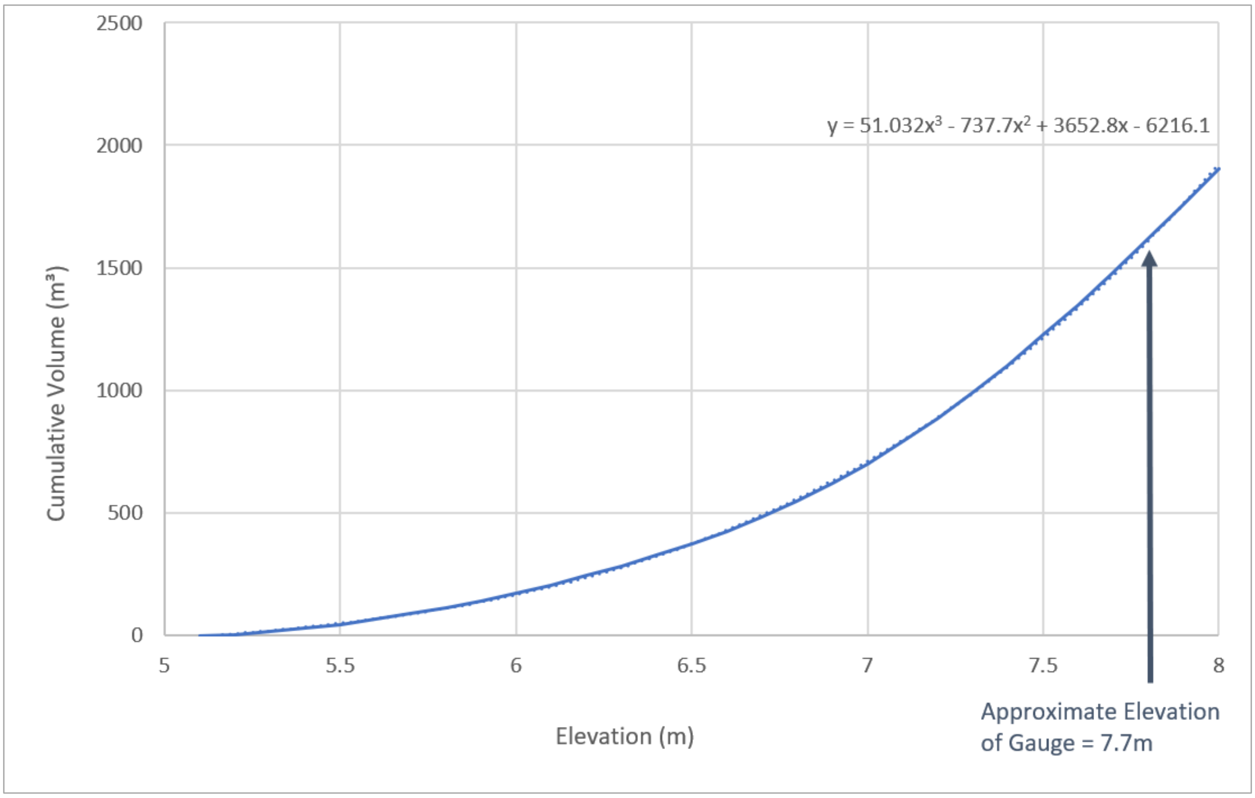


Figure 30: Relationship between cumulative volume of the upper habitat pool (m3) and elevation (m AHD) with approximate elevation of gauge recorded (7.7m).

To consider ground water loss from the pool, it was important to isolate periods where a cease to flow exists, where infiltration is the primary driver of changes to pool volume and water surface elevation. Evaporation was not considered in this assessment due to the timestep over which losses and cease to flow conditions were identified. Evaporation for this location is typically as low as 3 to 5 millimetres per day. These calculations were undertaken by isolating periods where a cease to flow exists and calculating the daily changes in volume. Any positive changes may have been attributed to rain events or pulses of flow releases, whereas any negative changes in volume were attributed to pool infiltration into the groundwater reserve.

It was calculated that the average daily infiltration during cease to flow periods was 0.09 ML/day, with infiltration rates recorded spanning between approximately 0.001- 0.3 ML/day (Table 5)

Table 5: Minimum, Maximum and Average Daily Infiltration rates including the volume of water lost from the Habitat Pools.

Infiltration Statistics	Volume of Groundwater Loss per Pool
Minimum Daily Infiltration	0.001 ML/day
Maximum Daily Infiltration	0.30 ML/day
Average Daily Infiltration	0.09 ML/day

An analysis into the seasonality of these infiltration events was also undertaken, with the largest infiltration events occurring during summer and autumn (Figure 31).

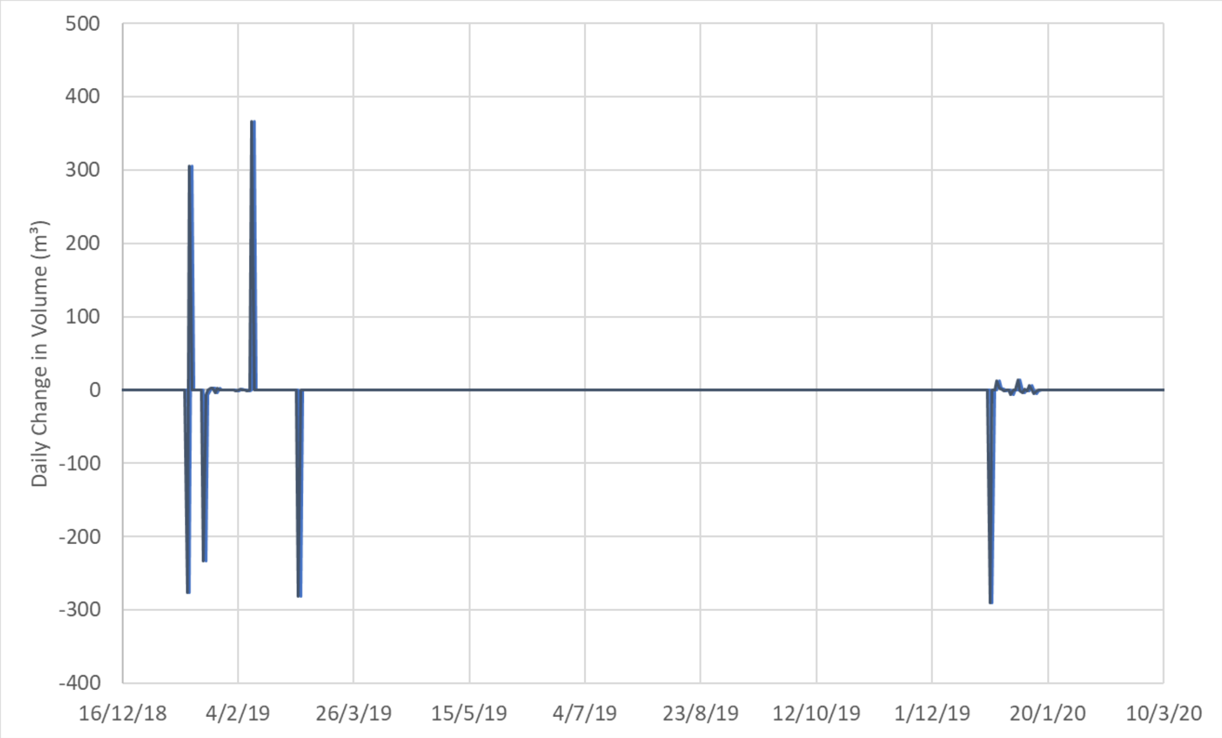
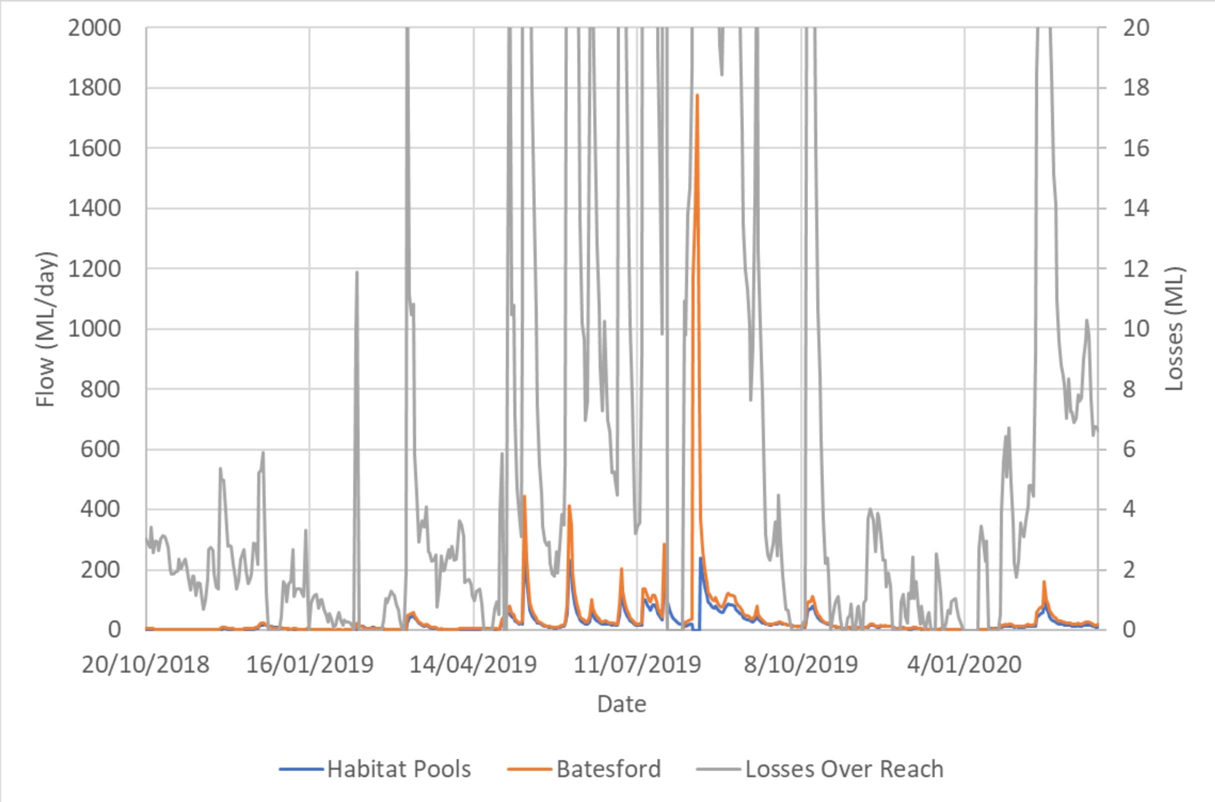


Figure 31: Daily change in pool volume over time (periods with flows through the system are recorded as 0).

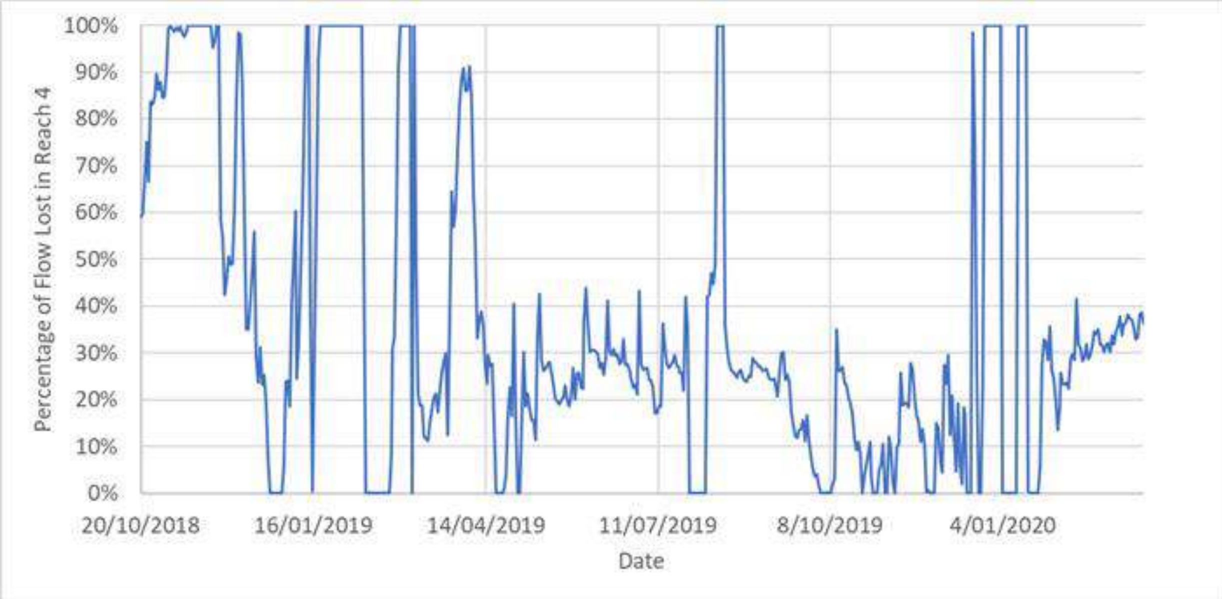
6.5 Lower Moorabool Reach Losses

A comparison of the losses over the reach from Batesford to the habitat pools was undertaken to provide background loss data and support discussion with respect to the potential increases in releases from the environmental entitlement held in Lal Lal Reservoir required to meet the recommended environmental flows.

Figure 32 provides a graphical comparison and demonstrates the inferred losses within the reach from the Batesford gauge to the habitat pools (includes losses from the habitat pools).



a. Comparison of daily flows in the Lower Moorabool River with inferred losses from the Batesford gauge to the habitat pools adjacent the Batesford quarry.



b. Percentage loss comparison for daily flows in the Lower Moorabool River in the habitat pools reach adjacent the Batesford quarry.

Figure 32: Inferred losses from the Batesford gauge to the habitat pools adjacent the Batesford quarry.

The flow data provided demonstrates that losses in the Lower Moorabool can be expected to occur in a magnitude of approximately 3 to 20 ML/day (median of 5.14 ML/d). Note that the analysis is on a relatively short data record with only two years of data, and there are a few large changes in flow that have caused the spiking to occur. This estimate could be refined further with a longer dataset.

This resulting loss in magnitude implies that these additional volumes would need to be met in order to satisfy the flow recommendations for the habitat pools.

Table 8: Losses to groundwater for the Lower Moorabool from Batesford to the habitat pools, by season (mean ML when losses occur)

Season	Mean Loss as Volume (ML)	Loss as Percentage of Flow
Winter	19.2	29%
Spring	4.80	38%
Summer	3.17	41%
Autumn	5.48	35%

While these losses may not be entirely attributable to groundwater losses, the additional uses on the Lower Moorabool have not been evaluated. In the event that significant irrigator extractions are prescribed for Reach 4, these would account for the high variability in the ratio of losses to daily flow observed.

6.6 Upper Moorabool Reach Losses

A comparison of the losses over the reach from Morrisons to Batesford was undertaken to provide a foundational assessment of the flow requirements from Lal Lal Reservoir to provide environmental flows to the Lower Moorabool. Figure 33 below demonstrates the flow at both locations over the period in which the logging infrastructure was present in the habitat pools.

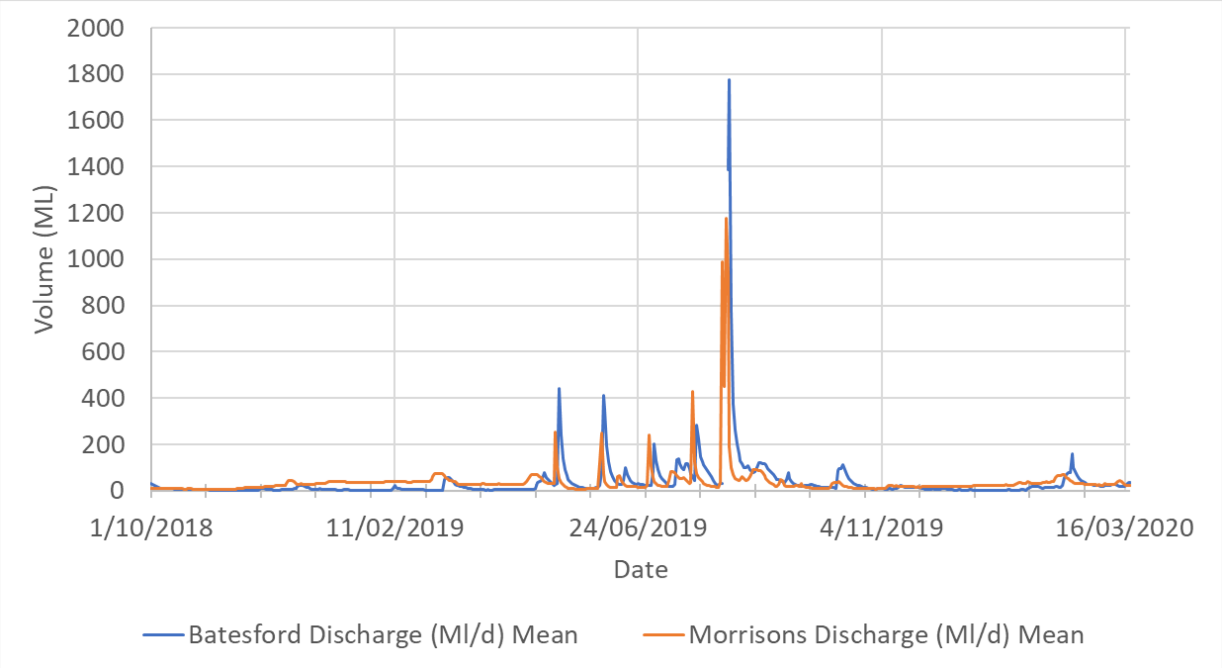


Figure 33: Comparison of Daily Flows in the Moorabool River at Batesford and Morrisons.

It was observed that a time delay existed in the flows recorded for both locations of approximately 2 to 4 days. To accommodate this, the relative change in flow was offset by 3 days.

A flow duration curve is provided below in Figure 34 to demonstrate the relative magnitude of flows to be expected for a given portion of the record.

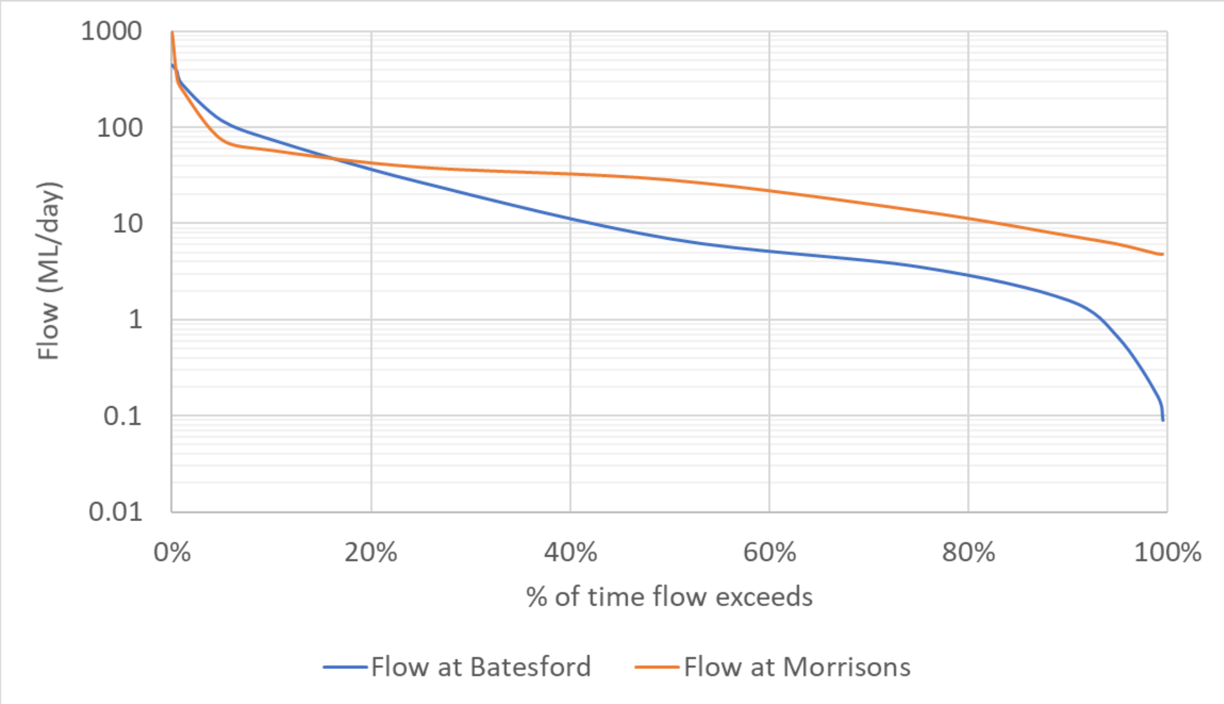


Figure 34: Flow duration curve for the Moorabool River at Batesford and Morrisons.

Figure 35 provides an assessment of the difference in flows from the gauge at Morrisons and Batesford for changes in flow less than 100ML in magnitude.

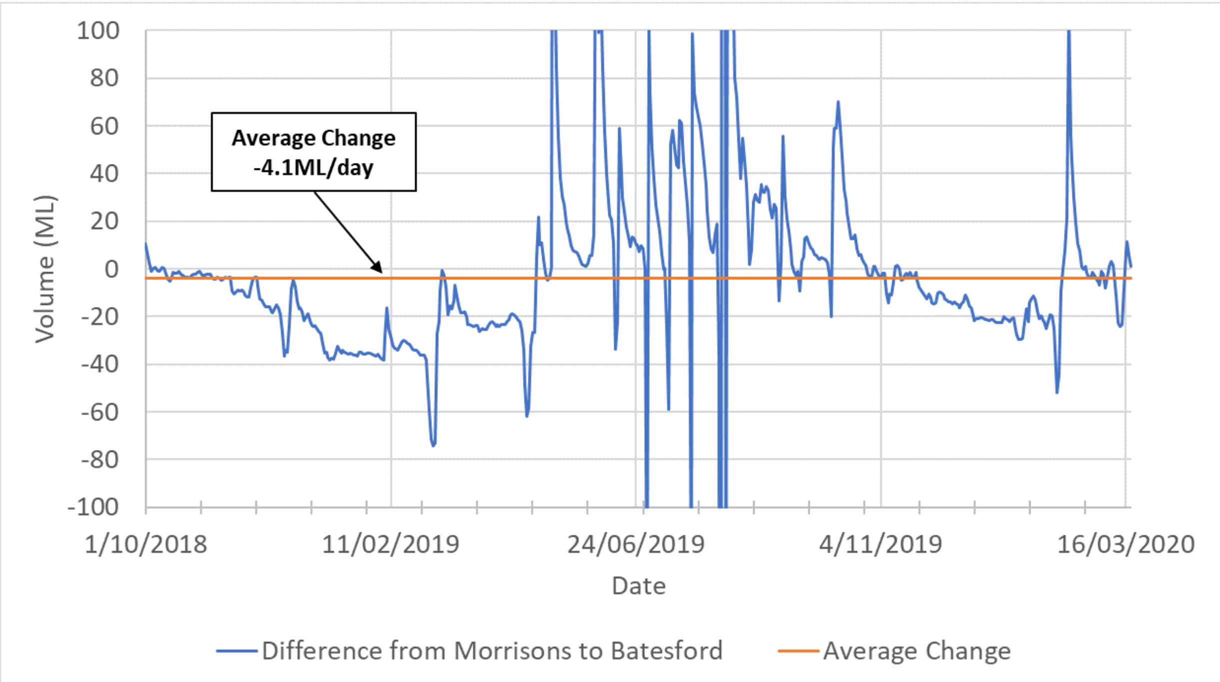


Figure 35: Difference in flows from Morrisons to Batesford on the Moorabool River.

Based on this comparison, the average change in flow from Morrisons to Batesford is -4.1 ML/day, but can reasonably be expected to potentially experience significant losses through the connecting reaches of up to 80 ML/day – though this is largely attributable to extractive uses for irrigation and other licensed uses.

7 FLOW RECOMMENDATIONS

This report has examined the flow requirements of fish and associated flora and fauna of the Lower Moorabool River, building on the work of Jacobs (2015). Therefore, the FLOWs recommendations within this section are presented for both the habitat pools and the upstream compliance point Bakers Road Bridge which is still in Reach 4, but is seven kilometres upstream from the habitat pools.

We expect the recommendations to be different for three reasons:

1. The distance between the two sites;
2. The different cross sections, based on the geomorphology, at each site; and
3. The fact that the stream reach concerned is a losing reach with no tributary inflows.

Both sets of recommendations are valid, but generally within a reach we choose the most conservative (higher) flows to ensure we meet the required objectives for the reach and, given the habitat pools are also downstream, the FLOWS method would recommend using these flows. However, both are based on similar objectives and the Bakers Road Bridge recommendations would achieve the required objectives, especially if extra water is supplied to make up for losses in the reach (estimated elsewhere in this report to be 3 ML/d to 20 ML/d; median of 5.14 ML/d).

7.1 Flow Recommendations for Habitat Pools (Reach 4)

The FLOWS assessment of the habitat pools section of Reach 4 of the Moorabool River is an extension of the detail and understanding of previous FLOWS studies (Jacobs 2015), biological investigations and surveys (ARI 2015; Raymond 2015); investigations of the habitat pools (Jacobs 2017; Kingfisher Research 2018) and new flow monitoring data (Ventia 2018-2020).

This section examines the flow recommendations of the new site with Reach 4 based at the habitat pools. This site was based on reconstructed cross-sections developed by this work (see section 6) from Ventia (2018-2020) surveys of the habitat pools and their flow monitoring. The new flow data has allowed an investigation of the habitat loss in cease-to-flow periods and its impact on fish and other aquatic fauna and flora. We also considered the local and regional groundwater situation and its impact on the flow recommendations for the habitat pools section of Reach 4 of the Moorabool River. We utilised the information in Jacobs (2015), revised flow objectives for the fish fauna of the reach and modelling at a new site. This provides new flow recommendations from the current application of FLOWS specifically for the habitat pools section of Reach 4. The revised environmental flow recommendations for the habitat pools section of Reach 4 and specific objectives they aim to meet are summarised in Table 6. These recommendations may provide for flow components at a greater or lower level than Jacobs (2015), but these are specific to this reach and therefore are more likely to account for the needs of this critical reach for the Moorabool River.

7.1.1 Summer/Autumn low flow

Summer/autumn low flows provide water in pools and riffles for fish habitat and for their food sources such macroinvertebrates and other fish. In addition, aquatic and riparian plants are supported by full pools and flow between the riffles. Aquatic plants are required in their own right but also provide valuable fish and invertebrate habitat. Platypus require permanent pools and flowing riffles to allow them to forage for aquatic invertebrates. Flow between pools also provides mixing of the water column within pools and in riffles which helps maintain good water quality.

A continuous low flow of 20 ML/Day is required to meet these conditions. Jacobs (2015) provided a low flow recommendation of 10 ML/Day in dry years, with a statement that this is a bare minimum to maintain water quality conditions. However, a flow of 10 ML/day will mean very little flow between pools and the loss of water within pools at 10/ML day means the pools will dry relatively quickly (see section 3). Therefore, flows as low as 10 ML/day are not recommended with this new information.

7.1.2 Summer/Autumn freshes

Three freshes are required and recommended for this site during the summer/autumn period:

I. Freshes of 125 ML/day which last for 3 days and occur about 5 times per season will provide water over riffles to allow longitudinal connectivity and for fish to move between pools to breed, feed and find new habitats. These flows will also allow platypus to move throughout the reach and maintain access to habitat. These higher freshes will allow extensive areas of the streambed and lower benches to be inundated creating additional macroinvertebrate and fish habitat, supporting other elements of the ecosystem.

II. A fresh of 280 ML/day which last 3-5 days occurring 3 times per season is required to provide water over riffles which allow fish to migrate downstream from estuary (especially for the Australian grayling). These flows will also trigger downstream spawning migration of adult migratory fish for the short-finned eel (in Jan-Feb) and upstream migration in May).

III. A large fresh of 900 ML/day which lasts for 1 day occurring twice per season will help submerge and clean woody debris & hard surfaces to provide breeding substrate for the river blackfish.

7.1.3 Winter/Spring low flow

Winter/spring low flows also provide water in pools and riffles for fish habitat and for their food sources such macroinvertebrates and other fish and is especially important in the spring months, as this when fish are preparing to breed, and putting on condition to allow high levels of spawning. As in the summer/autumn period these flows support aquatic and riparian plants, macroinvertebrates and platypus by keeping the pools full and flow between the pools through the riffles. This flow also provides mixing of the water column within pools and in the riffles, which helps maintain good water quality. Section 3 shows that when flows falls below 10 ML/day, the temperature does increase by a few degrees, although less so in winter.

A continuous low flow of 20 ML/Day is required to meet these conditions. Jacobs (2015) provided a low flow recommendation of 86 ML/Day as an aspirational flow requirement and while this FLOWS analysis did not indicate this need (no doubt due to different morphology of the stream bed in this reach), it is likely that a higher base flow will occur in the winter period naturally, but the recommendation is mainly targeted during the spring period.

7.1.4 Winter/Spring freshes

Three freshes are also required and recommended during the winter/spring period:

I. Freshes of 125 ML/day which last for 3 days and occur about 5 times per season will provide water over riffles to allow longitudinal connectivity and for fish to move between pools to breed, feed and find new habitats as in the summer/autumn. Importantly, these flows provide connectivity to allow galaxias to migrate downstream to breed in the estuary. These flows will also benefit macroinvertebrates and platypus populations by inundating low benches supporting aquatic and instream vegetation.

II. A fresh of 280 ML/day which last for 3-5 days occurring 3 times per season is required to provide water over riffles which allow fish to migrate upstream from estuary (especially for the eels, tupong [Oct-Feb], and Australian grayling [Oct – Dec]).

III. A fresh of 907 – 924 ML/day, lasting 3-5 days twice per season, will provide prolonged seasonal inundation of vegetation beds and instream benches to stimulate invertebrate hatching and fish breeding and provide fish habitat (galaxias, smelt, big headed gudgeon and southern pygmy perch, blackfish).

7.1.5 High flows

Jacobs (2015) recommended a high flow component from their modelling. This project was unable to model the bankfull flows due to missing information in cross sections available for the habitat pools.

However, high flows are known to be important for maintaining the channel form and dimensions as the high flows scour the bed and banks of the channel, entraining sediments and deepening pools. Jacobs (2015) recommended a high flow of 3000 ML/Day every 2 years with a duration of 1-2 days in wet/average years. These flows will be relatively infrequent and are generally beyond regulation, so these should occur naturally.

Table 6: Flow recommendations from the current application of FLOWS to the habitat pools section of Reach 4.

Season	Component	Flow Objectives met	Magnitude	Duration	Frequency	Rise and Fall
Summer/Autumn (Dec to May)	Low flow	a) Provide water in pools and riffles for habitat & food sources	20 ML/day	Continuous	Continuous	1.86/0.68
	Fresh	b) Provide water over riffles to allow longitudinal connectivity and for fish to move between pools c) Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	125 ML/day	3 days	5 per season	1.86/0.68
		d) Trigger downstream spawning migration of adult migratory fish (for short-finned eels [Jan-March] and Australian grayling [April-May])	280 ML/day	3-5 days	3 Per season	1.86/0.68
		e) Submerge/clean woody debris & hard surfaces to provide breeding substrate (blackfish)	900 ML/day	1 day	2 per season	1.86/0.68
Winter Spring (June to Nov)	Low flow	f) Provide water in pools and riffles for habitat & food sources	20 ML/day	Continuous	Continuous	1.86/0.68
	Fresh	g) Provide water over riffles to allow longitudinal connectivity and for fish to move between pools h) Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats i) Provide connectivity to allow fish to migrate downstream to breed (spotted and common galaxias)	125 ML/day	3 days	5 per season	1.86/0.68
		j) Provide water over riffles to allow fish to migrate upstream for (especially for the eels, tupong [Oct-Feb], and Australian grayling [Oct – Dec])	280 ML/day	3-5 days	3 Per season	1.86/0.68
		k) Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding (galaxias, smelt, big headed gudgeon and southern pygmy perch, blackfish)	900 ML/day	3-5 days	2 per season	1.86/0.68

7.2 Flow Recommendations for Bakers Road Bridge (Reach 4)

The details of the Jacobs (2015) report and it is summarised in table 7 and in Figure 33.

In the summer/autumn period, Jacobs (2015) recommend for the Bakers Road Bridge site within Reach 4:

- A low flow of 20 ML/d (10ML/d as a bare minimum)
- A fresh of 60 ML/d

In the winter/spring period, Jacobs (2015) recommend for the Bakers Road Bridge site within Reach 4:

- A low flow of 86 ML/d (20 ML/d as a minimum)
- A fresh of 162 ML/d
- A high flow of 3000 ML/d

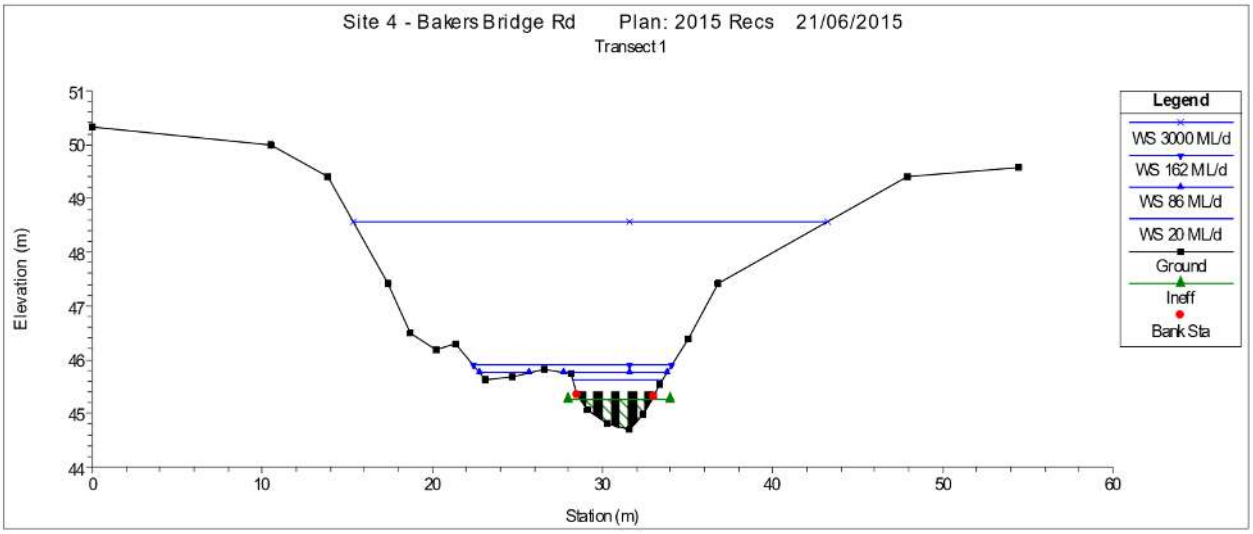


Figure 33: Flow Recommendations for the Bakers Road Bridge site within Reach 4

Table 7: Flow Recommendations for the Bakers Road Bridge site within Reach 4.

Waterway	Moorabool River: Moorabool River: Sharps Road to Barwon River		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
Summer / Autumn (Dec–May)	Low flow	Maintain pool and riffle habitats for fish, macroinvertebrates, Platypus and submerged aquatic vegetation (F1, F2, M1, V1, P1, P2, P3). Maintain water quality (W1).	Wet/Average	20 ML/Day Minimum	December to May		NA
			Dry	10 ML/Day Minimum	December to May		NA
	Fresh	Flush silt, and scour biofilms and algae from streambed (M1). Water fringing marginal zone vegetation (V2, V3). Allow fish and Platypus movement through the reach and maintain access to habitat (F1, F2). Trigger downstream spawning migration of Short-finned Eel and Grayling (F1).	Wet / Average	60 ML/Day Minimum	2 events, January/February (Short-finned Eel) and April/May (Grayling)	5 Days	2.0/1.7
				30 ML/Day Minimum	1 event, February/March to water fringing vegetation	3 Days	2.0/1.7
			Dry	60 ML/Day Minimum	1 event every 2 to 3 years, April/May (Grayling)	5 Days	2.0/1.7
		Freshen water quality when DO < 5 mg/L (W1)	Dry	20 ML/Day Minimum	1 event as required	2 Days	2.0/1.7
Winter / Spring (Jun-Nov)	Low flow	Allow fish movement throughout the reach (F1, F2). Maintain clear flow path and control intrusions by terrestrial vegetation (V1).	Wet/Average	86 ML/Day Aspirational 20 ML/Day Minimum	June to November		
			Dry	86 ML/Day Aspirational 10 ML/Day Minimum			
	Fresh	Allow fish and Platypus movement through the reach and maintain access to habitat (F1, F2). Trigger downstream spawning migration of adult Tupong. Upstream migration of juvenile Galaxias, Tupong, Short-finned Eel and Grayling (F1). Flush silt, and scour biofilms and algae from streambed (M1) and transport of organic matter (W2). Promote growth and recruitment of native riparian vegetation including woody shrubs and promote strong vegetation zonation on the banks (V2, V3).	Wet / Average	162 ML/Day Aspirational 80 ML/Day Minimum	1 event in May to August (Tupong) and 2 events in September to November (Galaxias, Tupong Short-finned Eel and Grayling)	10 Days Aspirational 5 Days Minimum	2.0/1.7
			Dry	162 ML/Day Aspirational 80 ML/Day Minimum	1 event in May to August (Tupong) and 1 event in September to November (Galaxias, Tupong, Short-finned Eel and Grayling)	10 Days Aspirational 5 Days Minimum	2.0/1.7
	High	Scour pools and maintain channel form and dimensions (G1). Flushing of sediment to improve spawning sites (F2). Inundate billabongs (G1, G2, V4).	Wet / Average	3000 ML/Day Minimum	1 event every 2 years, preferably in Winter to avoid risks to Platypus	1 to 2 Days	2.0/1.7
			Dry	Not expected			

8 OUTCOMES

This reach of the Moorabool River is notable because of the amount of water within the reach which is lost to groundwater. This is exacerbated by the quarry in the low reaches of the river which creates a significant cone of depression, further drawing the water from the river. This section reviews the likely impact of these losses on flow recommendations, provides adjusted flow recommendations and proposes complementary actions and further investigations to support these flows.

8.1 Impact of Groundwater loss on FLOWS Recommendations

While the direct data for assessing the actual loss of water from the river to the groundwater is currently unknown, we do know the quarry dewatering has created a significant cone of depression drawing regional groundwater downward and toward the quarry pit. The losses can be estimated from the pool scale losses directly or on a reach scale.

Based on calculations for the various scales provide some good lines of evidence that the leakage directly from the river to groundwater is significant in Reach 4. These scales, increasing in significance, are shown below.

- At the pool scale - the assessment in section 6.4, which used a hydraulic approach to assessing loss from the habitat pools themselves, indicating that loss could reach up to 0.3 ML/d (300m^3/day). This is expected to have a small bearing on the flow recommendations in section 7.1.
- At the cone of depression scale applying Darcy's Law, the leakage could be as high as 150m^3/day (0.15 ML/d) whereas the leakage estimated by Nolan-ITU was 102 ML/yr = 0.28ML/d = 280m^3/day.
- At the habitat pool reach scale (about 1km of stream, incorporating the pools) Dahlhaus (pers comm) and the lines of evidence suggest that a significant proportion of the water lost (possibly 75%) from groundwater seepage to the quarry is drawn from groundwater that could otherwise have gone to the river as baseflow contributions (equivalent to the 9 ML/d water pumped from the quarry). This means that there is 6-7 ML/d which should be baseflow to the Moorabool River, but it is drawn from groundwater that could otherwise have gone as baseflow to the river.
- On a reach scale there are a number of estimations that can also be applied, and is more applicable to assessing impact on flows recommendations. This is corroborated by the flow data observed, demonstrating a loss in daily flow from Batesford to the habitat pools typically varying in volume from 3 ML/day to 20 ML/day (median of 5.14 ML/d; section 6.5).

These observations and monitoring over the last 2 years (outlined in section 3) are consistent with the data which shows the pools typically drying within 3 to 10 days of a cease to flow event. The rapid drying was observed when river flows were below 10ML/d in the antecedent period and that at 20 ML/d the pools did not dry even if there are short cease to flows. Section 6 shows that with pool volumes being relatively small at 1500-2000 m^3 (1.5 to 2ML), the pools could empty within 7 days of a cease-to-flow event occurring. This strongly supports the low flow recommendations throughout the year (sections 7.1.1, 7.1.3 & 8).

The flow data observed, which demonstrated a loss in daily flow from Batesford to the habitat pools, typically varying in volume from 3 ML/day to 20 ML/day (median of 5.14 ML/d) or 29 to 41%, depending on the season. This suggests that there is possibly a significant impact on the river from drawdown due to the cone of depression associated with the quarry.

The relative degree with which losses to groundwater occur in the Lower Moorabool is largely dependent on the season in which the loss occurs, with the greatest volumetric losses occurring in winter, but the greatest losses by percentage of upstream flow occurring in summer. This is demonstrated in table 8 below.

Table 8: Losses to groundwater for the Lower Moorabool from Batesford to the habitat pools, by season (mean ML when losses occur).

Season	Mean Loss as Volume (ML)	Loss as Percentage of Flow
Winter	19.2	29%
Spring	4.80	38%
Summer	3.17	41%
Autumn	5.48	35%

While these losses may not be entirely attributable to groundwater losses, the additional uses on the Lower Moorabool have not been evaluated. In the event that significant irrigator extractions are prescribed for Reach 4, these would account for the high variability in the ratio of losses to daily flow observed.

8.2 Modified FLOWS Recommendations

The losses to groundwater in the Reach 4 flows means that the flow recommendations would need to be topped up by the amount of these losses at the habitat pools site in Reach 4. The same analysis was undertaken for the Upper Moorabool to look at losses along the system to help make recommendations for flows at Lal Lal and Morrisons (Section 6.6; and summarised in Table 9).

The project's deliverables include the flow recommendations (Table 6 and Table 9 – details in Section 7.1) which are broadly in line with the recommendations of Jacobs (2015) but all are slightly higher, being required to **achieve FLOWS recommendations in Reach 4 of the Moorabool River** which is explained by the different cross sections and geomorphology at the habitat pools, the distance from the Bakers Road Bridge site, and the fact this is a losing stream with little inflows.

The following recommendations will be required at the habitat pools at Batesford, in order to meet the following requirements:

- **to maintain connectivity within Reach 4** then freshes are required (shown in sections 7.1.2 and 7.1.4; Table 6) and with accounting for groundwater losses, flows of 128 – 145 ML/d will allow water of at least 500mm over riffles within the reach. These flows are required to allow fish to move between pools within the reach (and will also provide connectivity to downstream also);
- **to maintain flows for fish & ramp down rates,** a flow fresh of 67 ML/day for one day will allow the habitat pools to be drowned-out (as the flow will drop down to 23 ML/d over 3 days) and allow fish to escape the pools as they dry out at the rates of rise and fall indicated in Table 6; and
- **to top-up & maintain pool depth at the habitat pools,** low flows of 23 ML/day – 40 ML/day will be required in all seasons, especially during the summer/autumn period (Table 6), to ensure the necessary longevity of water in the pools at all times to support the fish and aquatic fauna upon which they depend to persist.

Table 9: Flow Recommendations for the flows at Lal Lal, Morrisons, and Batesford site to meet requirements at the habitat pools accounting for losses to groundwater in Reach 4.

Season	Flow Component	Magnitude Lal Lal	Magnitude Morrisons	Magnitude Batesford	Magnitude Habitat Pools	Duration	Frequency	Rise and Fall
Summer/Autumn (Dec to May)	i) Low Flow to maintain Pools	27 – 44 ML/day	27 – 44 ML/day	23 – 40 ML/day	20 ML/day	Continuous	Continuous	1.86/0.68
	j) Fresh 1 - Provide water over riffles	132 – 169 ML/day	132 – 169 ML/day	128 – 145 ML/day	125 ML/day	3 days	5 per season	1.86/0.68
	k) Fresh 2 - Trigger fish spawning &/or migration	287 – 304 ML/day	287 – 304 ML/day	283 – 300 ML/day	280 ML/day	3-5 days	3 Per season	1.86/0.68
	l) Fresh 3 – Scour pools/support blackfish breeding	907 – 924 ML/day	907 – 924 ML/day	903 – 920 ML/day	900 ML/day	1 day	2 per season	1.86/0.68
Winter Spring (June to Nov)	m) Low Flow to maintain pools	27 – 44 ML/day	27 – 44 ML/day	23 – 40 ML/day	20 ML/day	Continuous	Continuous	1.86/0.68
	n) Fresh 1 - Provide water over riffles and longitudinal connectivity	132 – 169 ML/day	132 – 169 ML/day	128 – 145 ML/day	125 ML/day	3 days	5 per season	1.86/0.68
	o) Fresh 2 - Trigger fish spawning &/or migration	287 – 304 ML/day	287 – 304 ML/day	283 – 300 ML/day	280 ML/day	3-5 days	3 Per season	1.86/0.68
	p) Fresh 3 - Provide prolonged inundation to stimulate breeding and growth	907 – 924 ML/day	907 – 924 ML/day	903 – 920 ML/day	900 ML/day	3-5 days	2 per season	1.86/0.68

8.3 Complementary Actions and Further Investigations

A suite of other actions could be implemented to assist the environmental flows to be affective in improving the condition of the stream and mitigating impacts occurring within this reach. These actions (or investigations) could include:

1. Works to improve the riparian or instream habitat quality such as riparian revegetation or instream stabilisation, which will provide improved condition within the pools, as riparian vegetation will shade and provide food for pool-based organisms. Stabilisation of the stream bed (affected by concrete lining) will allow improvements in physical habitat and aquatic vegetation to establish. The stabilisation could be achieved through the planned rock ramp fish ways within the reach to allow fish easier access out of pools forming downstream of concrete channelling.
2. Moving the 9 ML/day which is currently being discharged from the quarry downstream of these habitat pools to discharge upstream of the upper pool. This would provide continuous habitat in these pools and support the environmental (and natural) flows that are provided. The water quality which is being pumped out of the quarry has a very similar water quality to the river and would provide a solution while the quarry was in operation. After that they could use low flow pumps (solar or windmill) to maintain a groundwater flow by drawing groundwater from the deeper sections of the aquifer to supplement the river flows. These could be automatically operated to pump only when the stream level dropped below a trigger point. This would also allow time for the fish to leave these pools on cease to surface flows.
3. Further, a detailed drone-based survey of the pools and the Moorabool River upstream and downstream can be undertaken to develop a more detailed understanding of the waterway in this region for very specific flow recommendations. This should be done when the flow in the pools is at its lowest or when the pools are dry to produce a complete picture of their geometries. Subsequent flights can also be undertaken to produce impact and condition mapping that informs the CMA of their relative success in some aspects of the flow regulation.
4. The flow recording at the habitat pools has been very useful for the assessments in this project, but the placement of the logging infrastructure was not located at the deepest point in that cross-section. Relocating these loggers to the deepest location possible, and for sampling to be undertaken on a sub-daily timestep (e.g. hourly), will allow for a complete range of the rise and fall of water levels in the pools to be assessed and the resultant pool losses isolated.
5. Sealing the streambed in the habitat pools reach to prevent/slow leakage could be undertaken. That is, reinstate the concrete seal or use another solution such as a liner membrane or clay lining. However, it should be noted, depending on method used, this could have un-intended environmental consequences and these would need to be assessed prior to any works.
6. If more detail and quantification is required on volumes for groundwater baseflow scenarios (present and future), it would require an investigation that installed monitoring bores alongside the habitat pools. Ideally these would also be accompanied by water level gauging in the river at the same location. These data could be collected using sensors and either telemetered or periodically downloaded.

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